Evaporite Karst at the Horton Group - Windsor Group Contact, South-central Cape Breton Island[1]

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Introduction

The Mississippian basement contact between the Horton Group and the basal Windsor Group has been one of the most explored and prospective exploration targets for carbonate-hosted base metal, silver, celestite and barite deposits in Nova Scotia. Past producers have included the Walton Barite-Pb-Zn-Ag mine, the Gays River Zn-Pb mine, and the Loch Lomond-Enon celestite mine (Fig. 1). Concordant and discordant mineralization are associated with the contact, both with and without associated fault/fracture systems. The Horton - Windsor and basement contact is a favourable zone due to: (1) the basal Windsor carbonate (e.g. Macumber or Gays River Formation) is a chemically and physically receptive host that lies concordantly but disconformably on top of; (2) coarse- and fine-grained siliciclastics of the Horton Group (or unconformablly on crystalline basement) that served as hydrogeological conduits for mineralizing fluids (and the source of metals), and; (3) the basal anhydrite- and evaporite-dominated Windsor Group overlying the basal carbonate serves as a hydrogeological seal or barrier (aquiclude) to confine and focus fluid flow at the Horton - Windsor contact.

In some areas, such as Rear Black River (Dundee), the Horton Group thins and pinches out on pre-Carboniferous basement and the basal Windsor carbonate (carbonate buildup facies) is deposited directly on basement. More extreme onlap and overstep of Windsor Group strata occur in the Loch Lomond area of southeastern Cape Breton Island where middle and upper Windsor Group strata progressively onlap basement rocks (Boehner and Prime, 1993). Post-depositional tectonics and evaporite karst processes have preferentially affected the Horton - Windsor contact zone. Underground and surface mining operations at Walton, Gays River, and to a lesser extent Loch Lomond, encountered unstable ground conditions as well as large volumes of karst and fracture system controlled groundwater to mine depths exceeding 300 m. The geological features that were favourable to host these mineral deposits, both sealing evaporites and host carbonates, were also conducive to later structural disturbance and subsequent preferential karst development in the near-surface environment. This karst development is integral to the origin of economic high-grade gypsum deposits in south-central Cape Breton Island (e.g. Big Brook, Sugar Camp, Little Narrows, etc.). It also may be important in the development of the late Paleozoic basin petroleum system.

Horton Group - Windsor Group Contact

The outcrop and near-surface geology of the Windsor Group, and especially the Horton - Windsor contact (Fig. 2), is complex due both to a long history (multiple episodes) of structural disruption by faulting and folding as well as evaporite karstification (Paleozoic, Mesozoic and Cenozoic). The lowermost Windsor Group (Major Cycle 1), comprising the basal anhydrite and basal carbonate (Macumber Formation), together with the underlying Horton Group and/or basement rocks, behaved as a structurally competent and relatively immobile structural unit during the tectonic events that deformed the Carboniferous basins (Boehner, 1992; Giles and Lynch, 1994). This contrasts with the highly deformed and mobile (incompetent) strata of the overlying, salt-dominated, middle and upper parts of the Windsor Group. The contact near the top of the basal

