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CARBONIFEROUS EVAPORITES ALONG CANADA'S CONTINENTAL SHELVES

by P. SONNENFELD (*)

ABSTRACT. - Carboniferous evaporites on the margins of Canada must also have been marginal to Eurasia, if we assume that Pangaea was extant at that time.
Lower Carboniferous Tournaisian and Viséan evaporites (belonging to the Horton and Windsor groups) in the Maritime Provinces (New Brunswick, Nova Scotia, and Newfoundland) contain calcium sulfates, sodium and potassium chlorides. As Tournaisian and Viséan anhydrites also occur in the British Isles, it is proposed that the latter constitute the distal shelf deposits of the same sea. The presence of sylvinites on the flanks of various subbasins indicates that :

1. organic nitrogen compounds in the saturated brine impeded carnallite precipitation,
2. a density stratification prevented oxidation and destruction of these organic compounds,
3. the entrance strait was extremely restricted, and
4. the beds were well compacted before Permian sulfatic brines could alter the deposits.

The margins of the Middle Carboniferous Bashkirian evaporites (belonging to the Otto Fiord Formation) in the Canadian Arctic Archipelago probably extended to Spitsbergen, an island group that has since been displaced. They do not seem to have extended into northern Siberia prior to the opening of the Arctic Ocean. Potash beds have hitherto not been discovered in this basin, but are likely present as either sylvinites, carnallitites, or both.
In both instances, the salt basins also contain earlier and later anhydrite cyclothems.

RESUME. - Les évaporites du Cabonifère des bordures du Canada appartenaient aux marges de l'Eurasie, si l'on suppose que la Pangée existait à cette période.
Les évaporites tournaisiennes et viséennes appartenant aux groupes Horton et Windsor (Carbonifère inférieur) dans les provinces Maritimes (Nouveau Brunswick, Nouvelle Ecosse, Terre Neuve) contiennent des sulfate de calcium, des chlorides de potassium et de sodium. Puisque les anhydrites viséennes se retrouvent également dans les Iles Britanniques, on peut considérer que celles-ci correspondent aux dépôts de la plate-forme distale du même domaine.

(*) University of Windsor, Windsor, Ontario, Canada.

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La présence de sylvinite sur les bords de quelques sous-bassins indique que
1. des composés organiques azotés, dans la saumure saturée, ont empêché la précipitation de la carnallite;
2. une stratification par densité a empêché l'oxydation et la destruction de ces composés organiques;
3. le détroit assurant l'entrée des eaux marines a été extrêmement réduit;
4. les couches ont été bien compactées avant que les saumures sulfatées permiennes n'altèrent les dépôts.

Les bords des évaporites bachkiriennes appartenant à la formation Otto Fjord (Carbonifère moyen) dans l'Archipel Canadien s'étendait probablement jusqu'à Spitzberg (Svalbard), un groupe des îles qui ont été déplacées depuis. En apparence, ces évaporites ne sont pas étendues jusqu'à la Sibérie du Nord avant l'ouverture de l'Océan Arctique. Les couches à potasse n'ont pas été découvertes dans ce bassin, mais elles sont probablement présentes, soit sous forme de sylvinite, soit de carnallite, soit les deux associées.
Dans les deux cas, les bassins ont contenu également des cyclothèmes anhydritiques précoces et tardifs.

INTRODUCTION.

The Carboniferous equator crossed Labrador, placing the Arctic Archipelago and northern Greenland in subtropical regions on the north side and the Maritime Provinces into the subtropics of the southern hemisphere. In the Late Paleozoic Laurasian continent, Norway and Greenland had not yet separated, and likewise. Nova Scotia and Africa were still in close proximity. There were seaways on the continental crust of northern Europe, which fed marginal bays in Britain, in northern and eastern Canada, and in the Maghreb. The core areas of the Canadian bays became centers of rapid subsidence and with in sites of chloride precipitation flanked by gypsum deposition along the rims. These gypsum shelves then extended from New Brunswick and Nova Scotia through Newfoundland and Ireland into Britain in the Tournaisian and Viséan, from the Canadian Arctic Archipelago into Spitsbergen in the Bashkirian epoch (Zharkov, 1984). Towards the end of the Carboniferous, the seaways were considerably altered by the Hercynian orogeny; the Permian seas were restricted to central and northern England, findind their shoreline somewhere west or northern Ireland (GASS et al., 1974). A Triassic opening of the Atlantic Ocean eventually moved Spitsbergen to the east of its original position and also initiated an anticlockwise rotation of this island group.

