Windsor Group Salt and Potash in Nova Scotia, Canada

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ABSTRACT

The Windsor Group (Viséan) is a regionally widespread unit up to 1000 m thick. It is dominated by subaqueous and diagenetic marine evaporites including halite, anhydrite, gypsum and potash with subordinate interstratified redbeds and marine carbonates. These rocks display a wide range of structural and stratigraphic complexities within the Carboniferous depositional and tectonic setting. Carboniferous basins in Nova Scotia are part of the complex Magdalen (Fundy) Basin system developed in the Acadian Orogen in Atlantic Canada. They contain up to 7000 m of pull-apart basin molassic sediments with minor, but economically important, marine evaporites of the Windsor Group. Deformation varies from negligible in the relatively stable platform blocks characterized by thin sediment accumulation to substantial in the fragmented basinal areas involving Hercynian strike slip, thrust and normal faulting, gravity sliding, evaporite diapirism and folding of the thick sedimentary fill.

Until recently, the distribution and geology of the evaporites, especially salt and potash, have been poorly understood because of limited data. Recent drilling has established that salt is present throughout the Windsor Group section. The principal salt unit including potash (sylvite and carnallite) is located in a major carbonate-sulphate-chloride cycle at the base of the Windsor Group. Thinner and younger salt beds with minor potash are locally present in association with anhydrite and marine carbonate in numerous saline "minicycles."

The large salt resources of Nova Scotia, together with geographic location and the presence of potash, are important factors which may encourage future development of mining and chemical industries and underground storage facilities.

INTRODUCTION

Recent expansion in offshore petroleum exploration and the discovery of economic potash deposits in New Brunswick have increased interest in salt and potash exploration in Nova Scotia (location, Figure 1). In addition, active exploration for base metals, coal and petroleum in Carboniferous rocks during the last decade has resulted in the generation of voluminous drillhole information. This unprecedented data base has allowed a dramatically improved understanding of Windsor Group evaporites in many parts of Nova Scotia. Historically, salt production has been an important contribution to the economic development of Nova Scotia. The first underground salt mine in Canada operated at Malagash in northern Nova Scotia between 1919 and 1959. Potash was occasionally produced in minor amounts as a by-product of salt. At present, salt production is confined to the underground mine at Pugwash operated by The Canadian Salt Company Limited and to the brining mine operated by Domtar Chemicals Group (Sifto Salt Division) at Nappan. The presence of large deposits of salt, together with the varied uses for salt, give Nova Scotia an important mineral resource base for potential development of new mines, chemical industries and underground storage structures.

The purpose of this paper is to outline the general stratigraphy and geological setting of Windsor Group evaporites in Nova Scotia. Emphasis will be placed upon the salt and potash resources because these are the least known in published literature.

Data Organization. This paper is based upon two major sources of information: 1) indirect, i.e., compilation of data, and 2) direct study of the geology of selected Carboniferous areas. The compilation was undertaken as part of a mineral inventory project with the aim to update the locations, limits and structural configurations of Nova Scotia's salt deposits through a review of the available data. The major source of these data is the mineral assessment files of the Nova Scotia Department of Mines and Energy which contain, for the most part, unpublished reports submitted by exploration companies. Less abundant but very important data are available in a limited number of published papers dealing with many aspects of the geology of Nova Scotia's salt deposits.

The compilation has been organized by area (region)

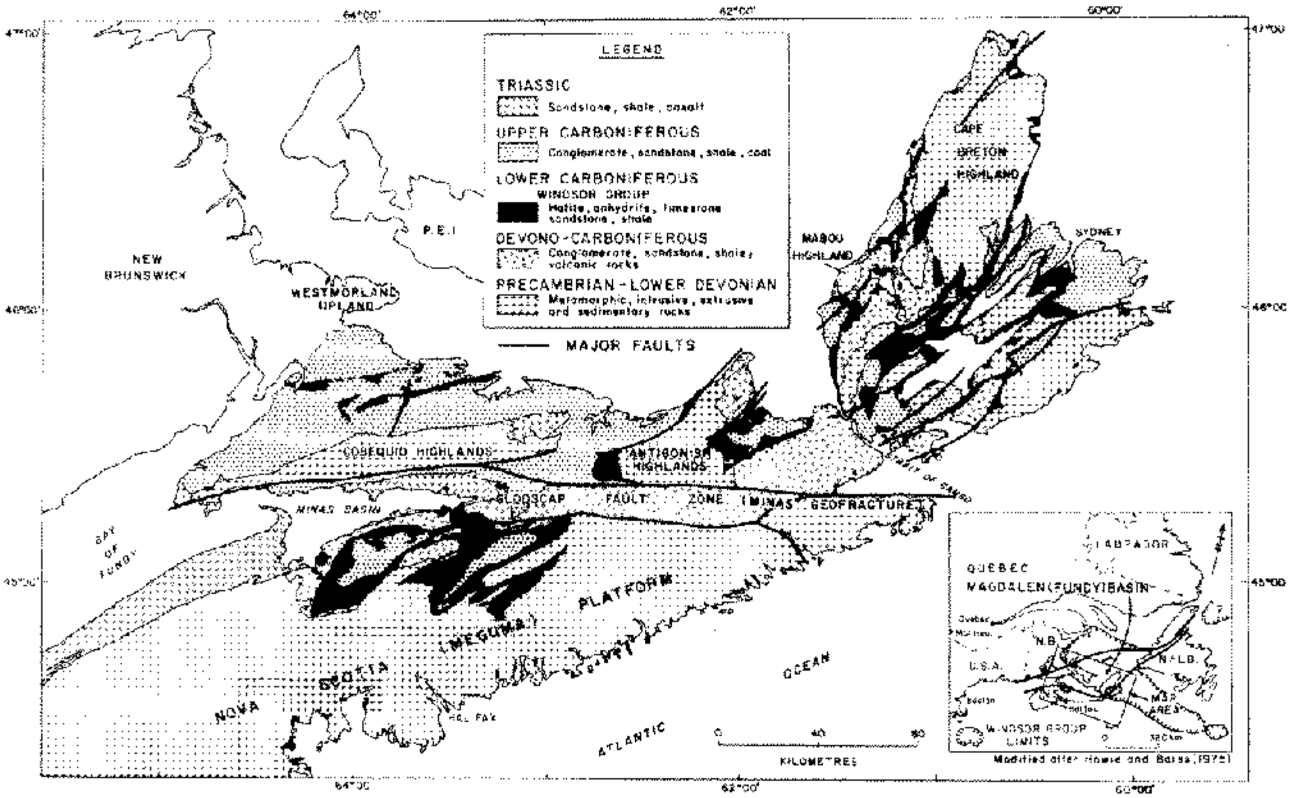

Figure 1. Location and general geological map of Nova Scotia, Canada.

and deposit or occurrence. The subjects and organization documented for each deposit/occurrence are shown in Table 1.

This data base has enabled extrapolation from areas that have been studied in detail into areas which have not been directly or completely investigated. Selected Carboniferous areas have been remapped using available outcrop and subsurface data. This work was conducted in conjunction with Dr. P. S. Giles, Nova Scotia Department of Mines and Energy. Results from these surveys in the eastern part of the Hants-Colchester area, Pictou area, Antigonish area and parts of the Sydney and Canso-Bras d'Or area are included in the following maps and reports: Giles (1981a,b,c, 1982); Giles and Boehner (1979, 1982a,b); Boehner and Giles (1982) and Boehner (1979, 1980, 1983).

The location and definition of salt deposits and occurrences are restricted to drilling, mainly by exploration companies, and by secondary indicators such as the presence of salt springs. Aside from field mapping, gravity surveys are the primary indirect method of locating and outlining salt resources. Systematic regional gravity surveys of potential salt areas throughout the Carboniferous basins in Nova Scotia have been undertaken over a period of several years by the Nova Scotia Research Foundation Corporation. Negative Bouguer gravity anomalies (up to 30 mGal) are generally coincident with Windsor Group salt deposits.

Well-documented stratigraphic and structural complications associated with several Windsor Group evaporite deposits together with a scarity of surface and subsurface data make accurate detailed assessment extremely difficult. Exceptions are the detailed work by Evans (1972) on the complexly deformed Pugwash Mine geology and the relatively undisturbed Shubenacadie-Stewiacke deposit described by Boehner (1979 and 1980).

