

Karst Geology in the Salt-bearing Windsor Group Evaporites and Controls on the Origin of Gypsum Deposits in South-central Cape Breton Island, Nova Scotia¹

R. C. Boehner, G. C. Adams² and P. S. Giles³

Introduction

All economically significant occurrences of gypsum and anhydrite found in Nova Scotia are hosted by the Mississippian (Early Carboniferous) Windsor Group (Fig. 1). The Windsor Group consists of interstratified marine evaporites, marine

carbonates and nonmarine siliciclastic sedimentary rocks (Figs. 2 and 3) which were deposited in a large complex intracontinental basin. The Windsor Group is typically underlain by the Horton Group, a thick sequence of continental siliciclastic sedimentary rocks. The Horton Group and locally the Windsor Group strata were deposited in the early stages of the basin system over older

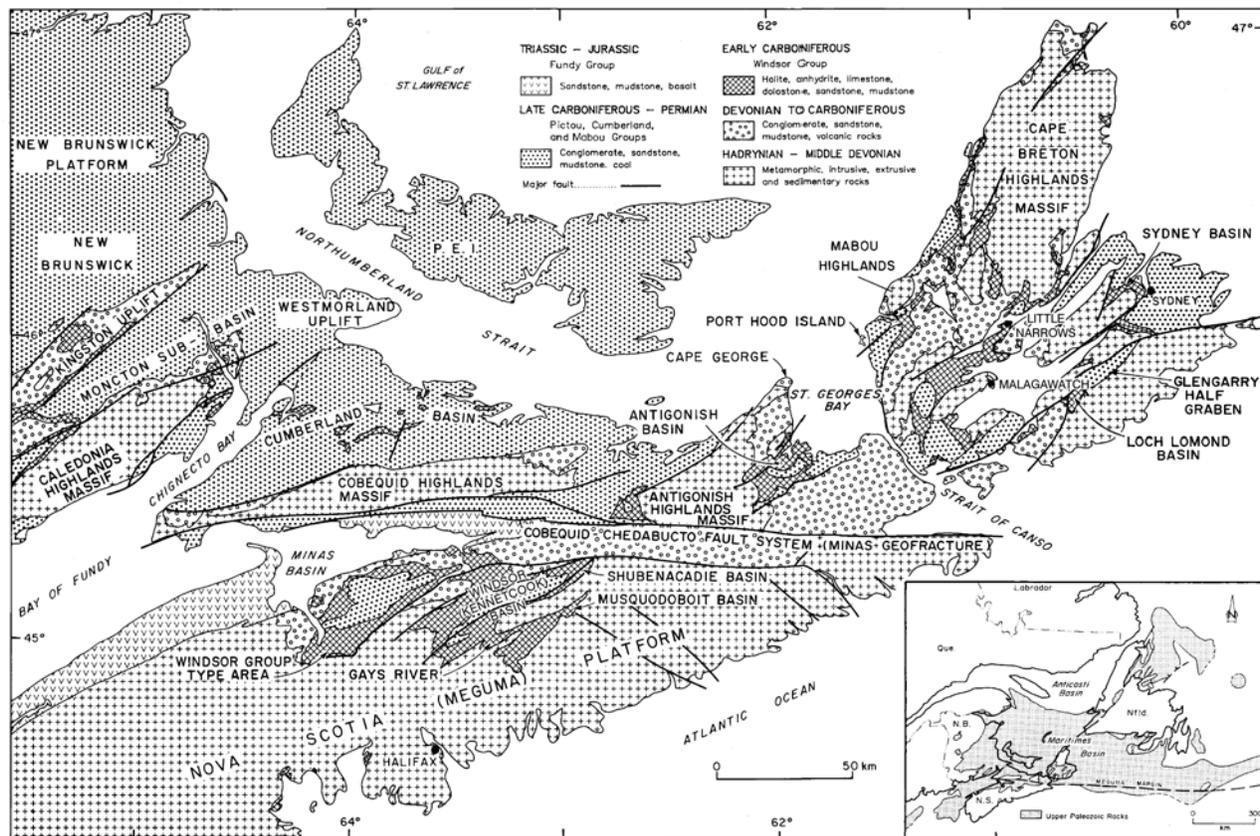


Figure 1. General regional geology and location map, Nova Scotia.

¹Funded by Natural Resources Canada and the Nova Scotia Department of Natural Resources under the Targeted Geoscience Initiative project: Geological Mapping for Mineral Development in South-central Cape Breton Island

²Nova Scotia Treasury and Policy Board, PO Box 1617, Halifax, NS B3J 2Y3

³Natural Resources Canada, Geological Survey of Canada, PO Box 1006, Dartmouth, NS B2Y 4A2

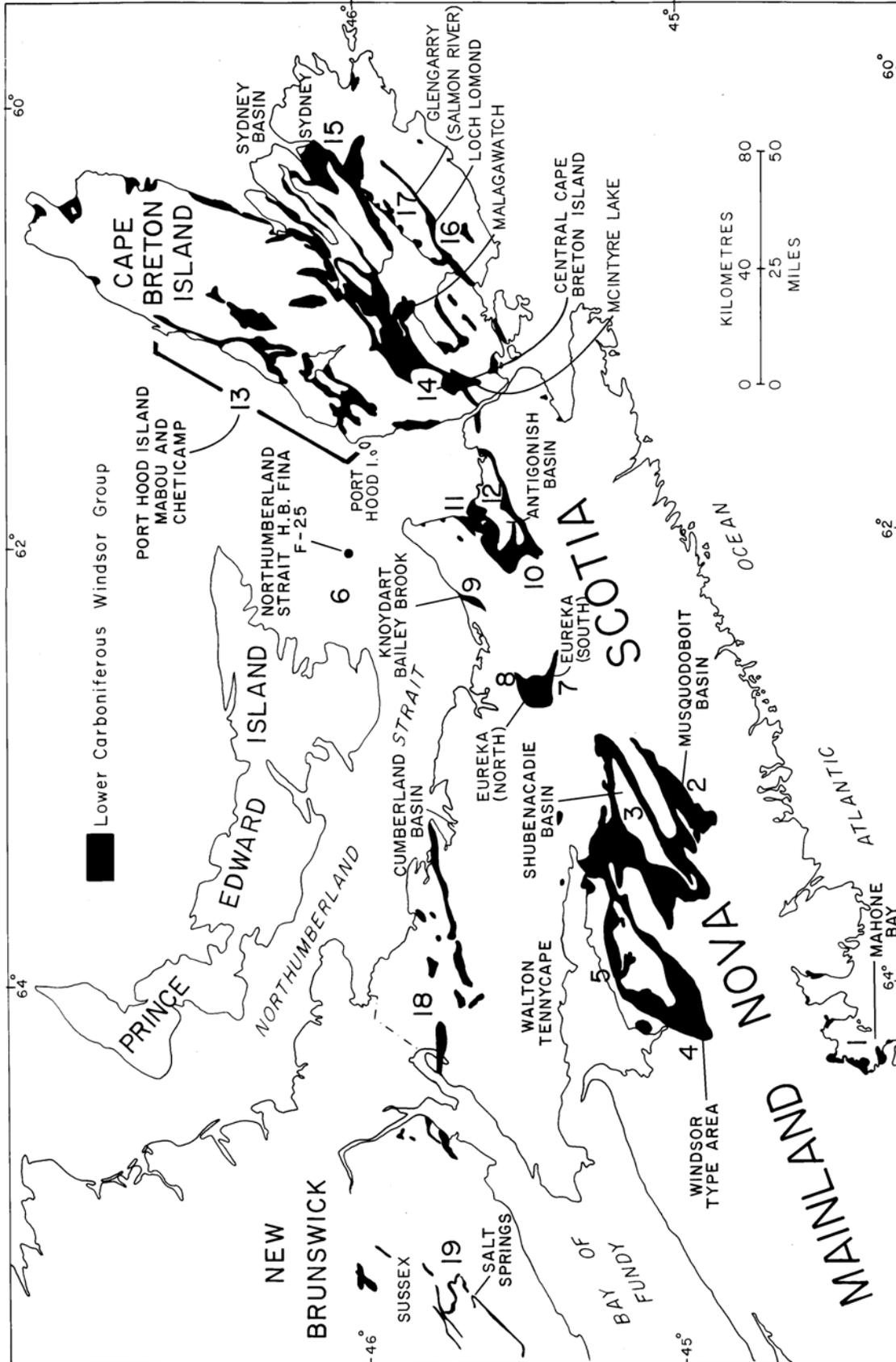


Figure 3. Location map for major cycle and stratigraphic sections in Nova Scotia.

deformed metamorphic and igneous rocks. Fine-grained continental siliciclastics of the Mabou (Canso) Group conformably overlie the Windsor Group, although locally, younger Carboniferous strata of the Cumberland (Riversdale) and Pictou groups may overlie the Windsor Group with an unconformity or fault contact.