THE MARITIME EVAPORITE BASIN.

There are two major Carboniferous salt cyclothems present in the Maritime Provinces, a Tournaisian one and a Viséan one. A Lower Carboniferous depression that covered Prince Edward Island, southern New Brunswick, and parts of Nova Scotia changed from a marsh or swamp to a semi-arid plain with typical red bed associations (BELL, 1929; HOWIE, 1984). Occasionally found glauberite (McLEOD, 1978) indicates the presence of hypersaline lakes on this plain, because glauberite normally occurs in lacustrine evaporite sequences. This low-lying terrain

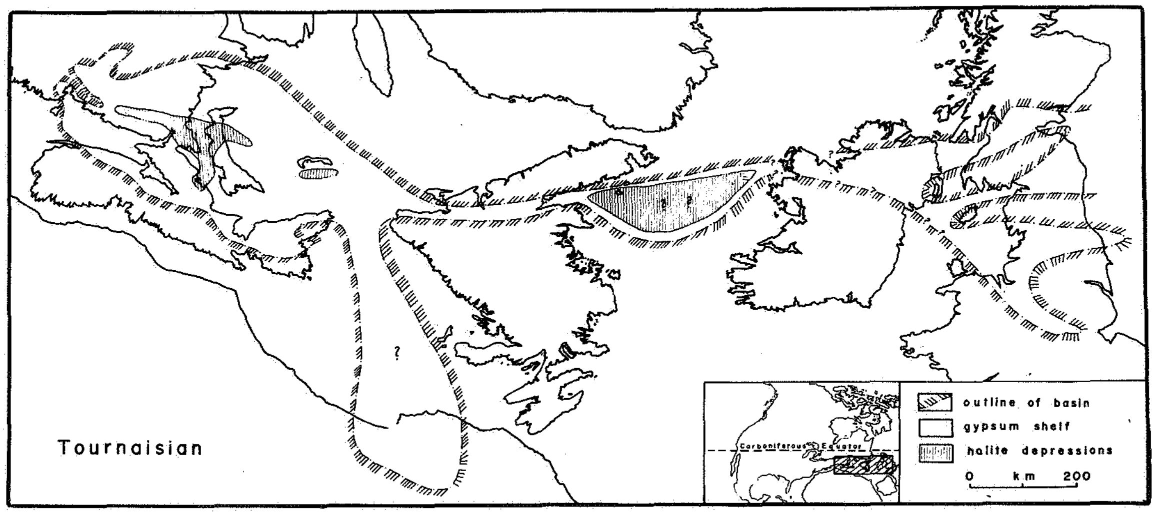

Fig. 1 - Approximate extent of the Tournaisian sea into the Maritime Provinces, showing saturation shelves and probable halite accumulation areas.

was inundated by a Tournaisian sea that entered from the NE, i. e., from northern Ireland and Britain. Tournaisian gypsum has been noted in northern Ireland (SHERIDAN et al., 1967; McDERMOT and SEVASTOPULO, 1973), and even ahydrite geodes in Belgium (GROESSENS et al., 1979), which were probably groundwater-derived in red beds that surrounded the evaporite basin. Halite is known from the Albert Formation (Horton group) of eastern New Brunswick, northern Nova Scotia and Prince Edward Island (McLEOD, 1978; HOWIE, 1984). Salt postulated for the shelf area to the NE of Newfoundlands's Long Peninsula may well be part of this older, smaller basin (Fig. 1). It is uncertain whether this basin extended onto the Grand Banks and its margins into North Africa. The salt deposition was interrupted by an episode of more humid conditions in the early Viséan, which is marked by a local regression and the spread of a carbonate bank with occasional reefs.

Ancient evaporite basins are usually represented by more than one cyclothem. The initial cyclothem frequently encompassed a small salt basin near the inlet with wide shelves where gypsum and carbonate banks or reefs were precipitated. In a subsequent cyclothem these shelves then became additional sites of rapid subsidence, and new more distal shelves were formed in a trangression onto former coastal flats. Consequently, evaporites precipitated onto an area enlarged by the collapse of the former shelves and the total water surface expanded through the formation of new, more distal shelves. For example, The Permian Salado basin surface was greater than that of the subsequent Castile Sea in Texas and New Mexico; the A-1 evaporite unit of the Michigan Basin did not encompass the Ohio and Alleghany basins, but subsequent units did; the Devonian Lotsberg salts of the Elk Point Basin were confined to Alberta, but overlying Prairie evaporites extended into Saskatchewan, Manitoba and North Dakota (SONNENFELD, 1984).