Historical Background. Major contributions to the stratigraphy, paleontology and structure of the Carboniferous succession, in particular the Windsor Group, in Nova Scotia and Atlantic Canada were made by W. A. Bell and other geologists with the Geological Survey of Canada. This work has formed the basis of Carboniferous geological understanding and has been further developed by subsequent workers. Early workers who have made contributions to the field of salt geology in Nova Scotia include Bancroft (1938), Bell (1929, 1944, 1958), Chambers (1924), Cole (1930), Ellsworth (1926), Hayes (1920, 1931) and Norman (1932, 1935) and more recently, Baar (1965, 1966), Bidgood (1970), Bidgood and Blanchard (1967), Evans (1970a,b, 1972), Goodman (1952), Goudge (1967), Howie (1979), Moore (1967), Sage (1954), Schenk (1969), Shea (1970) and Stacey

TABLE 1

Nova Scotia Department of Mines and Energy, Mineral Inventory Salt File and Sub File System

SUB FILE 1:	*Historical Background* NTS code Occurrence name.
SUB FILE 2:	*Geography and Physiography* 1:50 000 topographic map showing location Summary of existing reports.
SUB FILE 3:	*Geological Data* Copies of geological maps, reports Location map for drillholes Copies of all descriptive drill logs Copies of all graphic drill logs Mineralogy of the occurrence/deposit Geometry of the deposit, suggested structural configurations, cross-sections, etc. Stratigraphic position of the deposit.
SUB FILE 4:	*Geophysical Data* Copies of gravity surveys, regional and local Gravity cross-sections Reports of gravity interpretation Copies of all available magnetometer surveys Down-hole geophysics—copies of all logs.
SUB FILE 5:	*Geochemical Data* Specify "brine," "whole-rock," salt springs, etc. Standard format, list of elements, oxides, etc. Retabulation of all available data.
SUB FILE 6:	*Economic Considerations* (Table form) Economic minerals present Approximate depth Approximate dimensions Average grade Proven reserves Possible reserves Current utilization Comments.
SUB FILE 7:	*Source Documents* Bibliography including NSDME assessment file numbers.
SUB FILE 8:	*Assessment of File Quality* Data type (quantitative, qualitative, geological, geophysical, geochemical) Insufficient-sufficient Questionable-reliable Data update Utilization planning.

(1953). Many of these reports contain references to the historical development of salt resources in Nova Scotia (see Shea, 1970).

GENERAL GEOLOGY OF NOVA SCOTIA

Nova Scotia may be broadly divided into three major geological areas—southern Nova Scotia, northern Nova Scotia and Cape Breton Island. Southern Nova Scotia is separated from the latter two by the Minas Geofracture (Keppie, 1982), a major fault zone which trends westerly from Chedabucto Bay to the Bay of Fundy (Figure 1). A summary of the major stratigraphy and tectonic events affecting these complicated areas is presented in Figure 2. A brief description of the geology is included in the following paragraphs.

The Precambrian to Early Devonian rocks are generally penetratively deformed by one or more of three principal tectonic events—the oldest Precambrian Avalonian Orogeny, the Ordovician Taconian Orogeny and the Devonian Acadian Orogeny (Figure 2). The major orogenies have been attributed to collision tectonics (Keppie, 1977, 1982a). The Nova Scotia (Meguma) Platform to the south of the Minas Geofracture is composed of Lower to Middle Paleozoic sedimentary rocks. These regionally metamorphosed rocks have been folded during the Devonian Acadian Orogeny into northeasterly to easterly trending upright folds. According to Keppie (1977) granitic intrusion into the deformed sequences occurred through the Devonian and into the Late Carboniferous. Throughout the Carboniferous, nonmarine and minor marine sedimentation occurred mainly as molassic deposition upon the older rocks of the Acadian Orogen in downwarped and faulted areas. The eastern and western ends of the Minas Geofracture are marked by rift grabens or half-grabens in which Triassic Fundy Group sedimentary and volcanic rocks were deposited.

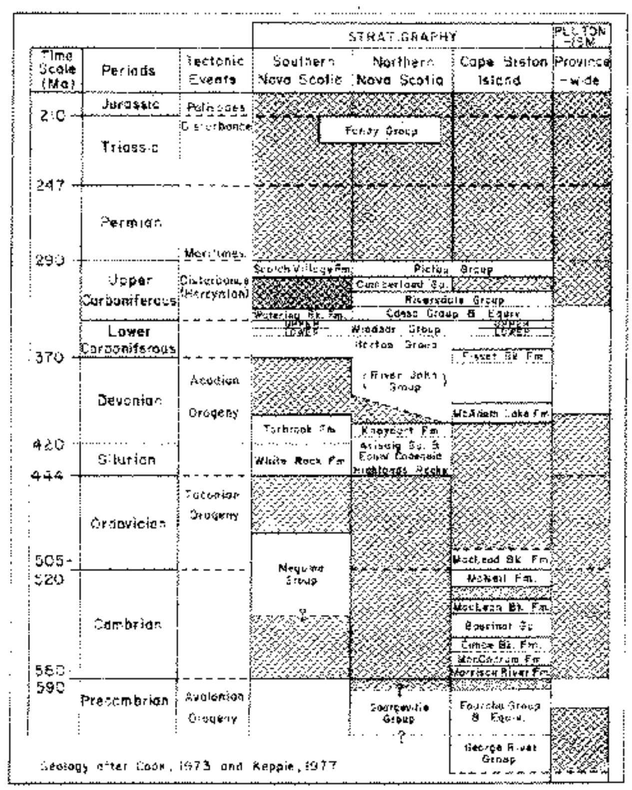

Figure 2. General stratigraphy and tectonic events of Nova Scotia.

The area to the north of the Minas Geofracture, including northern Nova Scotia and Cape Breton Island, is geologically more complex. On mainland Nova Scotia, Middle Paleozoic to Precambrian rocks occur in two major areas known as the Cobequid and Antigonish Highlands (Figure 1). Adjacent to these blocks, very thick successions of Carboniferous sediments of nonmarine and minor marine origin occur in wrench fault basins and/or synclinoria. Precambrian or older Proterozoic sedimentary and volcanic rocks outcrop in much of the northern Cape Breton Highlands and along southeastern Cape Breton. Smaller fragmented basement blocks are also found scattered over the remaining area. These rocks are overlain in southeastern Cape Breton by a Lower Paleozoic sequence of Cambrian sedimentary and volcanic rocks. Granitic and minor basic plutons of Carboniferous to Ordovician or older age intruded the older deformed rocks. Similar to mainland Nova Scotia, a very thick succession of Carboniferous molassic sediments occur in faulted and folded basins and synclinoria.

GENERAL CARBONIFEROUS GEOLOGY AND STRATIGRAPHY

The Carboniferous comprises interstratified nonmarine and minor marine sediments deposited in a complex fault basin system variously called the Fundy Basin (Belt, 1968), Fundy Epieugeosyncline (Bell, 1929, 1958), Fundy Aulacogene (Keppie, 1977), and Magdalen Basin (Bradley, 1982 and Keppie, 1982a). The earliest sedimentation is recorded by a thick continental sequence (locally greater than 2000 m) of coarse and fine siliciclastic rocks belonging to the Lower Carboniferous Horton Group. Rocks assigned to this Group, including interstratified volcanics near the base, are as old as Middle-Late Devonian in age (Howie and Barss, 1975). These rocks were deposited in subsiding areas adjacent to and on top of the deformed metamorphic and intrusive rocks of the Acadian Orogen. These basement rocks range from Precambrian (Hadrynian) to Middle Devonian in age. Minor salt (halite) occurs in rocks of the Horton Group in some areas such as the Cumberland area (Figure 3) in a situation similar to the Albert Formation (Gautreau Salt) near Moncton in southeastern New Brunswick (Hamilton, 1961, pp. 25–31). The evaporite facies of the Albert Formation (Horton Group) in New Brunswick contains halite, glauberite and anhydrite and probably represents localized continental evaporite deposition. The equivalent Horton Group salt in the Cumberland area of Nova Scotia is mainly halite and probably represents a similar depositional environment. Exploration activity to date has