Prior to Adams (1991), little information was published on the geology of gypsum and anhydrite resources of the province (Bell, 1929; Goodman, 1952; Schenk, 1969 and 1984; Lewis and Holleman, 1983). Substantial advances have been made in the past 20 years in understanding the geology, stratigraphy and structure of the Windsor Group rocks that host gypsum deposits in the province. Much of this increased knowledge has been made possible by new subsurface data generated by numerous drilling and seismic exploration projects for base metal, salt, potash and hydrocarbon deposits. Significant additions to the previous work by Adams (1991) on gypsum deposits include: (1) recognition of the close stratigraphic, structural and tectonic relationship between the geology of salt in the deep subsurface and gypsum in the near surface; (2) recognition of a more extensive distribution and thickness of anhydrite (parent mineral of gypsum in Nova Scotia) in the thick evaporitic sections of the Upper Windsor Group (Major Cycles 3 to 5 of Giles, 1981); and (3) increased understanding of the extent and role of complex, multiple-generation karst development in the origin of gypsum deposits in the evaporite-dominated Windsor Group (Boehner and Giles, 1993; Boehner and Prime, 1993).

In many ways, the Windsor Group gypsum deposits are the near-surface karst-altered derivatives of deeper basin (down-dip) anhydrite and salt deposits. This is especially applicable in heterogeneous and deformed gypsum deposits (types 3, 4 and 5 described by Adams, 1991). There has been a long-recognized mineral alteration/replacement facies change from gypsum down into anhydrite. It is now evident that this mineralogical change is also linked with further change down-dip to salt facies. The dissolution process involving circulating groundwater not only hydrated the anhydrite to gypsum, but also removed salt

associated with anhydrite to depths exceeding 400 m.

An important factor in the formation of major gypsum deposits is decollement tectonics. This occurs at both a local and regional scale (e.g. Ainslie Detachment, Lynch and Giles, 1995; Lynch *et al.*, 1998) and produces some of the complex recumbent and isoclinal folding characteristic of many areas in the salt- and anhydrite-dominated Windsor Group. Salt content in the stratigraphic section is a major factor in facilitating the development of this structural style (salt is highly ductile). The repetition of strata, especially the more competent anhydrite, by folding and faulting may be an important contributor to enhancing the hydration process as well as the economic thickness of gypsum deposits.

The stratigraphic, structural, tectonic and evaporite karst dissolution connections to the origin of gypsum deposits outlined above are the result of recent work in south-central Cape Breton Island funded by the federal-provincial Targeted Geoscience Initiative. This includes the detailed investigations by Giles (2003) of the complex geology of salt and potash deposits associated with the Windsor Group in central and southern Cape Breton Island. Because the geology of gypsum deposits is intimately linked to local stratigraphy and structure, readers are directed to descriptions and illustrations of basin scale geology as well as associated salt and potash deposits (e.g. Boehner, 1984, 1986, and 1992, Giles, 2003, Giles and Lynch, 1994, Lynch and Giles, 1995). The following section is an overview of the stratigraphy and lithologic composition of Windsor Group major and minor cycles.

Major Cycles

Bell (1929) systematically described the stratigraphy and paleontology of the Windsor Group in the type area near Windsor, Hants County. Workers from the late 1960s to the present introduced a detailed lithostratigraphic nomenclature of formations and members based on local structural basins (Giles, 1981). A complex nomenclature of numerous formations and

members (many are correlative units) has consequently developed (Figs. 2 and 3).

Giles (1981) used the lithostratigraphy as a basis for describing the Windsor Group as a system of five major transgressive-regressive depositional cycles (Fig. 2). Generally these major cycles are complex and comprise multiple minor deposition cycles. These minor or minicycles, with thicknesses of metres to tens of metres, typically include, in ascending order: marine carbonates, anhydrite, halite, and red/green mudrock. Although the five major cycles have been defined primarily on the basis of lithostratigraphy, they coincide closely with biostratigraphy defined by Bell (1929). Major Cycles 1 and 2 of Giles (1981) correlate with the Lower Windsor A and B subzones of Bell (1929), and Major Cycles 3 to 5 correlate with the C, D and E subzones of the Upper Windsor. The major cycle nomenclature has been applied to the Windsor Group throughout the province and serves as a simplified framework for correlation and comparison of facies variations (Figs. 2, 3 and 4). The uppermost of these cycles, Major Cycle 5, extends transitionally into the overlying Hastings Formation of the Mabou (Canso) Group.

Gypsum and anhydrite occur in all five major cycles in the Windsor Group (Figs. 2 and 4), and locally evaporite deposits (anhydrite and salt) extend into the basal part of the Mabou (Canso) Group. Economically significant sections of gypsum and anhydrite (Lewis and Holleman, 1983) are generally restricted to the lower Windsor Group, Major Cycles 1 and 2 (Giles, 1981; Boehner, 1984 and 1986; Adams, 1991). Major Cycle 1 is up to 400 m thick and comprises 40-90% CaSO₄, Major Cycle 2 is 150 to 530 m thick and is up to 55% CaSO₄, and Major Cycles 3 to 5 are 150 to 470 m thick and typically contain <20% CaSO₄. The evaporite component of these cycles may be increased substantially (Fig. 6), and locally dominated by the highly water-soluble mineral halite (NaCl) with local potash (KCl). For example, Major Cycle 1 may be up to 75% halite, and in saline evaporitic sections in central Cape Breton Island, Major Cycle 2 may comprise up to 55% halite, and Major Cycles 3 to 5 up to 35% halite. The composition of an average Major Cycle 1 section in the central Cape Breton Island area (Fig. 5) is 7% carbonate, 11% siliciclastic, 42% anhydrite and 40% salt. Major Cycle 2 is 530 m thick and comprises 7% carbonate, 16%