The concept of a transgression of the sea onto former shelf areas can also be applied to the Maritime basins, where the Viséan sea reclaimed territory lost in an end-Tournaisian or early Viséan regression and transgressed as far as western New Brunswick and northern Nova Scotia. It then inundated southern New Brunswick and much of remaining Nova Scotia in one direction, and the western Grand Banks shelf in the other (HOWIE, 1984; JANSA and MAMET, 1984). The shelves of the latter basin extended to coastal Morocco and hence into the Ahnet, Reggane and Tindouf basins in the Algerian Sahara (ALIMEN et al., 1952; COUBERT, 1952; ZHARKOV, 1984). Viséan halite with locally intercalated sylvinite beds occurs in New Brunswick, parts of Nova Scotia and southwestern Newfoundland (Fig. 2). The gypsum rims of this salt basin are found in west-central Newfoundland and hence through northern Ireland into Britain. Overlying the Tournaisian coastal gypsum occurrences in northern Ireland are Viséan ones (WEST et al., 1968; MacDERMOT and SEVASTOPULO, 1973; NAYLOR et al., 1980). They extend into Midlands of Britain (LLEWELLING and STABBINS, 1968), and likely even through the Downs of southern England as far as northern France and the Lowlands (ROUCHY et al., 1984; LAUMONDAIS et al., 1984). Here their stable isotope composition distinctly differs from similar Middle and Upper Devonian occurrences (Pierre et al., 1984).

Sylvite deposits, or rather sylvinite, a mixture of sylvite and halite, inside the Maritime depression can be explained by postulating a severely restricted and possibly convoluted entrance strait, since a brine concentration to potash saturation requires an inflow area more than eight orders of magnitude smaller than the total available water surface (LUCIA, 1972). Moreover, halite precipitation rates are

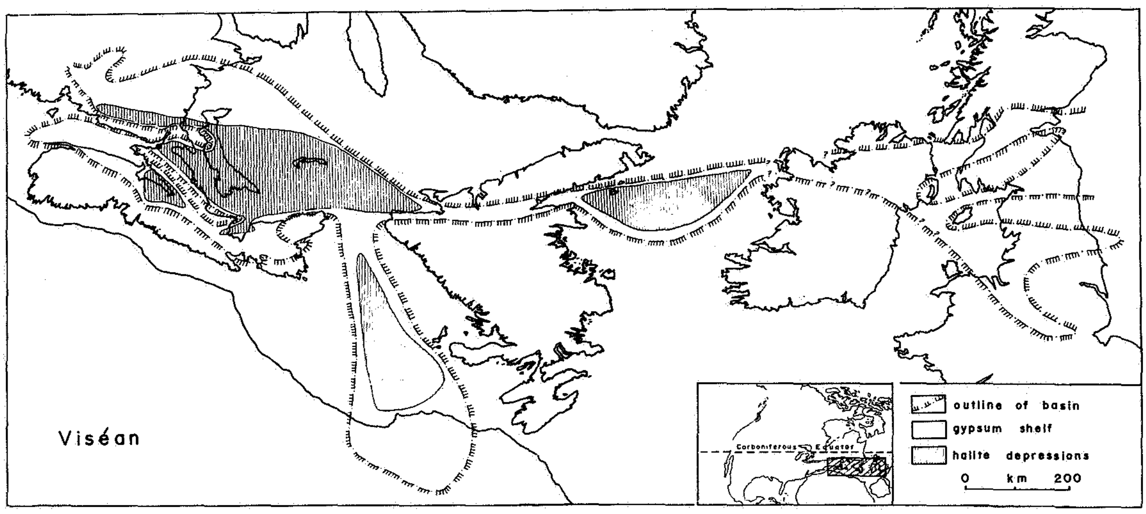

Fig. 2 - Approximate extent of the Visean sea into the Maritime Province, showing saturation shelves and probable halite accumulation areas.