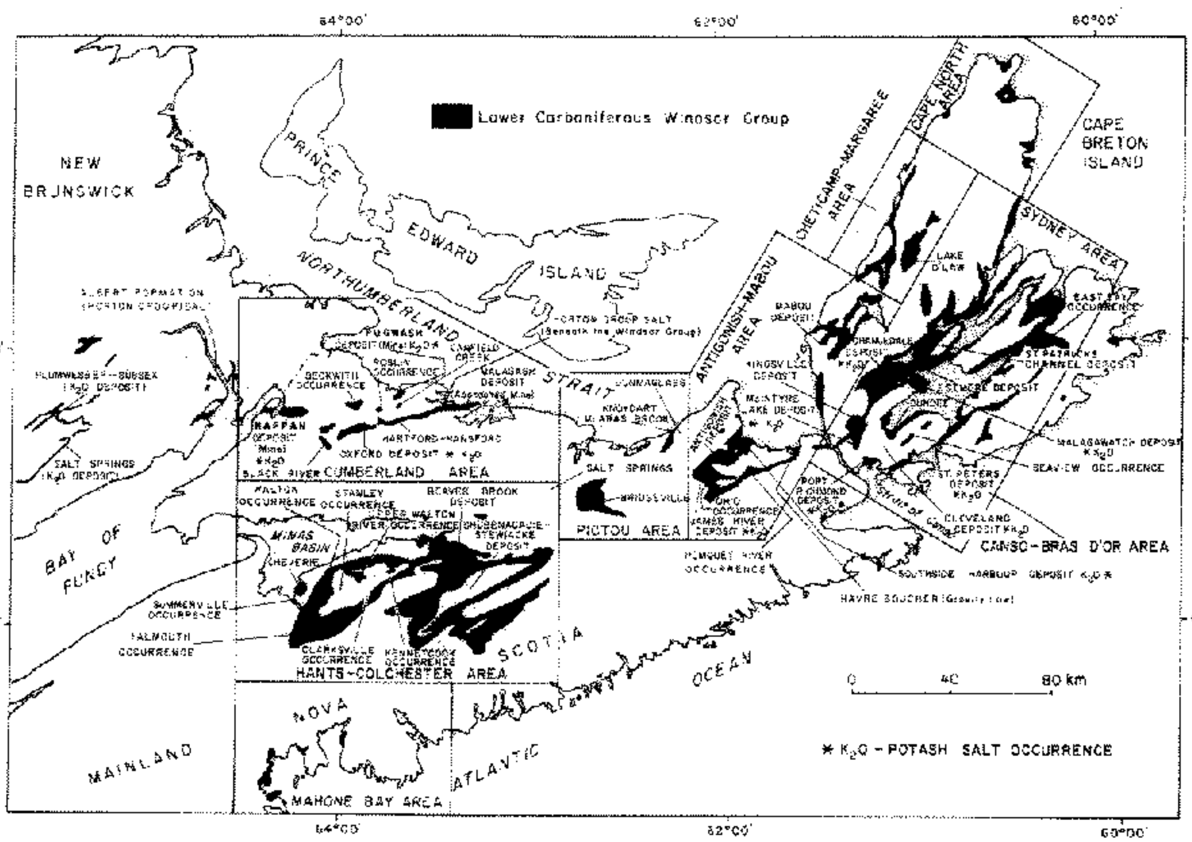

Figure 3. Salt and potash occurrences and deposits in Nova Scotia.

not been attracted to these evaporites. The majority of the salt deposits and occurrences in Nova Scotia are confined to the Lower Carboniferous Windsor Group (Figures 3 and 4) which is widely distributed throughout Atlantic Canada (Figure 1).

The Windsor Group contains the only major marine deposits in the Carboniferous sequence that began and ended with deposition of thick continental sediments (Figure 4). The Windsor has a stratigraphic thickness of 1000 m + but may be thicker in some of the poorly known deep basin areas. Generally more than 50% (and up to 70%) of the Windsor Group consists of evaporites, primarily anhydrite, gypsum and halite with lesser, but economically significant, potash. The evaporites occur as thick and thin beds, rhythmically alternating, and are often closely associated with fossiliferous marine limestone and dolostone and red to maroon and green siltstone, sandstone and conglomerate.

The Windsor Group is overlain in most areas both conformably and unconformably by a locally very thick sequence (up to 5000 m) of Upper Carboniferous nonmarine sediments consisting primarily of interbedded sandstone, siltstone, shale and conglomerate. Groups recognized in this succession from oldest to youngest are the Canso, Riversdale, Cumberland and Pictou Groups (Figure 4). The major coal deposits in Nova Scotia are found in rocks assigned to the Cumberland and Pictou Groups. A large number of formation names have been applied to subdivided units within the groups and a summary of these is included in Howie and Barss (1975).

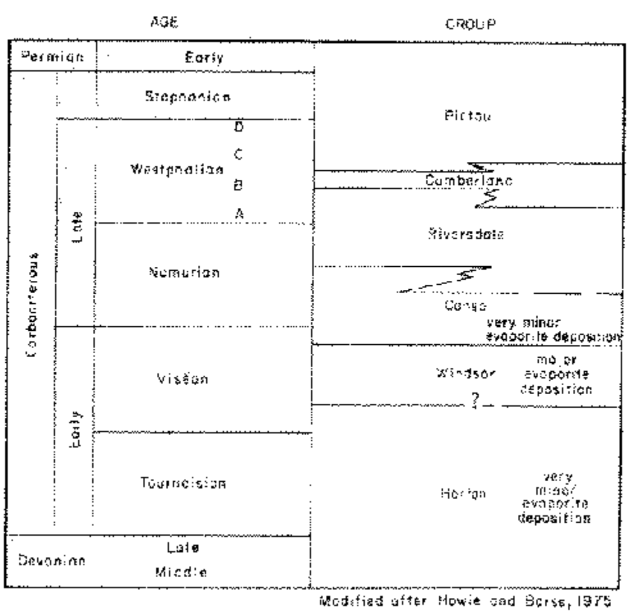

Figure 4. Carboniferous stratigraphy and evaporites in Nova Scotia.

WINDSOR GROUP MAJOR CYCLES

The distribution, thickness and stratigraphic position of salt and potash within the Windsor Group were generally poorly understood until deep core drilling was conducted by mineral exploration companies in the deeper parts of the Windsor Group in the Hants-Colchester area during the mid 1970's. Prior to this, deep drilling was scarce and the holes were rarely cored completely. They were frequently located in structurally complicated areas making the stratigraphic succession difficult to determine. Detailed stratigraphic studies in the extensively drilled Shubenacadie and Musquodoboit Basins in the eastern part of the Hants-Colchester area by Giles and Boehner (1979, 1982a,b) revealed that salt (halite) occurred in association with anhydrite and siltstone at several stratigraphic positions within 5 Major Cycles of the Windsor Group (Figures 5, 6 and 7).

The 3 Major Cycle system originated by Giles (1978) was applied by Boehner (1979) to the Shubenacadie and Musquodoboit Basins (Figures 5 and 6, Sections 2 and 3). It was subsequently refined and enlarged to 5 Major Cycles by Giles (1981b) who applied the system throughout Nova Scotia. The Major Cycle system is based primarily on detailed lithostratigraphy, paleontological data and comparisons to the British Dinantian Stages and represents major transgressive-regressive phases within the Windsor Group. According to Giles (1981b) the lower boundaries of the Major Cycles coincide closely with lithostratigraphic, macropaleontologic and micropaleontologic boundaries. He further concluded that the cycles were bounded by approximate time planes. To generalize the complicated lithostratigraphic nomenclature of the Windsor Group in Nova Scotia the 5 Major Cycle system is used in this paper. The Major Cycle system is introduced and outlined from the Shubenacadie and Musquodoboit Basins and then extended to other Windsor Group areas in Nova Scotia.

Major Cycle 1. The major salt in the Shubenacadie Basin (Figures 5, 6 and 7) occurs as part of Major Cycle 1, which is an evaporite dominated sequence up to 500 m thick comprising, in ascending order, a thin laminated basal carbonate (3–50 m of dolostone) which locally has a thick bank facies, a thick massive-to-stratified anhydrite (160–300 m thick), then stratified halite with minor siltstone and anhydrite (up to 300 m thick). In addition, a mixed siliciclastic facies representing nearshore marine deposition was recognized in the adjacent Musquodoboit Basin as a lateral equivalent of the anhydrite (Figures 5, 6 and 7). The classic vertical (and to a lesser degree lateral) succession of marine carbonate and evaporites ranging up to halite is well represented in this area. The halite facies is confined to the Shubenacadie Basin and typically comprises banded-bedded halite with alternating light coloured pure and dark impure couplets. It also has well