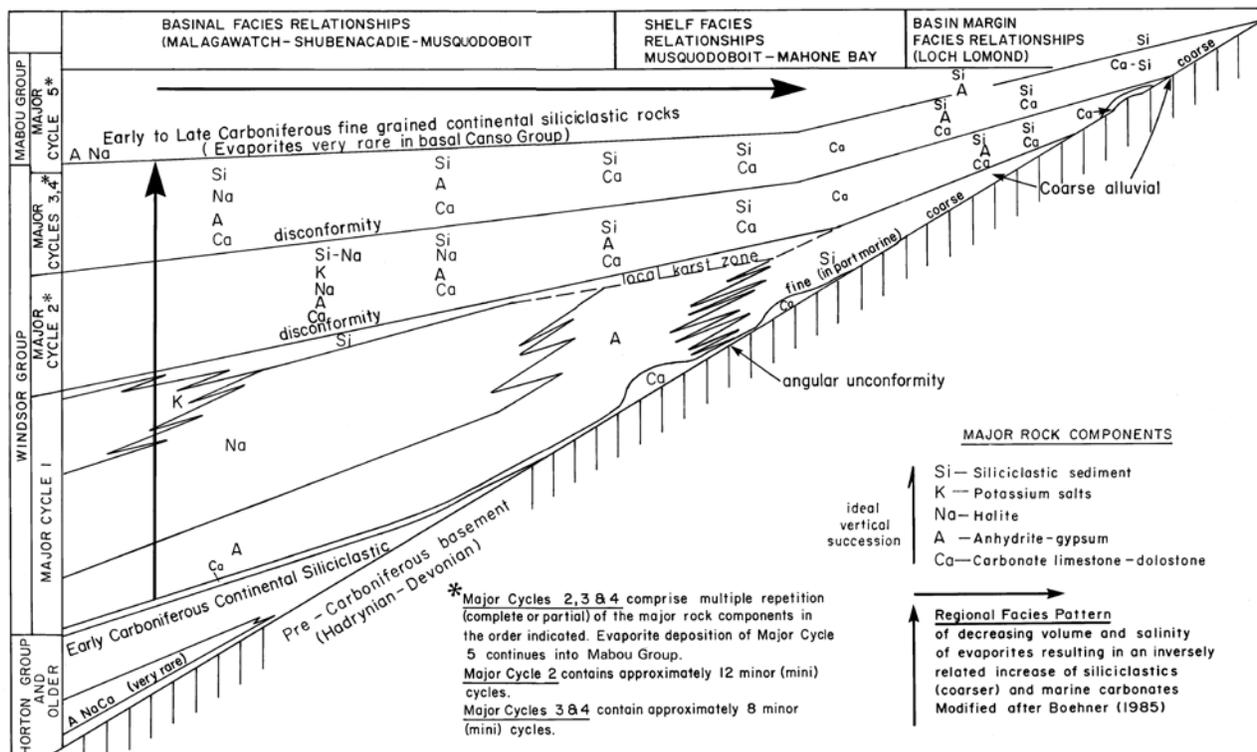


Figure 4. Schematic representation of Windsor Group facies relationships in Nova Scotia.

Windsor Group Reference Sections

200 km

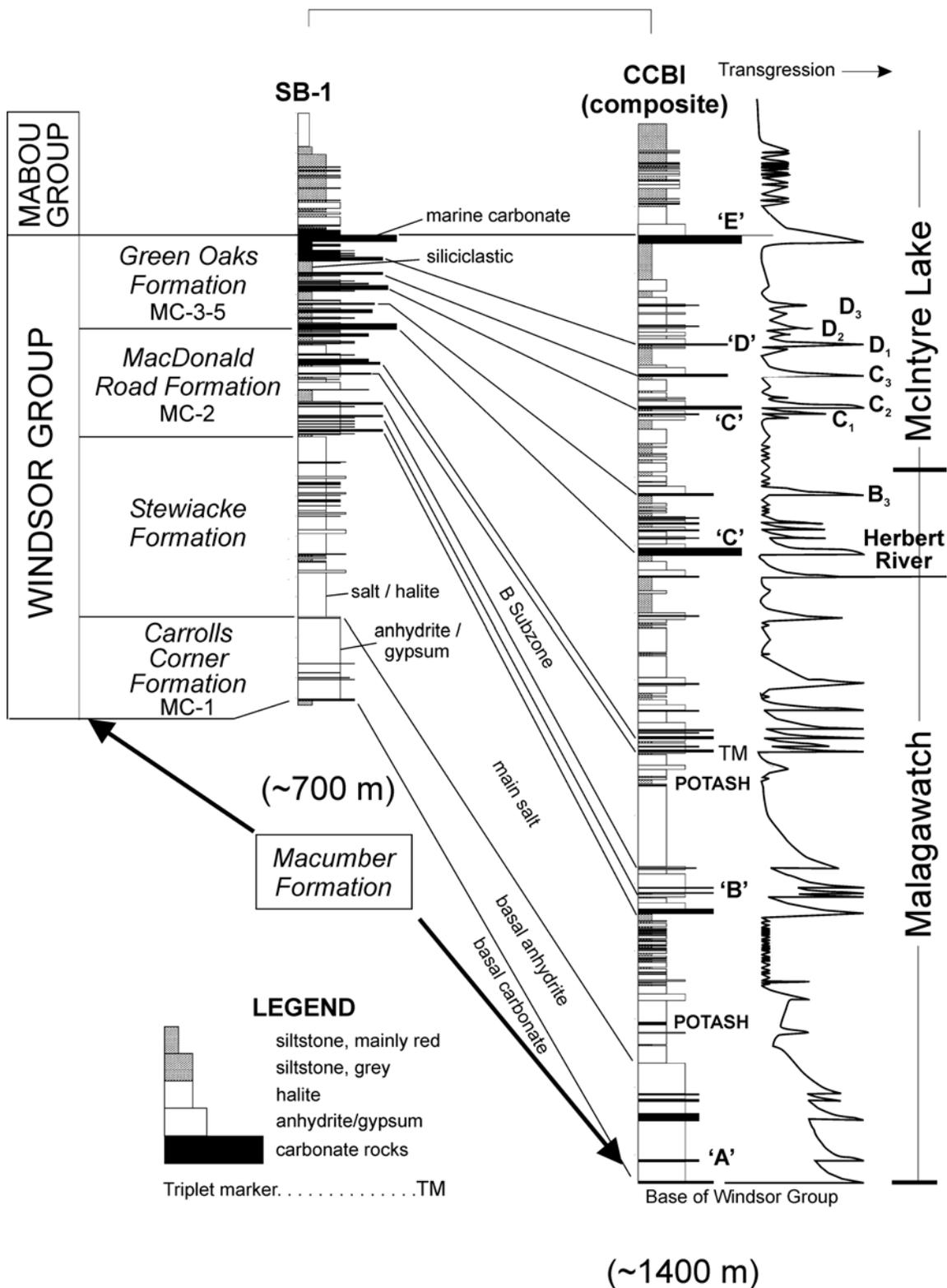


Figure 5. Reference section correlation, Shubenacadie Basin (SB1) and central Cape Breton Island composite section (CCB1 Malagawatch and McIntyre Lake).