such that only basin portions with rapid subsidence rates can accumulate significant quantities of precipitate. Halite is thus frequently restricted to graben structures due to synsedimentary tectonic movements. The absence of halite and sylvinite in correlative strata in the British Isles can either be due to the lack of a sufficient entrance restriction into those subsidiary basins or by extreme shallow conditions prevailing on a saturation shelf, where any seasonally precipitated halite was redissolved. The presence of such a "saturation shelf" in the sense of RICHTER-BERNBURG (1957) is also indicated in the Maritimes, where anhydrites occur both underneath and as lateral equivalents of the chlorides, namely locally in Nova Scotia in the Shubenacadie graben of the Minas subbasin or in the Musquodoboit subbasin both as basal Carrolls Corner/Gleason Brook Formation, and also as a lateral facies change from the Stewiacke salt (SCHENK, 1984). In New Brunswick, the Cassidy Lake Formation that comprises halite with sylvinite intercalations (ANDERLE et al., 1979) is the lateral equivalent of the Stewiacke salt; the Upperton anhydrite represents here the Carrolls Corner anhydrite (Fig. 3). That the gypsum beds or their later alteration to anhydrite are present both underneath the salt and beside the salt on the basin margins is common to most marine evaporite basins. It is likewise common that anhydrite and halite bed thicknesses are in quasi reciprocal proportions.

After the deposition of the Stewiacke-Cassidy Lake salt, the brine saturation at first returned to calcium sulfate saturation. Thereafter the precipitation oscillated from anhydrite to halite at least twice (the MacDonald Road Formation : HOWIE, 1984), before the salinity was lowered to a carbonate depositing environment. This suggests that the water deficit in the basins either oscillated because of changes in the degree of restriction of the entrance area through faulting or, more likely, by an episodic increase in rainfall and runoff.

The common potash ore is here sylvite, yet this mineral has a very slow rate of nucleation and normally does not precipitate under water temperatures ambient in the subtropics; carnallite is then the normal precipitate. However, if sufficient protein decomposition products, notably urea and cyanides, are present in the brine, sylvite solubility is reduced and magnesium chloride is prevented from precipitating (SONNENFELD, 1984). Carnallite can then not form and bivalent iron also remains in solution. Where the brine is exposed to air, the organic decomposition products are oxidized and bivalent iron complexes turn into trivalent iron oxides and hydroxides. In that case, carnallite can precipitate and contains needles of hematite and goethite. Redissolution of the magnesium chloride would lead to a red sylvite. Because of the preponderance of pale-colored sylvite and absence of carnallites, we can assume that the brine was density-stratified in the embayments in New Brunswick, where sylvinite accumulated, i.e., a mixture of halite and sylvite. Runoff from nearby land assured such a density-stratification for at least the major part of the year. When the low-density layer was burnt off by evaporation, the