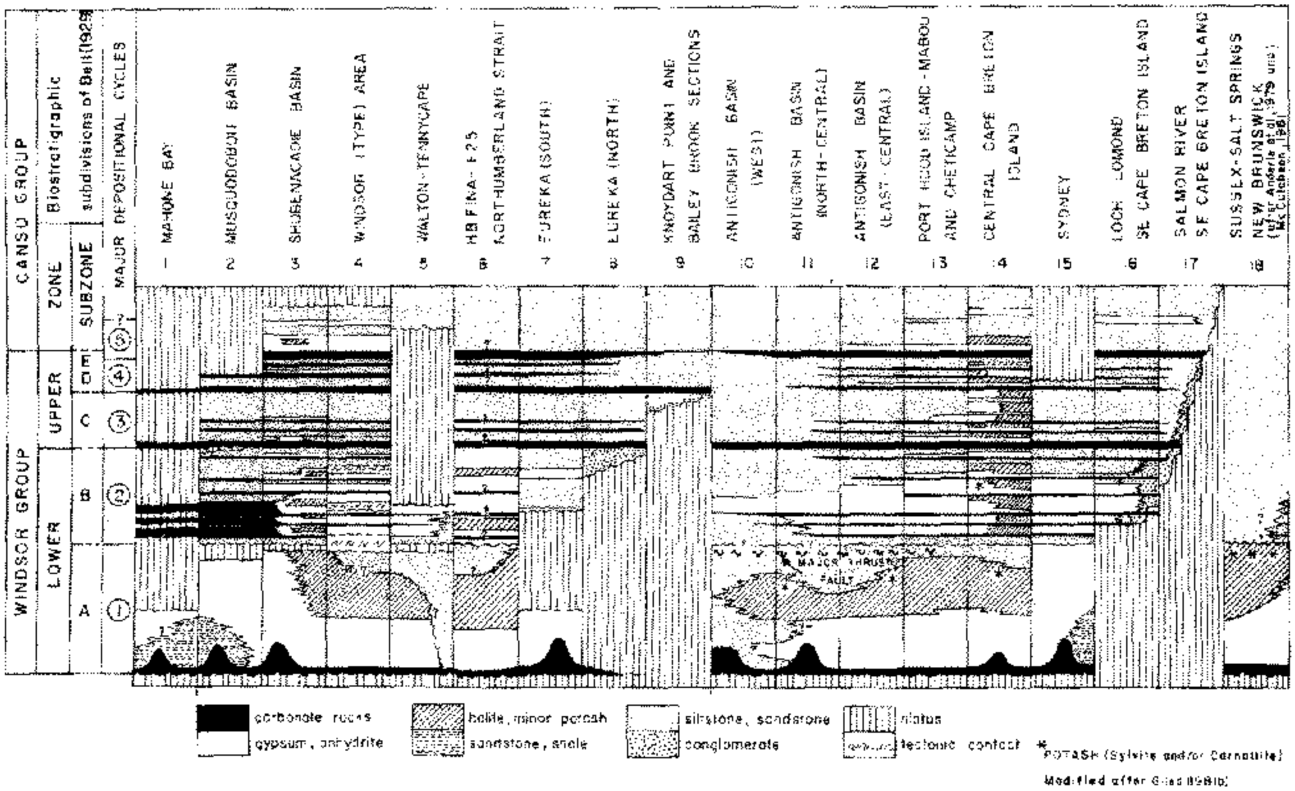

Figure 5. Lithostratigraphy and Major Cycles of the Windsor Group in selected areas of Nova Scotia (locations in Figure 6).

developed displacement and crust-like halite (shallow subaqueous to subaerial?) closely associated with green siltstone interbeds near the upper half of the section. Anhydrite interbeds (up to 5 m) are the dominant nonhalite impurity in the lower half of the halite facies. The top of Major Cycle 1 in the Shubenacadie and Musquodoboit Basins is a disconformity with karstification of the anhydrite facies at the basin edge and local reworking of anhydrite.

Based upon facies relationships, paleogeographic and paleotopographic reconstructions, Boehner (1979) concluded that Major Cycle 1 recorded very rapid marine transgression (possibly nearly instantaneous) into a preexisting subsea level continental basin with water depths possibly up to 200 m. The thin basal laminite carbonate, although generally sparsely fossiliferous, had locally developed fossiliferous banks at higher elevations. The absence of significant transgressive facies indicates rapid transgression. The basal carbonate (cryptalgal laminite and bank facies) succession mainly records salinity stratification and progressive increase in salinity (Geldsetzer, 1978 and Giles et al., 1979). Increasing salinity produced the successive deposition of anhydrite then halite that was localized in a shrinking basin adjacent to a contemporaneous subaerially exposed anhydrite surface. Major Cycle 1 in the Shubenacadie and Musquodoboit Basins is interpreted as generally representing regression restriction and increasingly saline subaqueous evaporite deposition in a preformed basin.

Major Cycle 2. Major Cycle 2 in the Shubenacadie and Musquodoboit Basins is up to 160 m thick and overlies the thick evaporite sequence of Major Cycle 1. It is an assemblage of up to 12 minor transgressive-regressive cycles (minicycles) 1–15 m thick, consisting of laterally extensive transgressive-regressive marine carbonates, continental red beds (in subequal proportions) with a variable, but generally dominant, proportion of evaporite (greater than 50%) including anhydrite and minor halite. A typical saline minicycle comprises, in ascending order, transgressive then regressive carbonate facies, anhydrite, halite, ± redbeds (Figure 7). Boehner (1979) described the anhydrite as ranging from nodules in matrices of siltstone or carbonate grading to coalescing nodular mosaic. The anhydrite associated with stratified halite is massive to locally laminated and halitic. The nodular anhydrite both *in situ* and as clasts was interpreted by Boehner (1979) as recording a diagenetic sabkha-type origin in low relief prograding coastal mud flats. The closely associated laminated and massive anhydrite and bedded halite was inferred to have been precipitated in shallow hypersaline pans and lagoons spatially associated with the sabkha environment.

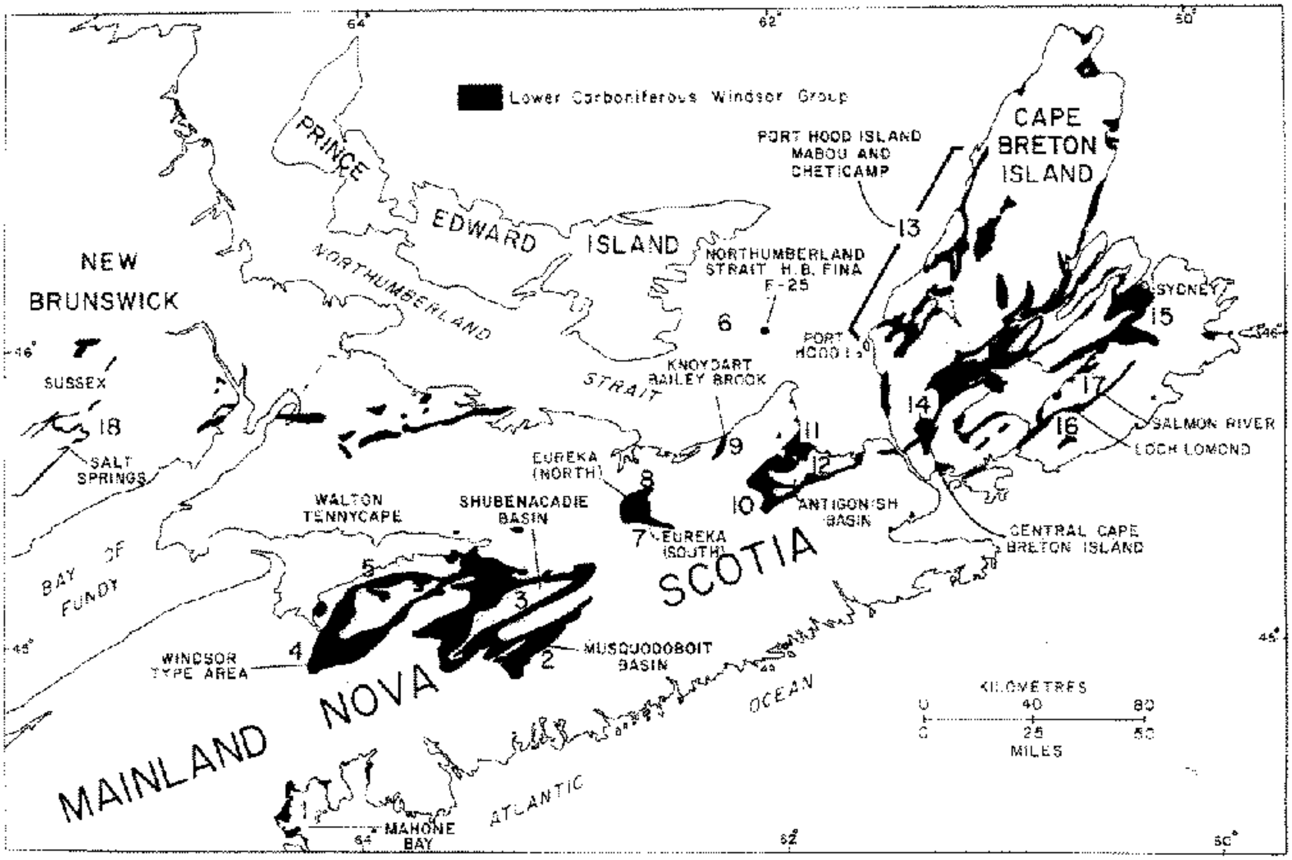

Figure 6. Location map for Major Cycle sections in Nova Scotia.