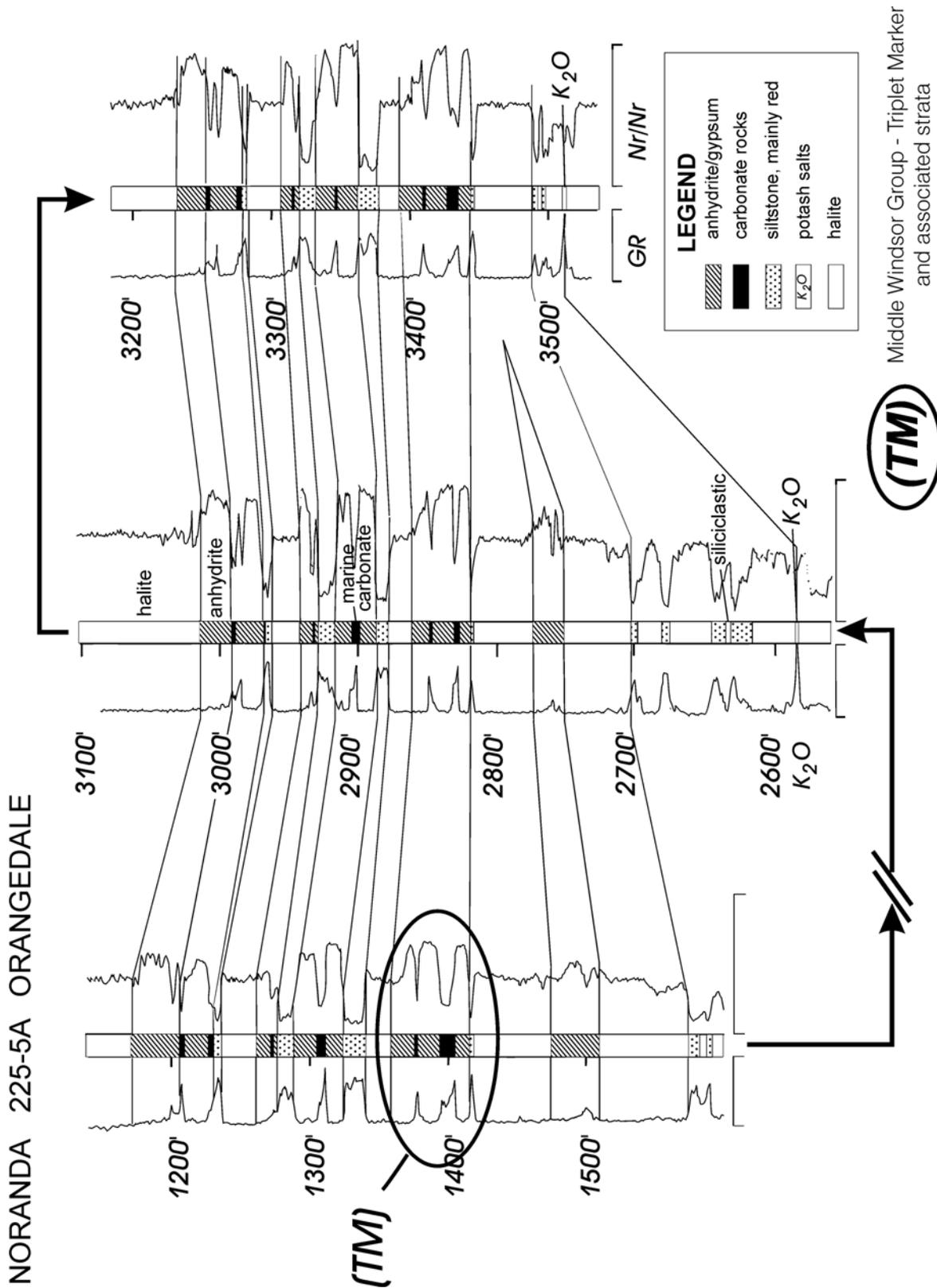


Figure 6. Major Cycle 2, B Subzone 'Triplet Marker' and associated strata correlation in complex fold repeated section, Noranda drillhole 225-5A, Orangedale Deposit near Malagawatch.

siliciclastic, 22% anhydrite and 55% salt. Major Cycles 3 to 5 comprise 11% carbonate, 36% siliciclastic, 17% anhydrite and 36% salt. The overall Windsor Group composition of Major Cycles 1 to 5 (1400 m thick) is 8% carbonate, 21% siliciclastic, 26% anhydrite and 45% salt.

The highly water-soluble halite is removed by dissolution in the near-surface environment and rarely occurs at depths shallower than 300-400 m. The relative proportion of the anhydrite, including both thick strata and thin interbeds common in the stratified salt sections, may increase when salt is removed. For example, if salt is removed from the saline evaporitic sections (e.g. Major Cycles 3 to 5 in central Cape Breton Island; Figs. 5, 6 and 7), the anhydrite component increases to approximately 27%. This increased thickness favours more economically attractive gypsum zones.

After dissolution of the salt, the overall composition of an average Major Cycle 1 section (240 m thick), calculated for the evaporitic sections above depths of 300-400 m, in central Cape Breton Island area is 11% carbonate, 18% siliciclastic and 71% anhydrite. This includes the variably abundant anhydrite interbeds in the main salt section. Portions of anhydrite are hydrated to gypsum to a maximum depth of 400 m (hydration decreases rapidly with depth) but the greatest concentration of gypsum occurs within the upper 100 m. Because Major Cycle 1 (basal anhydrite) is massive and relatively competent, fracture permeability has limited development and typically there is a thin hydration zone. Gypsum associated with the basal anhydrite, however, tends to high grade and white.

Major Cycle 2 in central Cape Breton Island, with the salt removed, is typically 240 m thick and comprises 15% carbonate, 35% siliciclastics and 50% anhydrite. A greater portion of the anhydrite is hydrated to gypsum to a maximum depth of 400 m due to permeability associated with the carbonate and siliciclastic interbeds and fracturing associated with folding and faulting. Major Cycles 3 to 5 in central Cape Breton Island, after removal of the salt, would be 300 m thick and comprise 17% carbonate, 56% siliciclastics and 27% anhydrite. Similar to Major Cycle 2, Major Cycles 3-5 typically have thicker hydration zones. The overall Windsor Group composition of Major Cycles 1 to 5

with the salt removed (780 m thick) is 15% carbonate, 38% siliciclastic and 47% anhydrite.

The relative proportion of anhydrite, and the vertical and lateral facies distribution in each stratigraphic unit or cycle, is thus a factor governing gypsum potential. Structural repetition by recumbent and isoclinal folding and faulting is preferentially associated with salt-bearing sections due to the relative incompetence and mobility of salt rocks. The resulting stacking of anhydrite zones in the deformed sections may be another major factor in enhancing gypsum potential. Many of the current gypsum mines in the province operate in this stratigraphic and structural environment.

Gypsum Deposit Classification

Adams (1991) described and illustrated five types of gypsum deposits in Nova Scotia (Fig. 8). Two of the types were associated primarily with Major Cycle 1 (A Subzone) and three were associated with Major Cycle 2 (B Subzone). Readers are directed to the detailed descriptions of Adams (1991) for deposit types 1 to 4, as well as the descriptive notes with Figure 8.

Subsequent to Adams (1991) there is a much greater understanding of the distribution of salt and related decollement structures in the down-dip and deeper basin extensions of Adams's (1991) type 5 deposits. Gypsum deposit type 5 is complex and occurs above the basal anhydrite near the base of Major Cycle 2 (B Subzone) as types 3 and 4. The deformation and disruption of the beds is typically so complete that little remains of the original beds that made up the section (Fig. 8). The mechanisms that produced these deposits are still unclear and may include tectonic brecciation related to faulting, either thrusting or decollement (Boehner, 1992), and/or collapse brecciation after the dissolution of halite. There is a close spatial and genetic relationship with salt dissolution zones and related residual accumulation of anhydrite/gypsum in the near-surface outcrop areas of the tectonically disturbed main salt at the contact between Major Cycles 1 and 2.