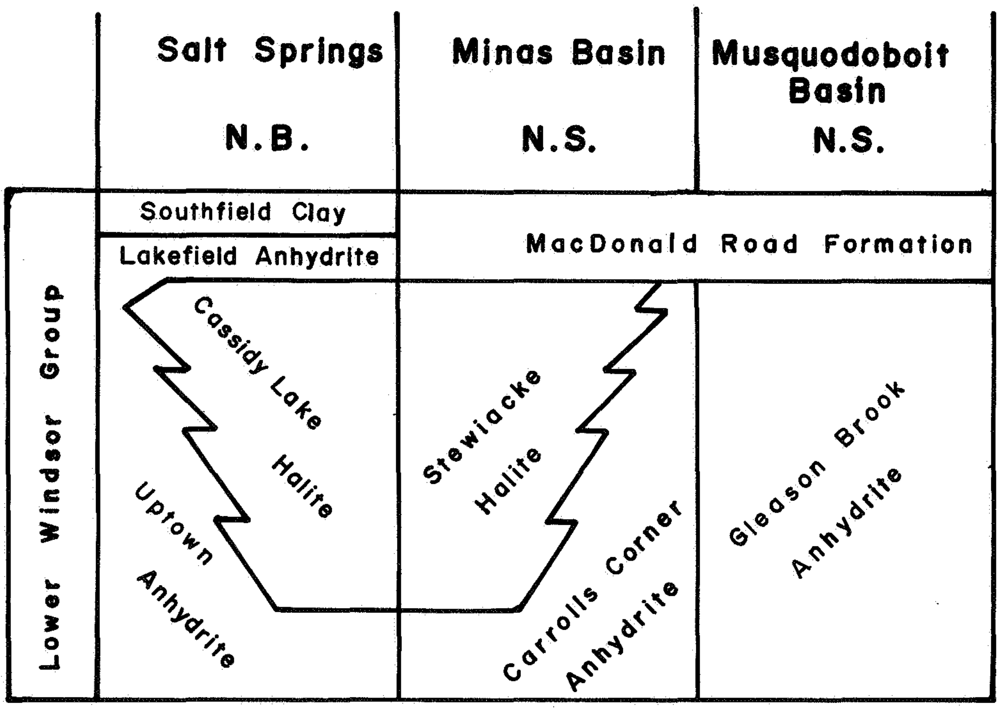

Fig. 3 - Correlation of the Lower Windsor evaporite cyclothem from New Brunswick to Nova Scotia (after ANDERLE et al., 1979, and SCHENK, 1984).

brine was warm enourgh to keep potassium chlorides in solution. During winter flash floods the brine was not only stratified, but also periodically could cool down sufficiently to reach potassium chloride saturation. Since a KCl-NaCl mixture reduces its density upon cooling (CORNEC and KROMBACH, 1932), the precipitation occurred mainly in shallow marginal bays within reach of rainwash and redissolution.

Every entrance strait into a marine embayment today contains a two-way flow. Surface inflow of near-normal salinity is turned by the Coriolis effect and is bound to hug the shores of a nearly circular basin, concentrating along its path. Rich planktonic faunas and floras develop, enticing even schools of fish into the surface waters of an evaporite basin. The botton outflow is hypersaline, low in oxygen and nutrients, deadly to stenoionic or stenohaline biota and repels migrating bottom dwellers. Consequently, nektonic and benthonic biota are severely hampered, become endemic, and eventually die out owing to the rising osmotic pressure of the brine. A lack of any correlation in bottom dwelling fauna between Britain and Canada (JANSA and MAMET, 1984) is not necessarily due to a barrier in the sea between Newfoundland and Ireland, but simply a consequence of the water circulation out of an evaporite basin, in this case, the Maritime salt basins. That a hypersaline bottom outflow was present is evidenced by the total lack of magnesium chlorides and a deficiency in potassium chlorides compared to a precipitation derived from an isochemical concentration of seawater.

The absence of bottom scavengers and burrowers leads to a cessation of bioturbation and consequent undisturbed lamination of sediments below wave base, especially in areas where the water column is shallow enough that salinities fluctuate seasonally across the boundary between the saturation fields of two minerals (Fig. 4). Reefs flourish along the path of the inflow current and especially in the entrance area both because of the absence of scavengers and because their growing parts extend into the nutrient-rich surface inflow, while only their dead trunks are washed by the hypersaline outflow. Tournaisian and Viséan reefs in the British Isles are thus telltale signs of proximity to the entrance area of the evaporite basins.

Although seawater contains three times as much sulfate as calcium, no sulfates other than calcium sulfates were formed. The basal and lateral calcium sulfate deposits must have been precipitated from sulfatic, i. e., oxygenated brines and all the remaining sulfate was removed by anaerobic bacteria. Whereas Permian and Neogene evaporites worldwide contain potash horizons altered by secondary sulfatization, the Carboniferous basins contain only sylvinites. This is not due to drastic changes in the composition of end-Paleozoic seawater, but merely indicates that sulfatic brines could not enter these deposits, or in other words, the evaporites were sufficiently compacted prior to the formation of such brines. Late Paleozoic eustatic sea level changes in response to glacial drawdown intermittently exposed Permian gypsum shelves and permitted the seepage of groundwater from there into as yet uncompacted chloride beds (SONNENFELD, 1985).