Major Cycles 3, 4 and 5. In the Shubenacadie and Musquodoboit Basins Major Cycles 3, 4 and 5 disconformably overlie Major Cycle 2. Major Cycle 5 includes the highest Windsor Group marine carbonate member and the transitional evaporites (anhydrite and halite) locally present at the base of the Canso Group. These Major Cycles, comprising up to 9 minicycles, are lithologically similar to Major Cycle 2 and have a combined thickness of up to 160 m. They differ from Major Cycle 2 mainly in the decreased proportion of evaporite (less than 30%). Typical saline minicycles include, in ascending order, transgressive then regressive carbonate facies, anhydrite and red beds (Figure 7). Halite is known only in Major Cycle 5 in the Shubenacadie Basin. The continuation of evaporite deposition including anhydrite and halite of Major Cycle 5 into post Windsor Group rocks (Canso Group) is interpreted as representing the terminal phase of marine invasion and evaporite deposition in restricted continental successor basins with uncertain marine influence.

The dramatic change from the single progressive evaporite sequence of Major Cycle 1 to the repeated minicycles within Major Cycles 2 to 5 was interpreted by Boehner (1979) to have resulted from the basin infilling and topographic levelling by the thick evaporites of Cycle 1. The resulting surface of low relief and gentle slope favoured shallow water and diagenetic evaporite deposition during regressive episodes following repeated marine invasions. Boehner (1979) recognized decreased and more localized evaporite deposition within successively younger Major Cycles of the Shubenacadie and Musquodoboit Basins.

Major Cycles Distribution and Correlation. The Major Cycle framework outlined from the Shubenacadie and Musquodoboit Basins is generally applicable to many Windsor Group outcrop areas in Nova Scotia (Figures 5 and 6). Major facies changes and stratigraphic onlap locally complicate the picture, especially in areas near basement blocks such as Mahone Bay, Eureka and Loch Lomond (Figures 5, 6, Sections 1, 8 and 16, and Figure 7). Typical Major Cycle 1 rocks are widespread throughout Nova Scotia and are well represented in the Antigonish-Mabou, Canso-Bras d'Or and Sydney areas where its thickness ranges from 300 m to 600 m. Redbeds are locally developed in some areas including western Hants-Colchester, Antigonish-Mabou and Canso-Bras d'Or (Figures 5 and 6, Sections 4, 5, 6, 10, 11, 12, 13 and 14). The redbeds are closely associated with the halite facies.

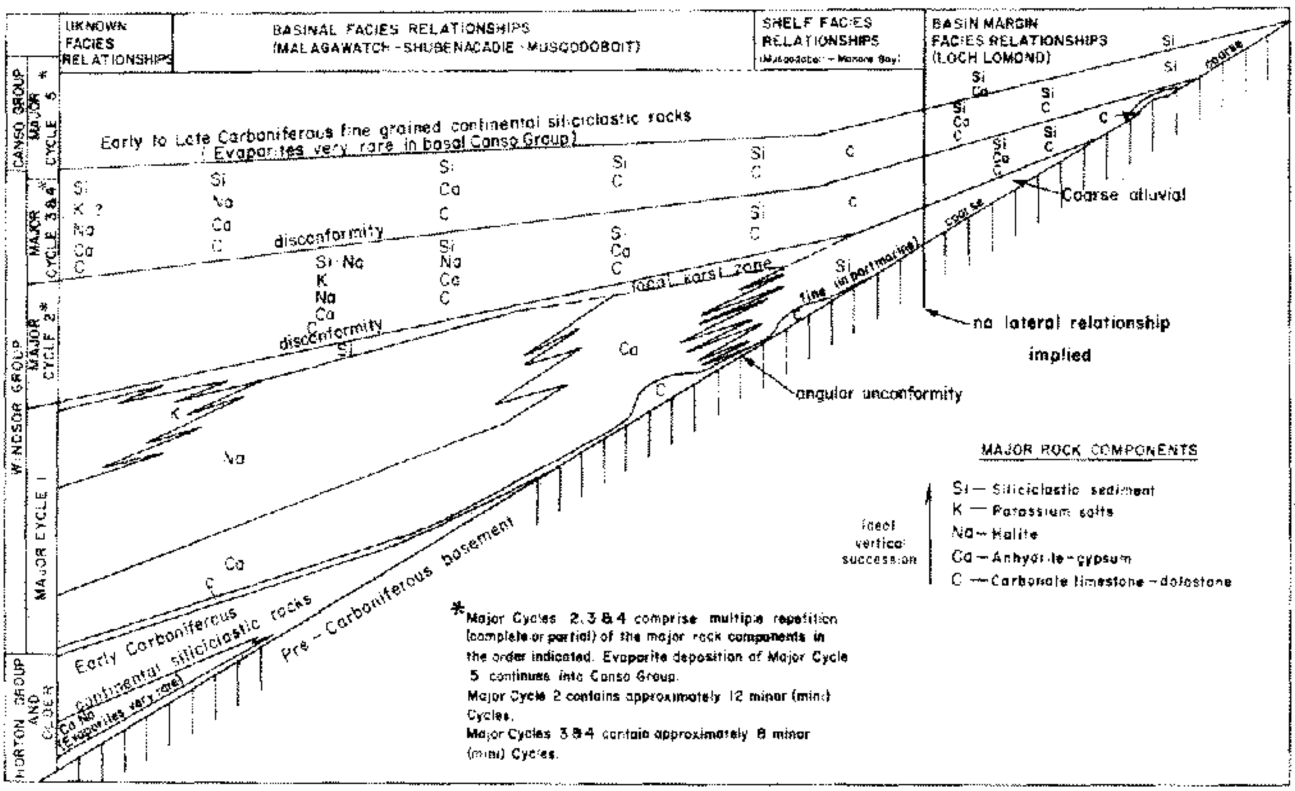

Figure 7. Schematic diagram of typical Windsor Group facies relationships recognized within Nova Scotia.

Halite is known to occur with Major Cycle 1 in most areas and it forms the most important salt resource in Nova Scotia. Boehner (1980) reported that the Shubenacadie-Stewiacke deposit in the Hants-Colchester area contains an estimated geological resource of 50 billion tonnes.

Potash salt, sylvite and minor carnallite are known to be associated with halite in Major Cycle 1 in the Antigonish and Canso-Bras d'Or areas (Figures 5, 6 and 7, Sections 10, 11, 12 and 14). Although encouraging for further exploration, economic quantities have yet to be discovered. Potash salts are not known to occur on the Nova Scotia Platform south of the Minas Geofracture. Major Cycle 1 rocks in this area were inferred by Giles (1981a) to have been deposited adjacent to seaways connected to a major Viséan sea through a shallow marine carbonate shelf on the Nova Scotia Platform. Successive Carboniferous structural basins in a northwesterly direction generally contain increasingly saline evaporite suites indicating significant lateral facies change and important paleogeographic control on evaporite deposition. Paleogeographic reconstructions across the Minas Geofracture are extremely uncertain at this time.

The distribution, thickness and facies variation of evaporites in Major Cycle 1 are unknown in most areas because of the scarcity of deep drilling. Stratigraphic thicknesses of up to 600 m are present in some areas with the thickest sections in the highly deformed saline Windsor Group facies of the Canso-Bras d'Or area. Major Cycle 1 is the major target for potash exploration in Nova Scotia as it is in New Brunswick (Figure 5, Section 18).

The thick halite-anhydrite-siltstone sequence in the highly deformed diapiric Windsor Group in the Cumberland area is of uncertain stratigraphic assignment (Figure 8). Drillhole sections and mine stratigraphic sections (Evans, 1972) are incomplete and their relationship to outcrop sections of Bell (1958) are uncertain. The stratigraphy of the evaporites in the Cumberland area is virtually unknown; therefore, stratigraphic comparison to well established sections in other areas is not yet possible.