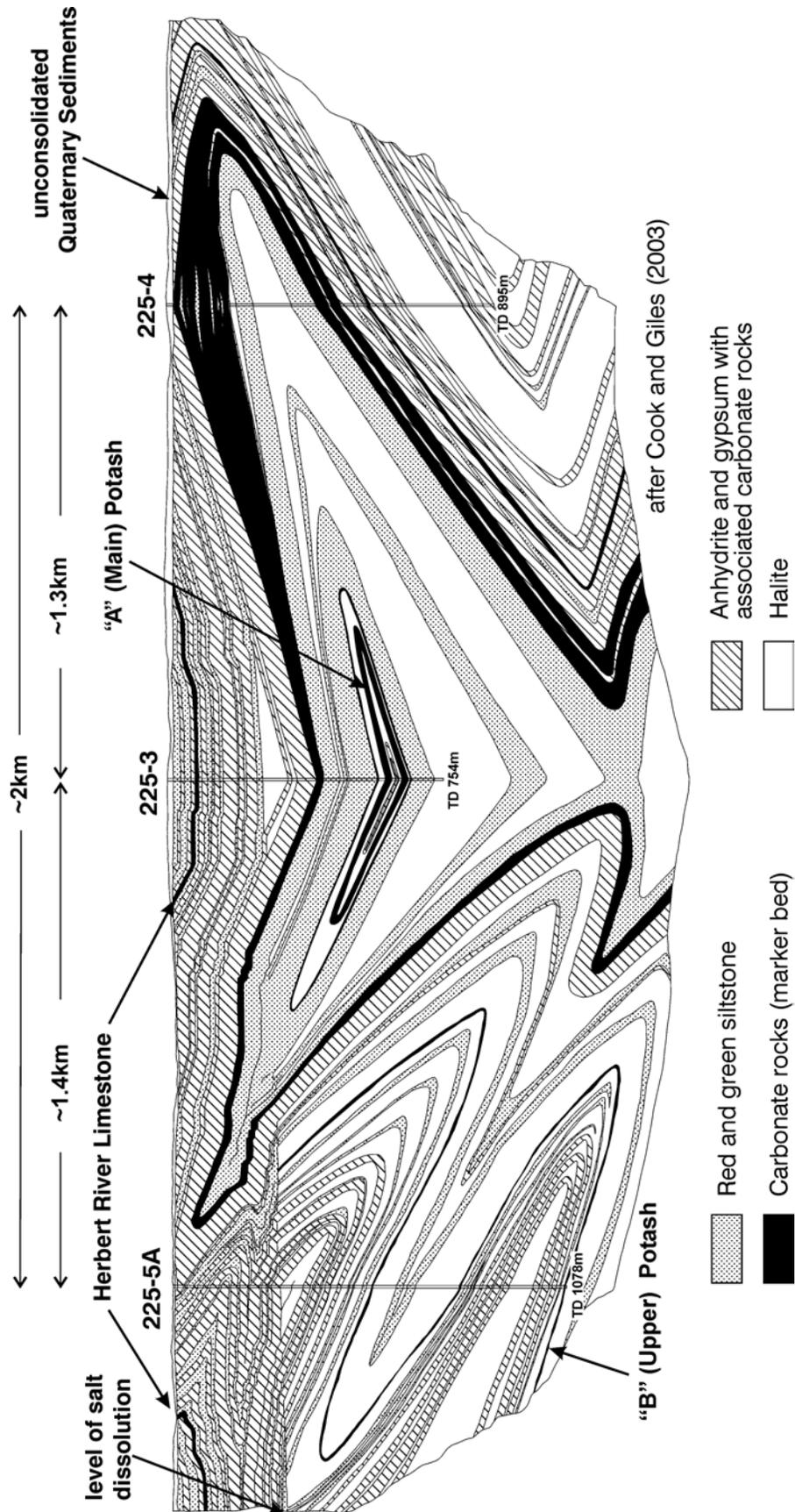


Figure 7. Detailed cross-section through part of the Orangedale salt deposit modified after Cook and Giles, 2003. Note the interpreted continuity of the stratigraphy (deflated, founded, brecciated with anhydrite variably hydrated to gypsum) in the near-surface evaporite karst zone. Here the salt has been removed by groundwater dissolution to depths exceeding 400 m.

The geology and origin of type 5 gypsum deposits are interpreted to be closely related to the tectonics and dissolution of salt associated with the regionally extensive main salt of Major Cycle 1. Although dominated by salt, there is a significant component of anhydrite interbeds that enhances the gypsum content of this stratigraphic/structural zone. Anhydrite content of the main salt section of Major Cycle 1 in saline basinal sections is approximately 8-10% or more, and may exceed 20% in transitional sections with the basal anhydrite. Therefore, with the removal of salt, they would attain a cumulative thickness of 30 to 60 m. In addition, anhydrite from the upper part of the basal anhydrite that is locally disrupted by faulting is also a contributor to the gypsum zone in type 5 deposits.

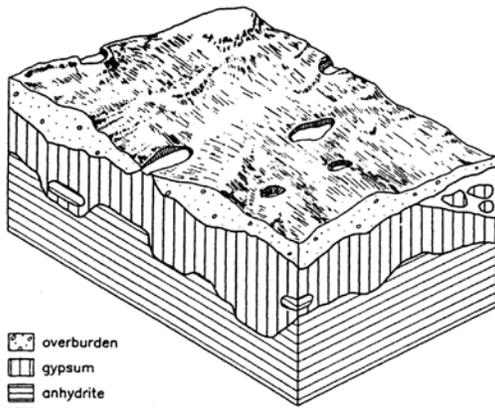
Geological Controls on Economic Gypsum Deposits

Lewis and Holleman (1983) described the stratigraphic location and identified deposit genesis factors associated with major gypsum and anhydrite production sites in Nova Scotia. They placed all active mines within the A and B Subzones of the Lower Windsor Group (Major Cycles 1 and 2 of Giles, 1981). Several factors were identified as important in the localization of these gypsum deposits including: (1) a large primary component of CaSO_4 , (2) the influence of structural disturbance concentrated at this stratigraphic level (e.g. structural decollement, collapse, etc.), and (3) enhanced permeability due to structure and paleodrainage (geomorphology). These remain as the main factors; however, additional factors and variations of them (e.g. the salt connection) are presented here.

The significant relationship of tectonics, local structure, and anhydrite content of the stratigraphy to economic gypsum deposits is well documented in the Little Narrows area, where the near-surface extension of Major Cycle 2 strata is mined by Little Narrows Gypsum Company in a complexly folded section without significant salt (Wilson and Sharpe, 1994). The down-dip extensions of these units were intersected in deep diamond-drill core hole R1W, drilled by Chevron at MacIvers (McIvor) Point (total depth 1185 m/3890 ft.) approximately 3.5 km north of the gypsum quarries (Boehner and Giles, 2003). The R1W drillhole intersected a recumbently folded Major Cycle 2 and 3 section to a depth of approximately 1000 m. This interval was dominated by salt below a depth of 400 m. The major folds recognized in the drill core on the basis of multiple repeated stratigraphy (especially in Major Cycle 2), have limbs with dips of 30 to 60 degrees and fold limb intersection intervals of 50 to 150 m. The contact with the underlying Major Cycle 1 is inferred to be a decollement in the disrupted main salt section above the top of the basal anhydrite at a depth of approximately 1170 m. The decollement zone has a calculated dip of approximately 15 degrees to the north. This is based on an interpolated and extrapolated cross-section (southeast to northwest) of the St. Patricks Channel salt deposit (Boehner and Giles, 2003) constructed from Washabuck, through the Little Narrows Gypsum Quarry, to MacIvers (McIvor) Point R1W drillhole and St. Patricks Channel.

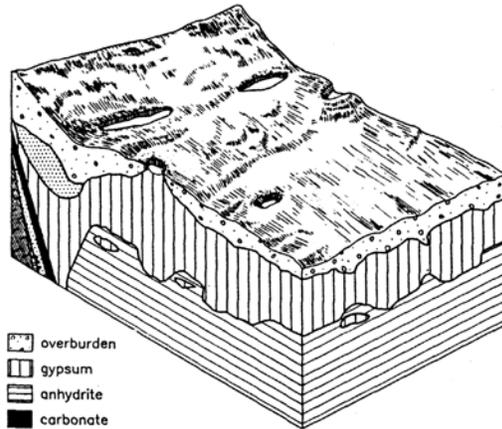
This disturbed contact is well defined in the Little Narrows gypsum quarries as a distinct structural break above the basal anhydrite. The associated enhanced hydration zone in the anhydrite beds found in the lower part of Major Cycle 2 and the upper part of the basal anhydrite

Figure 8 (facing page). Summary of evaporite deposit classification in Nova Scotia (after Adams, 1991). Deposit type 1 shows shallow surface hydration of massive 'basal anhydrite', with gypsum development limited by permeability (e.g. permeable carbonate interbeds or fracturing). Deposit type 2, a variation of type 1, shows surface hydration and deeper hydration along the contact with the underlying 'basal carbonate' of the Windsor Group and older strata, with gypsum development enhanced by increased permeability (e.g. permeable carbonate/siliciclastic interbeds or fracturing associated with this disrupted contact zone). Deposit type 3 shows surface hydration and deeper hydration enveloping the anhydrite along the contacts with permeable carbonate and siliciclastic strata of the Windsor Group. Deposit type 4, a variation of type 3, shows enhanced hydration enveloping the anhydrite associated with structural deformation and faults creating increased permeability in carbonate/siliciclastic interbeds or fracturing. Deposit type 5 shows massive disruption of the original strata, especially at the contact between the 'basal anhydrite' and the B Subzone (Major Cycle 2) of the Lower Windsor (a local and regional decollement fault zone). Hydration development extends to depths exceeding 100 m, and typically occurs up-dip from variably deformed stratigraphic sections dominated by salt but with significant anhydrite interbeds (e.g. 'main salt' of Major Cycle 1). Note that salt is typically preserved only below depths of 300 to 400 m.