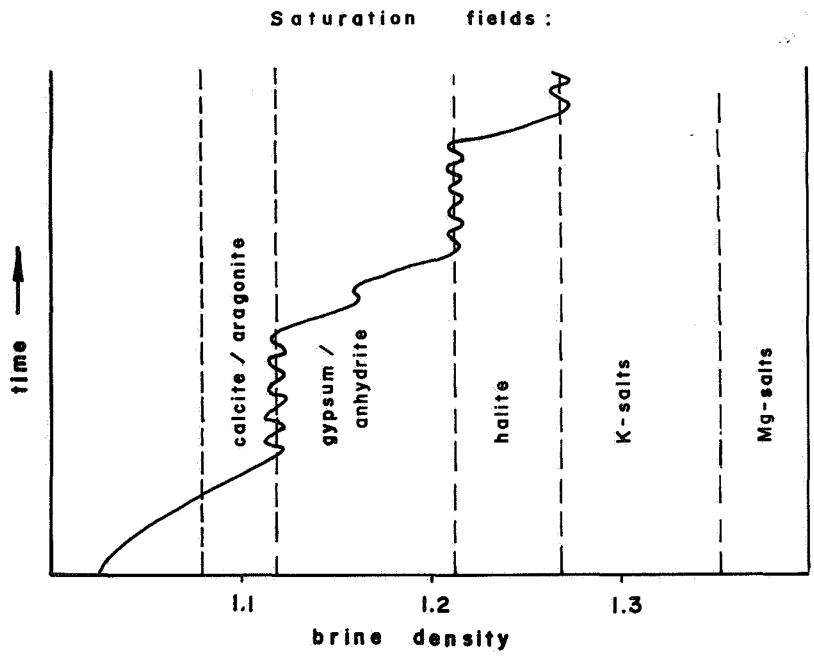

Fig. 4 - Salinities fluctuating seasonally across the boundary between the saturation fields of two minerals result in laminated sediments. Such seasonal changes in the salinity of the whole brine column can only be effected in shallow pools.

Today the Maritime basins are cut up into small remnant subbasins and are severely distorted due to several major strike-slip faults associated with the end-Paleozoic Alleghany orogeny. Salt cushions and small diapirs are witnesses to tensional forces that have been active in the past.

Consequently, it is not entirely possible to reconstruct an outline of the extent of the salt basins. The apparent narrowing of the waterway between White Bay and St-George's Bay in Newfoundland (HOWIE and BARSS, 1975) is likely to be due to a postdepositional movement on several strike-slip faults that are converging in the Green Bay area of Newfoundland. Since the outlines of the individual salt basins have been altered so severely by later tectonic events, it is impossible to ascertain the dimensions of the original surface area of salt precipitation, to estimate the total area of the basin or the cross sectional area of the entrance strait. In any case, because of the presence of potash deposits in New Brunswick it appears unlikely that the entrance area was more than a few kilometers across.

THE SVERDRUP EVAPORITE BASIN (Fig. 5).

Halites belonging to the Otto Fiord Formation occupy the central part of the Sverdrup Basin in the Arctic Archipelago of Canada (MENELEY et al., 1975), are Bashkirian in age, and thus somewhat younger that the Maritime salt deposits. They are also framed in gypsum beds (DAVIES, 1977a, b; DAVIES and NASSICHUK, 1975) that must have acted as the "saturation shelves" in the sense of RICHTER-BERNBURG (1957). If we assume that post-Carboniferous seafloor spreading forced Spitsbergen to move east the same distance as Norway was separated from Greenland and that Spitsbergen was rotated about a quarter turn anticlockwise in the process, then its coeval gypsum occurrences (GJELBERG and STEEL, 1981) form the proximal shelf margin to the Sverdrup Basin.

These evaporites dot not seem to have extended into northern Siberia. Thus a margin on this side of the Siberian coastline is indicated even prior to the opening of the Arctic Ocean. Potash beds have hitherto not been discovered in this basin, but there are few thick halite sequences known in the world that do not also contain potash deposits in some part of the basin. If found, these potash deposits would likely occur as either sylvinites, carnallitites, or both, in analogy to the mineralogy of all other pre-Permian potash deposits.

Because the Sverdrup Basin has not been cut up by wrench faulting and thrusting to an extent comparable to the Maritime basins, it is possible to generate rough estimates of basin size and water exchange. Halite precipitation is normally only possible, if the total water surface is significantly greater than the area of halite precipitation, i. e., if there are wide saturation shelves. According to SONNENFELD (1984) the ratio between total water surface and halite preservation area must be between about 2.5 - 4, and in this case it was probably closer to the latter figure. The severity of the entrance restriction controls the outflow, i. e., increments in inflow reduce the remaining cross sectional area. To retain enough solute in order to reach saturation for halite requires a ratio between inflow and outflow of 0.1154, for potassium chloride 0.0724 (SONNENFELD, 1984). At a higher ratio, too much solute can escape and concentration within the basin stabilizes short of saturation for the respective chloride.