It is of interest to note that the basal Windsor Group in the Anschutz Wallace Station No. 1 well (Figure 8) drilled near Malagash comprises a thick sequence of cherty-siliceous shales. These relatively undisturbed, gently dipping shales may represent deep water sediments. The Cumberland area is geologically important because it is close to the the New Brunswick Platform area where economic potash deposits have been discovered in Major Cycle 1 of the Windsor Group (Figures 5 and 6, Section 18). Potash salts, sylvite and carnallite have been reported from all known salt deposits in the Cumberland area, but not in economic quantities (Figure

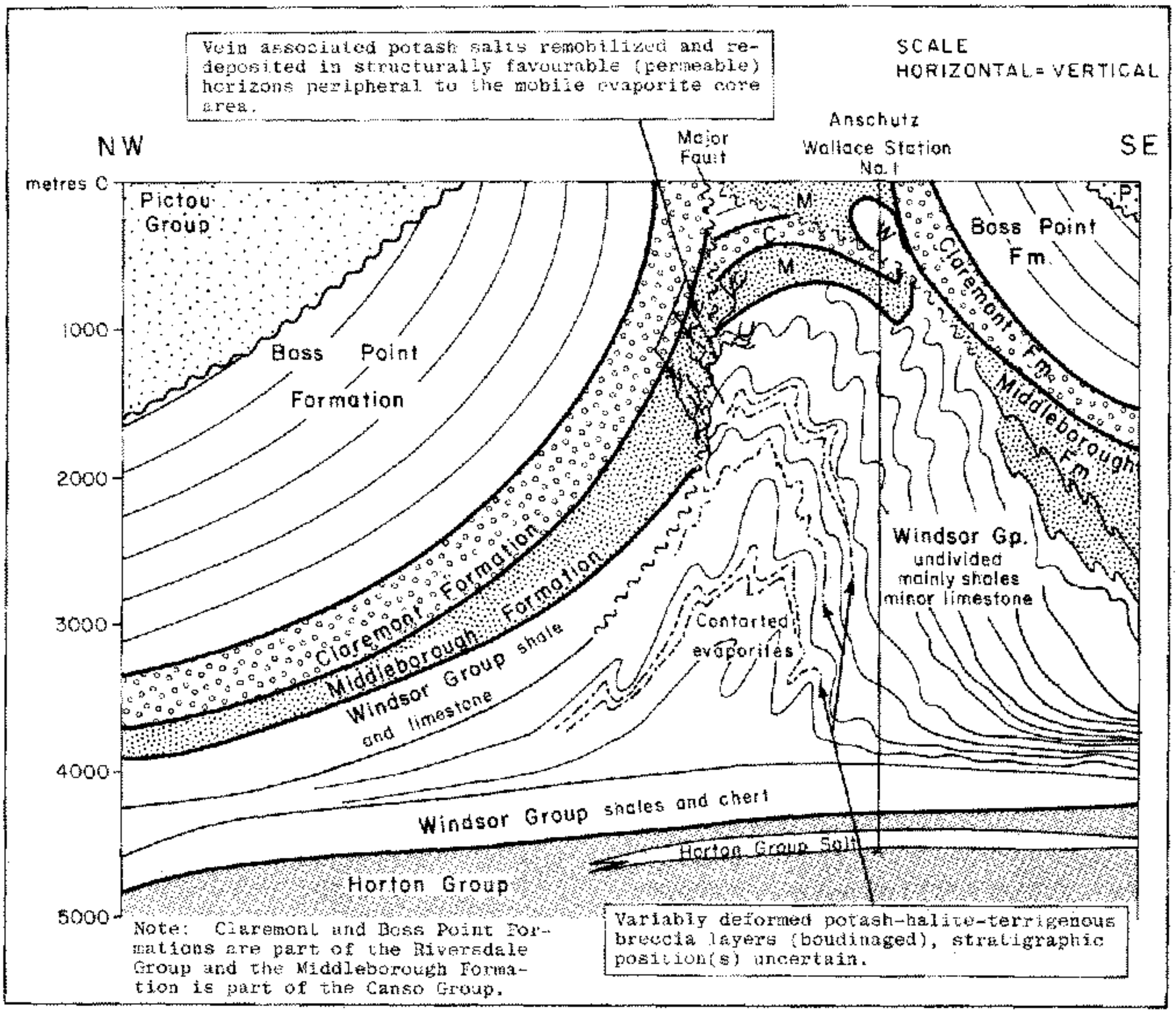

Figure 8. Cross-section of a major anticlinal evaporite diapir near Malagash deposit, Cumberland area, northern Nova Scotia.

3). Structural complexity and geological uncertainty are major factors that have hindered potash exploration in this area. Potash salts are found in two major settings (Figure 8) associated with the Windsor Group evaporite diapirs: 1) as mudstone-halite breccia and boudins in intensely folded stratified layers, and 2) as remobilized secondary veins and stockworks peripheral to and/or within the diapir. The precise tratigraphic position of these potash occurrences is unknown.

Major Cycle 2 is more widespread than Major Cycle 1. Major Cycle 2 displays major facies change regionally ranging from evaporite dominated to terrigenous dominated. It locally oversteps Major Cycle 1 to onlap onto pre-Carboniferous basement rocks (Figure 7) in marginal basin areas including Loch Lomond and Salmon River (Figures 5 and 6, Sections 16 and 17, Boehner, 1983). Similar changes are indicated by Giles (1981b) in the Eureka and Mahone Bay areas (Figures 5 and 6, Sections 1 and 8). The Mahone Bay area is similar to the Musquodoboit Basin (Figure 5, Section 2). Shallow marine shelf facies in Major Cycles 1, 2 and 3 indicated that these areas may have been proximal to a seaway connecting the Viséan inland sea on the Nova Scotia Platform to the Major Viséan sea to the southeast (Giles, 1981a). The major evaporite deposition appears to have been localized in deeper, more northerly parts of the inland sea.

Halite stratigraphically above Major Cycle 1 was first recognized with several carbonate-anhydrite minicycles within Major Cycle 2 in the Shubenacadie Basin (Figures 5 and 6, Section 3). The stratified halite and interbedded anhydrite horizons rarely exceeded thicknesses of 15 m, but subsequently thicker and more numerous halite beds have been confirmed in the highly deformed sections in the Canso-Bras d'Or area (Giles, 1981c and Dekker, 1982). Exploration drilling at McIntyre Lake, Malagawatch and Orangedale has intersected potash (sylvite and minor carnallite) in one carbonate-anhydrite-halite minicycle within Major Cycle 2. The presence of potash, although in subeconomic quantities in at least one horizon in this cycle, was previously unknown and may provide an additional potash exploration target.

Major Cycle 2 at Malagawatch is dominated by halite and is up to three times (500 m versus 160 m) as thick as in the Hants-Colchester area. Approximately 45% of the Malagawatch section is halite and 30% anhydrite. Corresponding sections in the Shubenacadie Basin are 14% halite and 51% anhydrite. The majority of the increase in statigraphic thickness at Malagawatch is contributed by the halite (230 m versus 22 m).

Major Cycles 3, 4 and 5 are more widely distributed than Cycles 1 and 2 (Figure 7). Onlap relationships have been documented by Boehner (1983) near Loch Lomond and Salmon River (Figures 5 and 6, Sections 16 and 17) in southeastern Cape Breton Island and near Knoydart Point in northeastern mainland Nova Scotia (Figures 5 and 6, Section 9) by Giles (1981b). Although salt was locally present in Major Cycle 5 in the Shubenacadie Basin it did not occur in Major Cycles 3 and 4. It was found, however, to be a substantial component in Major Cycle 3 and 4 in the Canso-Bras d'Or area. Here the Major Cycle 3 section is nearly four times as thick as corresponding sections in the Shubenacadie Basin (270 m versus 70 m) and consists of 34% halite and 28% anhydrite. Corresponding values are 0% and 10%, respectively, in the Shubenacadie Basin. As with Major Cycle 2 in the Malagawatch area, most of the increase in thickness is contributed by the halite.

Unfortunately data are incomplete to allow comparisons with Major Cycles 3 and 4 in other areas such as Antigonish-Mabou and Cumberland. Salt facies have not been confirmed in Major Cycles 2, 3, 4 and 5 in these areas. Anhydrite is present and the presence of salt (possibly with potash) may be established by deep basin drilling.

SALT DEPOSITS AND OCCURRENCES

The present distribution of Carboniferous rocks in Nova Scotia is controlled by post depositional tectonism and erosion. These factors, together with high angle transcurrent, dip slip and low angle faulting, make a precise outline of the original sedimentary sub-basins difficult. The relationship of the present structural basins or synclinoria to the original depocentre is sometimes uncertain. For these reasons the salt areas of Nova Scotia described in this report (Figure 2) are named as present day geographical and structural areas which may or may not correspond to the original sedimentary sub-basins outlined by Bell (1958).

The five areas with known salt deposits (Figure 3) found in Nova Scotia are the Hants-Colchester, Cumberland, Antigonish-Mabou, Canso-Bras d'Or, and Sydney areas. In addition, there are four areas underlain by Windsor Group rocks where salt may be present but has not been established by drilling. These include the Mahone Bay, Pictou, Cheticamp-Margaree and Cape North areas.