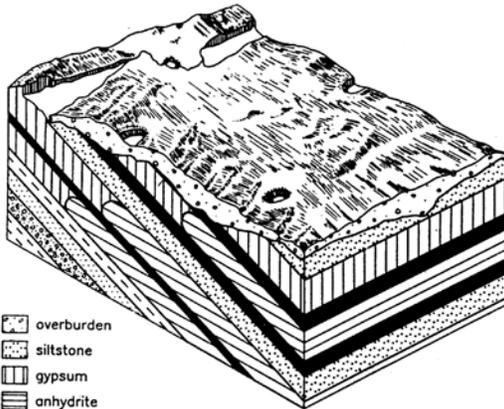
- overburden
- gypsum
- anhydrite
- gypsum blocks in a matrix of gypsum, carbonate and clastic fragments

type 1



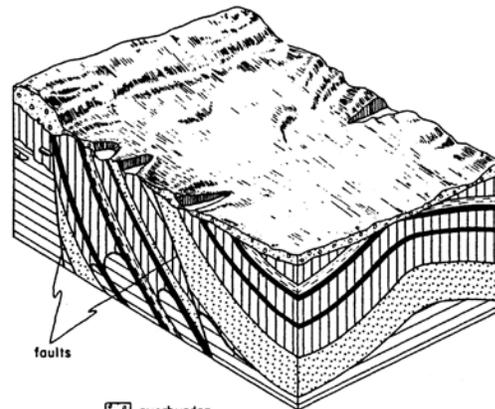
- overburden
- gypsum
- anhydrite
- carbonate
- sandstone
- metamorphic basement

type 2



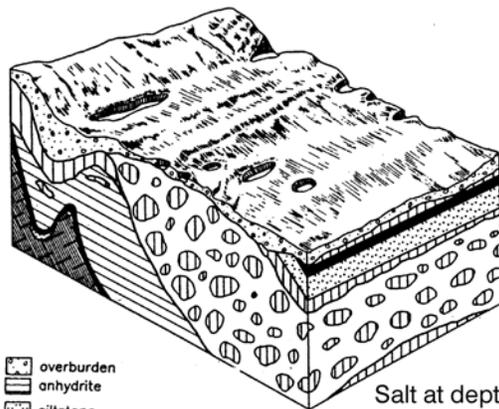
- overburden
- siltstone
- gypsum
- anhydrite
- carbonate
- shale
- sandstone
- conglomerate

type 3



- overburden
- gypsum
- anhydrite
- shale
- carbonate
- siltstone

type 4



- overburden
- anhydrite
- siltstone
- carbonate
- gypsum blocks in a matrix of gypsum, carbonate and clastic fragments
- sandstone
- metamorphic basement

type 5

Salt at depth below 300m (stratified) with anhydrite interbeds

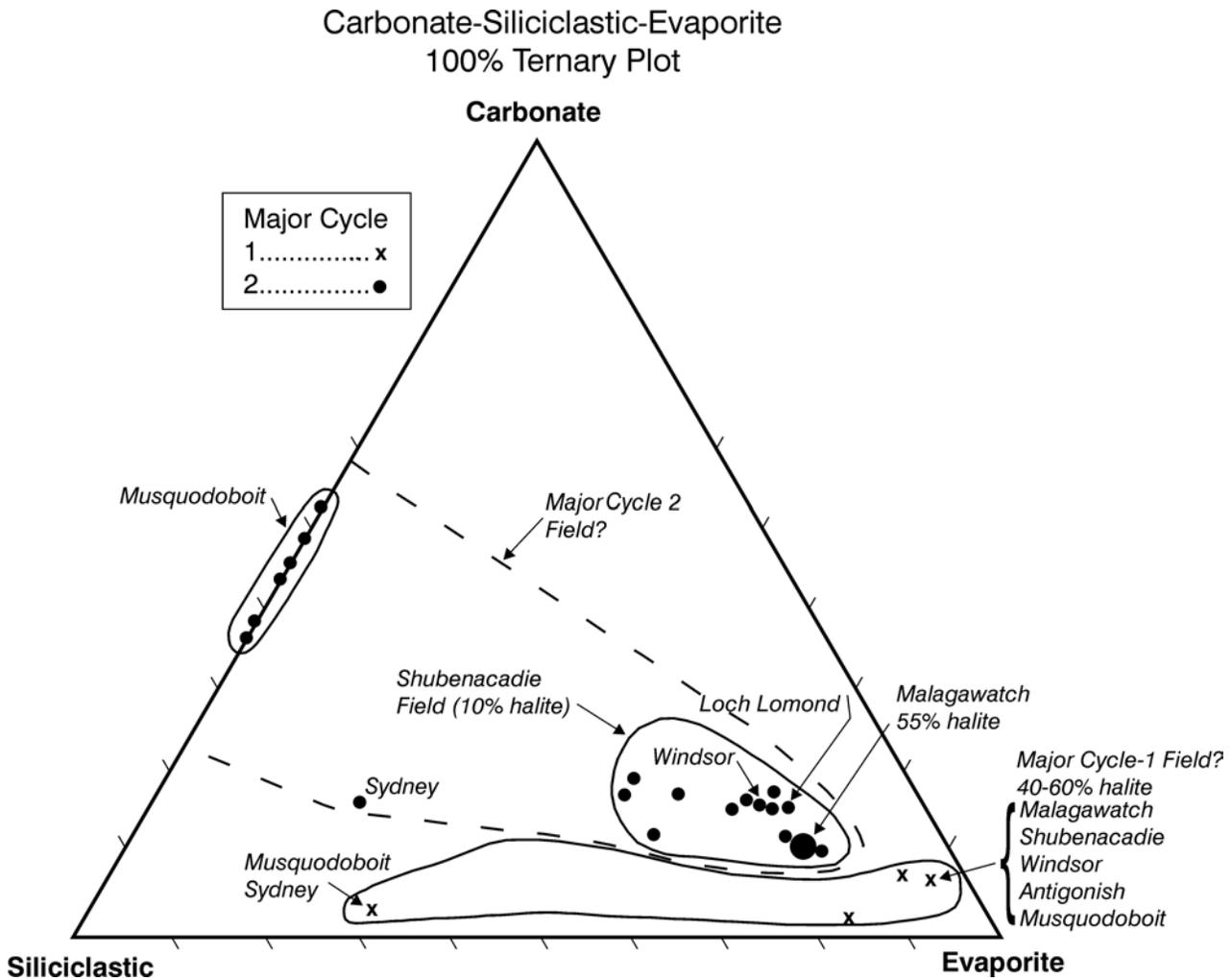


Figure 9. Ternary plot of the lithology of Major Cycle 1 and 2 sections in Nova Scotia.

comprises the main gypsum units mined at Little Narrows (Wilson and Sharpe, 1994). The anhydrite-dominated lower part of Major Cycle 2 and the upper part of the basal anhydrite, separated by an intervening structurally disturbed decollement/dissolution zone, are well known as a prospective environment for economic gypsum deposits throughout the province (Lewis and Holleman, 1983; Adams, 1991).

The middle part of the B subzone (Fig. 6) is also prospective because it also has a high concentration of anhydrite associated with the evaporitic facies of the constituent minor cycles (cf. triplet marker of Giles and Boehner, in prep.). The upper part of Major Cycle 2 typically has more siliciclastics and thus more waste material than the lower units. The Upper Windsor typically

contains less anhydrite than the Lower Windsor. Each marine carbonate member is overlain by anhydrite of variable thickness. Some groupings of these minor cycles in evaporitic sections may contain proportions and cumulative thicknesses of anhydrite comparable to Major Cycle 2 (Fig. 9). These become prospective exploration targets where the anhydrite beds are near surface and hydrated to gypsum. Anhydrite is well developed in several of the minor cycles of Major Cycles 3 and 4 (Fig. 10). Similarly, anhydrite may be a substantial component of the uppermost Windsor, Major Cycle 5 in the transition into the overlying Mabou Group.