We can express the constraints in figures based on some crude estimates, in order to obtain a sense of the right order of magnitude, even though the outlines of the morphology of the basin are not exact. Based on an area of about 186,000 km^2 of halite in the Sverdrup Basin, the total water surface must have been in excess of 745,000 km^2. At a nominal evaporite deficit of 0.8 m/year,

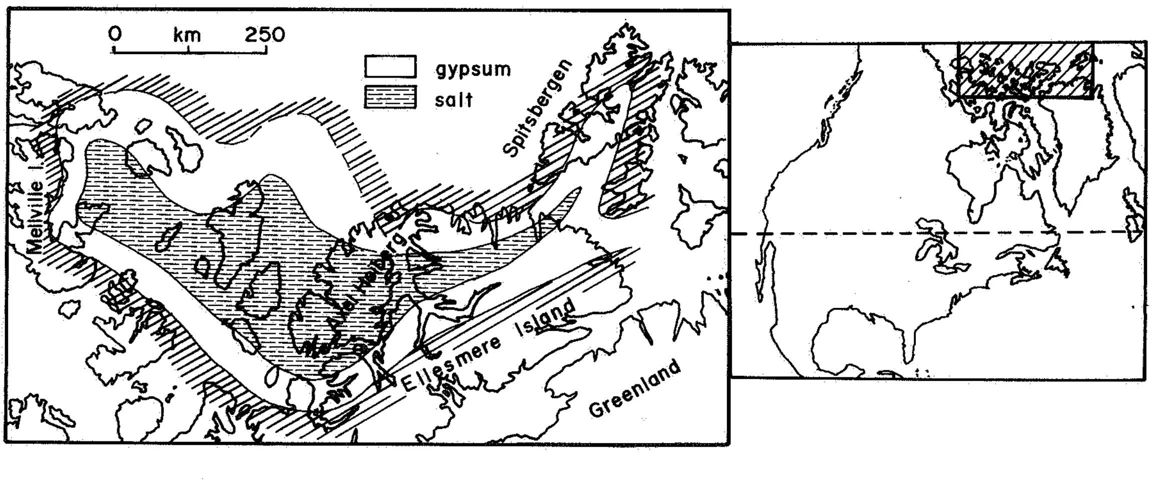

Fig. 5 - Approximate extent of the Sverdrup evaporite basin, showing saturation shelves and probable halite accumulation areas.

comparable to the present Mediterraean Sea, evaporation would remove 18,950 m^3/s, to be replenished by 20,450 m^3/s of seawater, of which 1,500 m/s would again escape. At a postulated velocity of 1.5 m/s for the inflow and 1 m/s for the outflow, the inflow area would occupy 13,650 m^2, the outflow 1,550 m^2, giving a combined cross sectional area of 15,200 m^2. That translates into a maximum entrance of about 3 km by 5 m deep. This size of the entrance is about twice as large as based on Lucia's (1972) estimate of the ratio between water surface and cross section of the entrance. Nevertheless, the resulting channel dimensions are then 3-4 orders of magnitude less than previous estimates. For evaporite basin the estimated average flow velocities are very conservative. They were probably in reality higher, requiring a smaller cross sectional area of the entrance. This entrance considers only the net area available for water exchange, after deductin for reef growth or islands within the entrance. Even so, such a severely restricted entrance strait is small enough to be easily missed in mapping, on the basis of subsurface control points.

The Bashkirian evaporites overlie an Ordovician evaporite group, and themselves are overlain by Lower Permian anhydrites that also extended into Spitsbergen (ZHARKOV, 1984).

CONCLUSION.

The Maritime evaporite basins represent the distal portion of a series of connecting basins progressively filled with concentrating brines flowing in through Britain, northern Ireland, and a channel through western Newfoundland. Syngenetic faulting produced subsidiary subsidence centers filled with chlorides and framed by calcium sulfate beds.

The Sverdrup Basin in Arctic Canada was much less distorted by syngenetic and epigenetic tectonic movements. It appears to have had its entrance strait, merely a few km wide, between Greenland and Spitsbergen. The salt precipitation was flanked by a saturation shelf that extended into Spitsbergen.

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