Within the five areas where salt is known to occur, 13 occurrences and 19 deposits are recognized (Figure 3 and Table 2). The exploration potential is based only on the limited drilled area of the deposit or occurrence. Areas without salt previously defined by drilling may have significant potential but cannot be objectively evaluated without more data. Figure 9 explains the structural types A, B, C and D used in Table 2.

The deposits and occurrences are sometimes defined in only a single drillhole so are inadequately known. The designation of "deposit" or "occurrence" is purely arbitrary. It is based upon 1) the quantity of salt actually intersected in drilling coupled with 2) the quantity which may reasonably be present by comparison to similar structural and geological conditions in other better defined deposits and 3) gravity data where available. The deposits and occurrences were assessed only on their geological merits, with the quality of the salt, mining factors and depth to salt not being specifically considered. The data related to these factors, with the exception of the depth, are generally unknown or highly variable and therefore of limited value.

GENERAL TECTONICS AND STRUCTURAL GEOLOGY

Keppie (1982a) indicated that the Carboniferous rocks in the Magdalen Basin and locally in adjacent areas were deformed between Early Westphalian and Late Triassic times. This deformation was attributed to movement on the Minas Geofracture associated with the Hercynian Orogeny. Deformation within the Magdalen Basin was most intense along its margins and was accompanied by evaporite tectonism in basinal settings such as the Cumberland area. Subsidiary strike slip and dip slip movement on major complex systems of northeasterly trending transcurrent faults produced local deformation in narrow Carboniferous areas bounded by fragmented basement blocks. This situation is common in the Canso Bras d'Or area. Locally severe deformation, including gravity sliding, occurred on the relatively stable Nova Scotia Platform. In the deeper basins disharmonic fold geometry

TABLE 2

Salt Deposits and Occurrences of Nova Scotia

	Deposit or Occurrence	Structural Type	Major Cycle(s)	Potential for Salt Exploration	Potential for Potash Exploration
Hants-Colchester Area					
Beaver Brook	Deposit	B	1	good	poor
Clarksville	Occurrence	B-C	5	fair	fair
Falmouth	Occurrence	?	1	poor	poor
Kennetcook	Occurrence	B-C	1	poor	poor
Shubenacadie-Stewiacke	Deposit	A	1,2,5	very good	poor
Stanley	Occurrence	B-C	1	fair	poor
Summerville	Occurrence	Vein	—	very poor	very poor
Upper Walton River	Occurrence	C	1-2?	poor-fair	poor-fair
Walton	Occurrence	B-C	1-2?	poor-fair	poor-fair
Cumberland Area					
Beckwith	Occurrence	C-D	?	fair	good
Malagash*	Deposit	D	?	fair	good
Nappan*	Deposit	D	?	fair	poor
Oxford*	Deposit	D	?	fair	fair
Pugwash*	Deposit	D	?	very good	good
Roslin	Occurrence	D	?	fair	fair
Antigonish-Mabou Area					
Antigonish	Deposit	B-C	1	fair	fair
James River*	Deposit	B-C	1	fair-good	fair-good
Mabou	Deposit	C-D	1-4?	fair-good	fair-good
Ohio	Occurrence	A	1	poor-fair	poor-fair
Pomquet River	Occurrence	C	1?	poor	poor
Southside Harbour*	Deposit	B	1	good	fair
Canso-Bras d'Or Area					
Cleveland*	Deposit	B-C	2-5?	fair	fair
Estmere	Deposit	B-C	2-5?	fair	fair
Kingsville	Deposit	C-D	1-5?	very good	fair-good
McIntyre Lake*	Deposit	C	1-5?	very good	good
Malagawatch*	Deposit	C?	1-4	good	good
Orangedale*	Deposit	C?	1-4	good	good
Port Richmond*	Deposit	C-D?	1-4	very good	fair
Seaview	Occurrence	C	1?	fair	fair
St. Patricks Channel	Deposit	C	1-4	fair-poor	fair-poor
St. Peters*	Deposit	C	1?	fair	fair
Sydney Area					
East Bay	Occurrence	A	1?	fair	poor

*Potash salts reported.

and structural style may be expected between pre- and post-Windsor Group rocks.

Carboniferous rocks were deposited in two principal tectonic settings, 1) on relatively stable platforms, i.e., Nova Scotia and New Brunswick Platforms (Figure 1) and 2) within an intervening fragmented pull apart area named the Magdalen Basin (Keppie, 1982). These settings developed, beginning in the Middle-Late Devonian, as part of transpression tectonics (Keppie, 1982b). Prominent transcurrent wrench faulting produced a molassic succession characterized by complicated facies variation and structural complexity. The easily mobilized evaporite deposits of the Windsor Group have locally undergone severe deformation and thickening, often resulting in large wall and plug-like diapiric intrusions. The most severe deformation is characterized by tortuous folding with isoclinal, recumbent to upright geometry, normal and reverse faulting, gravity sliding, and extensive plastic flow of salt and anhydrite rocks. Locally, as in the Cumberland area, unconformities are evident where younger Carboniferous units flank the structures (Figures 3 and 8), indicating the movement occurred over a period of time.

In Nova Scotia, Windsor Group evaporite, including

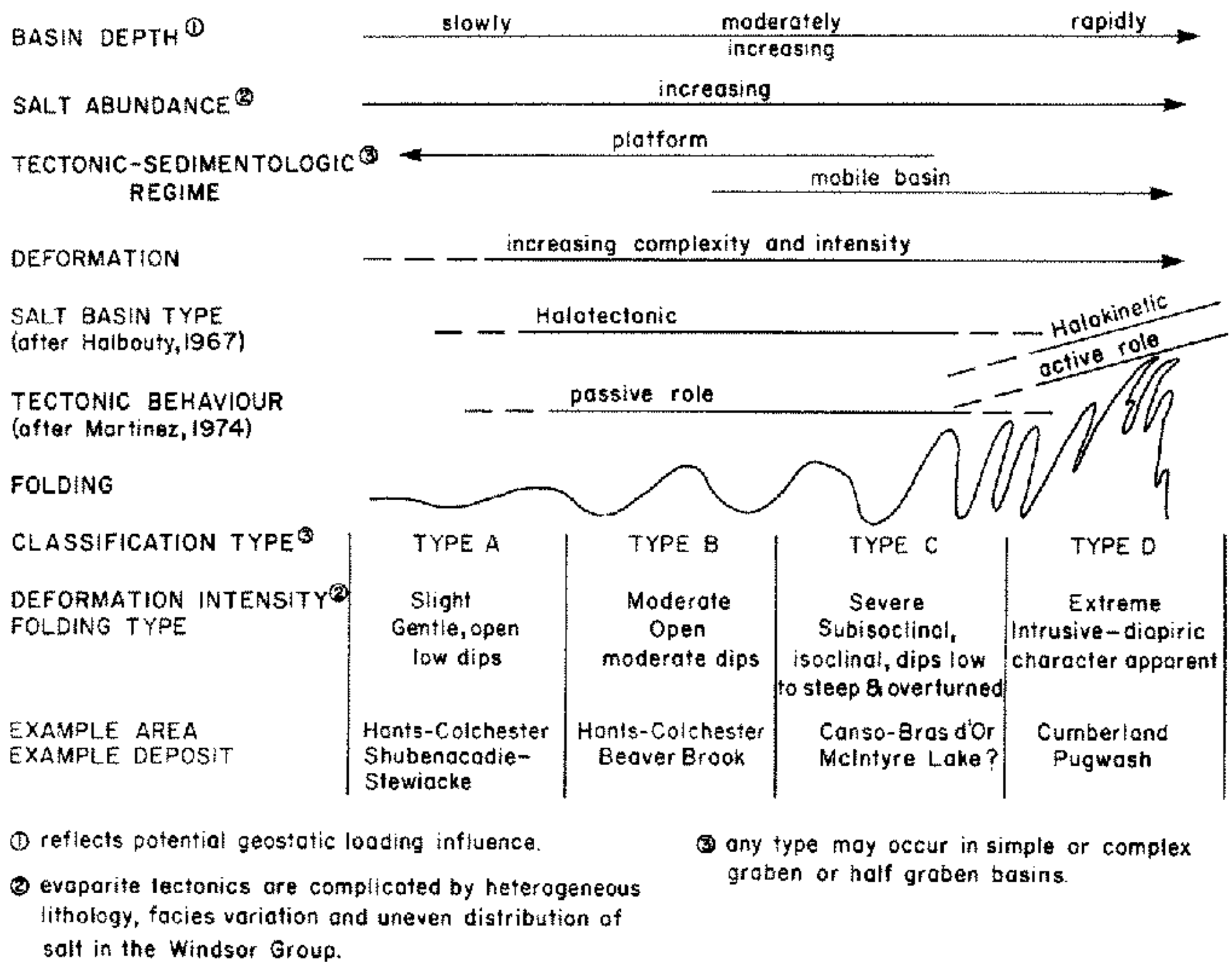

Figure 9. Summary of salt deposit structural classification scheme applied to Windsor Group evaporites in Nova Scotia. (For general distribution of structural types see Figure 9).