The cumulative thickness and stratigraphic (depositional) distribution of anhydrite, the parent mineral form of gypsum, is a primary factor in

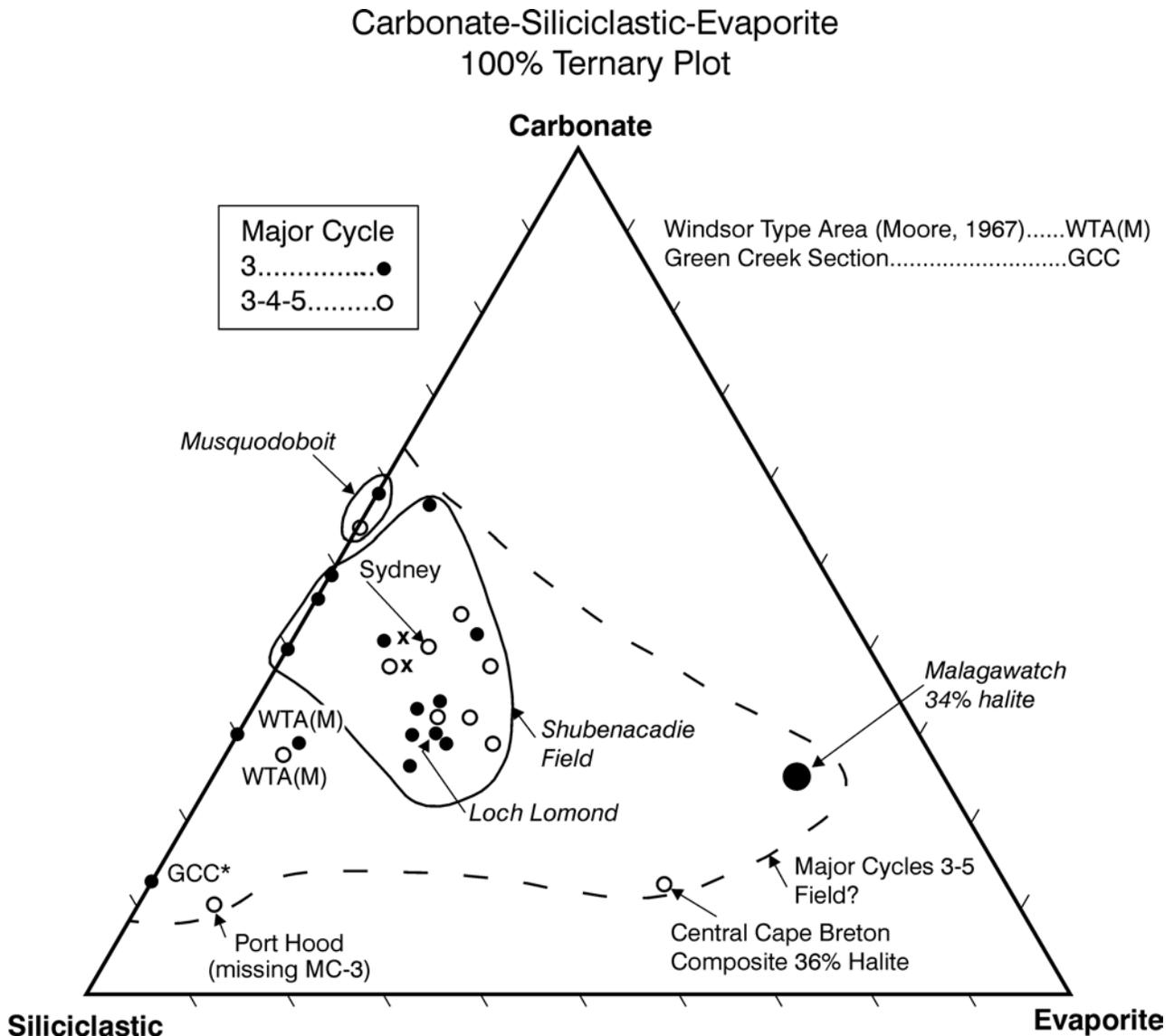


Figure 10. Ternary plot of the lithology of Major Cycle 3, 4 and 5 sections in Nova Scotia.

gypsum deposits. The following is an overview of the stratigraphic distribution of anhydrite in the major cycles of the Windsor Group. The proportion of anhydrite varies considerably, both stratigraphically and laterally, within and between basins in Nova Scotia (Figs. 2, 3 and 4) with major trends described by Giles (1981) and Boehner (1984).

The distribution of anhydrite in the thick saline Windsor Group sections in central Cape Breton provides further insight into prospective gypsum intervals. Visual inspection of the lithology distribution within the Windsor Group central Cape

Breton composite section (Giles and Boehner, 2001) indicates the anhydrite is not evenly distributed, especially in Major Cycles 2 to 5 (Fig. 5). Within Major Cycle 2 there are two prominent intervals of concentrated anhydrite strata. The degree of concentration may be further enhanced (thickened) when the halite intervals are removed, as illustrated in the following examples.

One interval occurs prominently at the base of Major Cycle 2. This is a zone comprising approximately: 41.5 m (136 feet) anhydrite, 2.7 m (9 feet) siltstone, and 4.9 m (16 feet) carbonate as aggregate thickness of the carbonate, anhydrite and

siliciclastic strata. These units are tentatively correlated with the main economic gypsum mining zone at Little Narrows comprising three to four minor cycle units described by Wilson and Sharpe (1994). They indicate that up to 75% of the mining section is gypsum, and it sometimes occurs as large (10 m) blocks with green siltstone. Individual gypsum beds are 1.5-20 m thick and average 7.5 m. Salt and anhydrite content increase with depth in the mining zone at Little Narrows (Holleman, 1976).

The second significant anhydrite interval occurs in the middle part of Major Cycle 2 at the stratigraphic level of the 'triplet marker' described by Giles and Boehner (2001). The 'triplet marker', which is a distinctive package of multiple minor cycles of carbonate, anhydrite, salt and siliciclastic strata, contains the significant anhydrite zone (Fig. 6). The 'triplet marker' comprises approximately 47.5 m (156 feet) anhydrite, 2.7 m (9 feet) siltstone, and 15.8 m (52 feet) carbonate. It correlates with the North Salem and Hardwoodlands members interval in the Macdonald Road Formation (Major Cycle 2) in the Shubenacadie Basin (Giles and Boehner, 1979, 1982).

The Major Cycle 2 section in the Windsor Group central Cape Breton composite section contains overall: 7% carbonate, 16% siliciclastic, 22% anhydrite and 55% halite. Consequently, removal of the halite component in the near surface by dissolution processes increases the proportion of anhydrite to approximately 49% and the resulting residual accumulation serves as the parent for subsequent gypsum formation by hydration. The volume of halite and its highly ductile behaviour also facilitates deformation and stacking (repetition) of the anhydrite beds (potential gypsum) by folding and faulting.

Within the Windsor Group central Cape Breton composite section (WGCCBC), the saline evaporite facies of both Major Cycles 3 to 5 and Major Cycle 2 should be considered as prospective sites for gypsum deposits where there are anhydrite-enriched stratigraphic intervals. The Major Cycles 3 to 5 section in WGCCBC section (Fig. 5) contains similar proportions of evaporites

as Major Cycle 2 sections that host economic gypsum deposits in other basins in the province. Anhydrite is not evenly distributed and overall the composition is 11% carbonate, 36% siliciclastic, 17% anhydrite and 36% halite. If salt is removed from the saline evaporitic sections of Major Cycles 3 to 5, the anhydrite component increases to approximately 27%. Similar to Major Cycle 2, if the salt component is removed there are three favourable intervals of concentrated anhydrite recognized.

There is a lower interval including several minor cycles constituting part of the C subzone including the C1, C2 and C3 limestones. This zone comprises approximately: 29 m (95 feet) anhydrite, 12 m (39 feet) siltstone, and 11 m (36 feet) carbonate. There is an overlying anhydrite-enriched interval including several minor cycles constituting part of the D subzone, including the D1, D2 and D3 limestones. This zone comprises approximately 20.4 m (67 feet) anhydrite and 3 m (10 feet) carbonate. The third interval of gypsum potential occurs above the E1 Limestone at the top of the Windsor Group in the transition to the overlying Hastings Formation of the Mabou Group. An anhydrite bed 15.8 m (52 feet) thick of potential economic interest occurs as the lowermost of several anhydrites in minor cycles of grey mudrock, anhydrite and halite.