salt and associated potash, occurs in a variety of structural situations as shown on Figures 9 and 10. This empirical classification is based primarily upon the degree of structural complexity, and thus each type is part of a continuous spectrum. These modes are controlled largely by location with respect to the major faults, the severity of tectonism, volume of salt and depth of burial. The relatively undisturbed stratified deposits (Types A and B) generally occur in the platform synclinoria marginal to the central mobile area (Figures 1, 9 and 10). At the opposite end of the spectrum, structurally complex deposits of the halotectonic type that result from compressive tectonic forces, (Halbouty, 1967, p. 2) are represented in the Canso Bras d'Or area (Types C and D). Intensely deformed deposits resulting, at least in the final stage of development, from halokinetic (isostatic) salt movement (Habouty, 1967, p. 2) are present in the Cumberland area (Figures 5, 8 and 10). Here Windsor Group evaporites occur as wall and dome, diapiric anticlinal intrusions. These intrusions appear to be restricted to areas of thick Carboniferous sedimentation and may occur in the Mabou and the Canso-Bras d'Or areas (Figure 10).

Moderate to strong deformation is present in the western and northern parts of the Hants-Colchester area, the Antigonish area and parts of the Bras d'Or area in central Cape Breton (Types B and C). In these areas the Windsor Group salt occurs in variably faulted synclinoria where thickening of the evaporites is generally minor. Thickening, where present, appears to be limited to local "welts" in anticlinal or synclinal cores or as fault bound synclinoria between basement blocks. A major thrust fault is inferred to occur at the top of Major Cycle 1 in the Antigonish Basin (Boehner and Giles, 1982). This fault, which may be related to major strike slip faulting, is suspected of occurring in other areas, including Mabou in western Cape Breton Island (Figures 3 and 10). Slightly de-

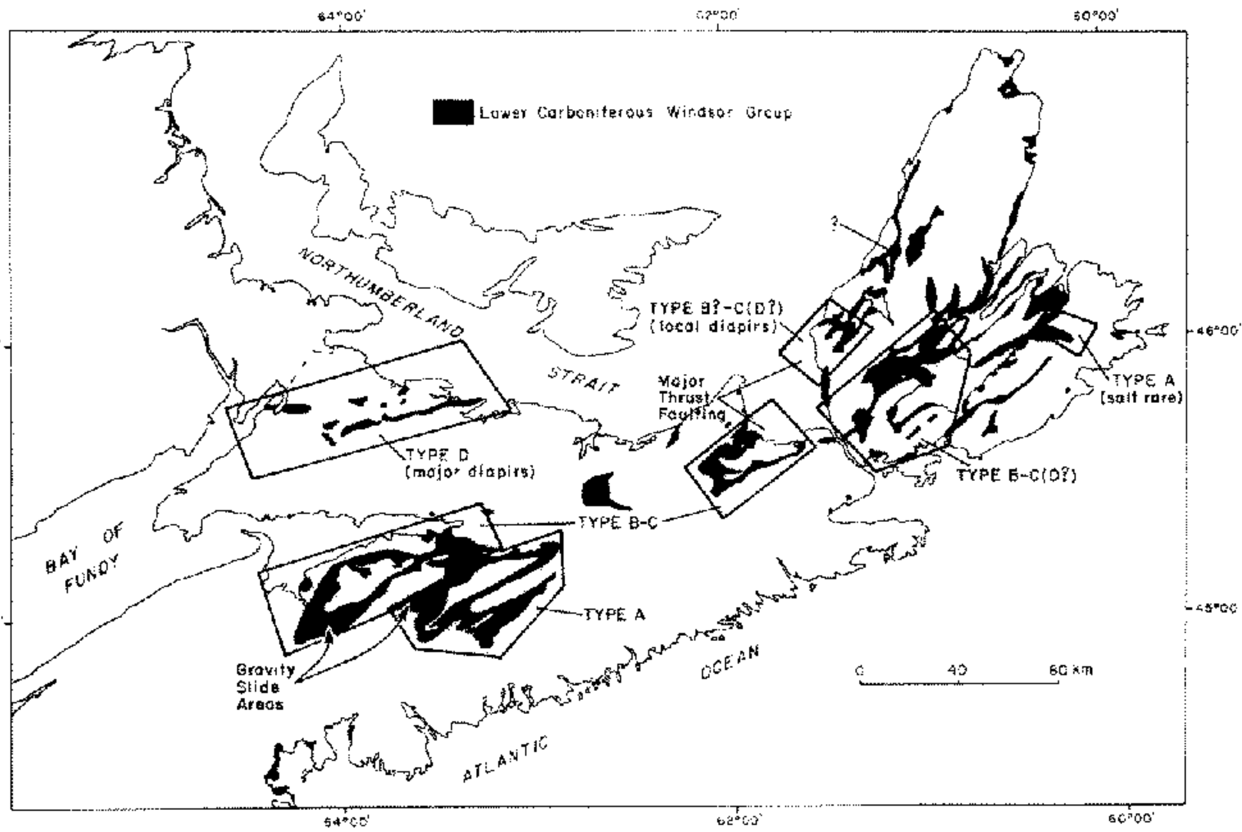

Figure 10. Distribution of salt deposit structural types in Nova Scotia.

formed, stratified salt (Type A) is rarely encountered in Nova Scotia, although in the eastern part of the Hants-Colchester (Shubenacadie-Stewiacke) deposit there is a major deposit of relatively undisturbed salt. This area of relatively thin sedimentary cover was probably subject to less intense deformation because it is outside the mobile central belt of the Magdalen Basin. Large and small scale recumbent fold structures with multiple repetition of stratigraphic units have been described locally in parts of the Hants-Colchester area (Figures 3 and 10) by Giles (1977), Boehner (1977) and Geldsetzer et al. (1980). This folding is inferred to have been related to tectonic uplift, detachment and gravity sliding on the top of Major Cycle I evaporites, especially the salt.

SALT DISSOLUTION FEATURES

Cap rock development of the Gulf Coast type described by Martinez (1974, 1978) and Walker (1974) is not known to occur in association with Windsor Group salt in Nova Scotia. Residual collapse breccia is common in areas where saline Windsor Group comes to the surface. The residual breccia is well developed in the Pugwash and Nappan deposits (Cumberland area Type D). Here blocks of gypsum and carbonate resistates are found in poor to unconsolidated mud forming an irregular cap to the evaporite diapirs. Giles (1981c) described telescoped sections of highly deformed saline Windsor Group in the McIntyre Lake deposit (Canso-Bras d'Or area, Type C). In this area, halite has been preferentially dissolved to a depth of 200 to 300 m, leaving the original stratigraphic succession intact but thinned. The collapse breccia comprises relatively insoluble brecciated anhydrite-gypsum, siltstone and carbonate infiltrated by mudstone. A similar situation has been described nearby in the Malagawatch deposit area by Dekker (1982). Salt removal, residual accumulation and collapse brecciation may be expected in the vicinity of faults and permeable strata in areas where they are in contact with the Windsor Group. The absence of salt springs and seeps in many areas of these features indicates salt dissolution has been reduced or halted, possibly by the sealing action of residual clay and mud. The abundance of salt springs, seeps and saline formation water regionally, however, indicates most salt areas are not stable or completely sealed.

CONCLUSION

The complicated stratigraphy and structure of Windsor Group evaporites, especially salt and potash, is inherited from an equally complicated paleogeographic and tectonic history. Detailed paleogeographic, sedimentation and structural models both at local and regional scales are difficult to construct. This difficulty is the result of uncertain correlation across major faults (i.e., Minas Geofracture) and the limited subsurface data, especially in deep basin areas. Models can be confidently made only in areas where the geology is well established following detailed examination of all available data, particularly exploration core drilling. Many parts of Nova Scotia, including the Cumberland area, are very poorly understood and await further drilling. Although it is evident from this general overview that advances are being made in understanding the geology of salt in Nova Scotia, it is clear that more comprehensive work remains to be completed on the stratigraphy, geochemistry, sedimentology and structure of Windsor Group evaporites and the Carboniferous in general.

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