In all three intervals of anhydrite enrichment, structural repetition and salt dissolution may produce enhanced thicknesses of anhydrite. Hydration of anhydrite to gypsum in the near-surface environment may produce economic deposits. The relatively high proportion of halite in the Major Cycles 3 to 5 section (up to 36%), although lower than in the underlying Major Cycle 2, may also be favourable for the development of complex folds. This is in contrast to correlative sections containing little or no salt, which is typical of many other basins in the province. The tectonics and structural disturbance at the lower stratigraphic levels, including the lower part of the B subzone and upper part of the basal anhydrite and the overlying main salt of the A subzone, are inferred to further enhance the development of substantial gypsum deposits (e.g. Little Narrows).

The salt dissolution and structural environment described above is an extension of, or process unification of the five gypsum deposit types identified by Adams (1991). Variations of this structural/dissolution gypsum environment, including local high-angle faults, are associated with the gypsum deposits at Big Brook, Sugar Camp and Melford. It is probably present in a related form at the Alba and Big Hill deposits, although the detailed geology is not well known.

Summary

Understanding the geologically favourable factors for gypsum deposit formation is important in developing an effective exploration and development strategy. Some of the important geological factors have been described previously and the following is a synopsis. The geological factors include:

- (1) the primary cumulative thickness and stratigraphic (depositional) distribution of anhydrite (parent form of gypsum) in each of the major cycles,
- (2) spatial localization of enhanced anhydrite cumulative thickness related to structural repetition of beds in proximity to major structural and paleotopographic features within and bounding the Windsor Group basins,
- (3) enhanced hydration of anhydrite beds resulting from an increase in permeability related to fracture density increases in proximity to major structural and paleotopographic features,
- (4) an increase in the cumulative proportion of anhydrite in each of the major cycles related to salt dissolution in the near-surface environment,
- (5) an increase in the mineralogical conversion of anhydrite to gypsum resulting from an increase in permeability in anhydrite related to evaporite karst development (collapse brecciation and fracturing) in the near-surface environment,
- (6) geological distribution of the favourable contacts associated with the deposits, for example the base of Major Cycle 1 (Horton/Windsor Group) or Major Cycle 1 and 2 contact, and
- (7) geological history to allow the preservation of the hydration areas and zones from erosion.

Cumulatively these are the primary geological factors influencing the location and geological

nature of gypsum deposits of economic significance (mineability, size and grade). Although these factors are not uniformly distributed stratigraphically, spatially or temporally, they can be integrated into exploration models and strategies. Non-geological, cultural, environmental and economic factors, including location with respect to transportation, mineability, land availability, use and access, are major (critical) governing factors on the development potential for any given deposit.

References

- Adams, G. C. 1991: Gypsum and anhydrite resources in Nova Scotia; Nova Scotia Department of Natural Resources, Mines and Energy Branches, Economic Geology Series 91-1, 293 p.
- Bell, W. A. 1929: Horton-Windsor District, Nova Scotia; Geological Survey of Canada, Memoir 155, 268 p.
- Boehner, R. C. 1984: Stratigraphy and depositional history of marine evaporites in the Windsor Group, Shubenacadie and Musquodoboit structural basins, Nova Scotia, Canada; Ninth International Carboniferous Congress, 1979; *Compte Rendu*, v. 3, p. 173-178.
- Boehner, R. C. 1986: Salt and Potash Resources in Nova Scotia; Nova Scotia Department of Mines and Energy, Bulletin No. 5, 346 p.
- Boehner, R. C. 1992: An overview of the role of evaporites in the structural development of Carboniferous basins in Nova Scotia; *in* Mines and Energy Branch, Report of Activities 1991, ed. D. R. MacDonald; Nova Scotia Department of Natural Resources, Report 92-1, p. 39-56.
- Boehner, R. C. and Giles, P. S. 2003: Preliminary report on the St. Patricks Channel salt deposit, Victoria County, Cape Breton Island, Nova Scotia; *in* Mineral Resources Branch, Report of Activities 2003, ed. D. R. MacDonald; Nova Scotia Department of Natural Resources, Report ME 2003-1, p. 25-32.

Boehner, R. C. and Giles, P. S. 1993: Geology of the Antigonish Basin, Antigonish County, Nova Scotia; Nova Scotia Department of Natural Resources, Memoir 8, 109 p.

Boehner, R. C. and Prime, G. 1993: Geology of the Loch Lomond Basin and Glengarry Half-graben, Nova Scotia; Nova Scotia Department of Natural Resources, Mines and Minerals Branch, Memoir 9, 68 p.

Cook, L. and Giles, P. S. 2003: Stratigraphy and structure of the Orangedale Salt Deposit, central Cape Breton Island, Nova Scotia; Geological Survey of Canada Open File 1529, 1 sheet.

Giles, P. S. 2003: Stratigraphy and structure of the Malagawatch Salt Deposit, central Cape Breton Island, Nova Scotia; Geological Survey of Canada Open File 1531, 1 sheet.

Giles, P. S. 1981: Major transgressive and regressive cycles in the middle to late Viséan rocks of Nova Scotia; Nova Scotia Department of Mines and Energy, Paper 81-2, 27 p.

Giles, P. S. and Boehner, R. C. in prep: Windsor Group stratigraphy and structure drill core orientation field trip 2001 guidebook; Nova Scotia Department of Natural Resources, Minerals and Energy Branch, Open File Report.

Giles, P. S. and Boehner, R. C. 1982: Geological map of the Shubenacadie and Musquodoboit basins, central Nova Scotia; Nova Scotia Department of Mines and Energy, Map 82-4, scale 1:50 000.

Giles, P. S. and Boehner, R. C. 1979: The Windsor Group stratigraphy in the Shubenacadie and Musquodoboit basins of central Nova Scotia; Nova Scotia Department of Mines and Energy, Open File Report 410.

Giles, P. S. and Lynch, G. 1994: Stratigraphic omission across the Ainslie Detachment in east-central Nova Scotia; *in* Current Research 1994-D, Geological Survey of Canada, p. 89-94.

Goodman, N. R. 1952: Gypsum and anhydrite in Nova Scotia; Nova Scotia Department of Mines, Memoir No. 1, 75 p.

Holleman, M. 1976: The nature, origin and distribution of chloride in the lower B Subzone evaporites of Little Narrows, Victoria County, Nova Scotia; M. Sc. thesis, Acadia University, Wolfville, Nova Scotia.

Lewis, W. L. and Holleman, M. 1983: Gypsum in Atlantic Canada; Ontario Geological Survey, Miscellaneous Paper 114, Toronto, p. 79-95.

Lynch, G. and Giles, P. S. 1995: The Ainslie Detachment: A regional flat-lying extensional fault in the Carboniferous evaporitic Maritimes Basin of Nova Scotia, Canada; Canadian Journal of Earth Sciences, v. 33, p. 169-181.

Lynch, G., Keller, J. V. A. and Giles, P. S. 1998: Influence of the Ainslie Detachment on the stratigraphy of the Maritimes Basin and mineralization in the Windsor Group of northern Nova Scotia, Canada; Economic Geology, v. 93, p. 703-718.

Moore, R. G. 1967: Lithostratigraphic units in the upper part of the Windsor Group, Minas Sub-basin, Nova Scotia; *in* Collected Papers on the Geology of the Atlantic Region; Geological Association of Canada, Special Paper No. 4, p. 245-266.

Schenk, P. E. 1969: Carbonate-sulphate-redbed facies and cyclic sedimentation of the Windsorian Stage (Middle Carboniferous), Maritime Provinces; Canadian Journal of Earth Sciences, v. 6, no. 5, p. 1037-1066.

Schenk, P. E. 1984: Carbonate-sulfate relations in the Windsor Group, central Nova Scotia, Canada; *in* Ninth International Congress on Carboniferous Stratigraphy and Geology, Comptes Rendu, v. 3, p. 143-162.

Wilson, G. A. and Sharpe, R. D. 1994: Quarrying operations of the Little Narrows Gypsum Company, Victoria County, Cape Breton Island, Nova Scotia, Canada; *in* Guide Book, Field Trip #4, Industrial Minerals in Nova Scotia, 30th Forum on the Geology of Industrial Minerals (1994), p. 22-30.