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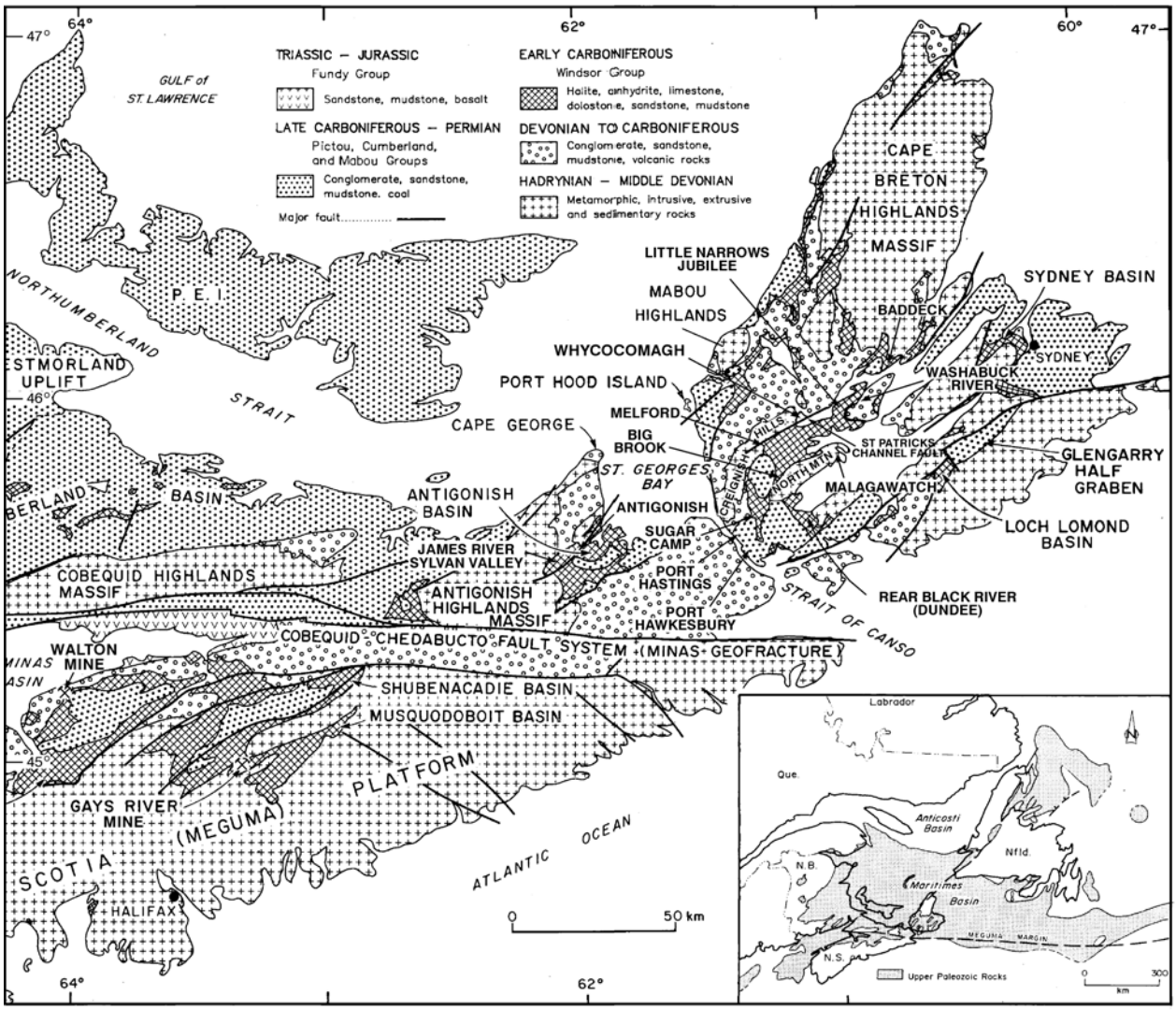

Figure 1. General geology and location map, south-central Cape Breton Island.

anhydrite is often the location of the regionally extensive Ainslie Detachment (Giles and Lynch, 1994), which has developed in the highly ductile, salt-dominated strata above the relatively immobile and competent basal anhydrite.

Strata at the base of the Windsor Group in south-central Cape Breton Island display either faulted or intact depositional conjtacts with older rocks. There are long linear contacts of moderately dipping concordant strata (dips of less than 35 degrees with 10 to 20 degrees typical). The base of the Windsor Group is in normal sedimentary contact (relatively undisturbed) with varying thicknesses of the underlying Horton Group. Examples based on available drilling and geological mapping (Kelley, 1967; Lynch and Brisson, 1996) in south-central Cape Breton Island are described as follows. The northwestern border of North Mountain between Big Brook and River Denys is inferred to have a relatively undisturbed section of the basal Windsor Group; however, the extent is not well confirmed by drill core or availble outcrop. The Washabuck block near Little Narrows and the Sugar Camp block near Port Hawkesbury are relatively well defined in drill core and outcrop. Similar, relatively intact but more steeply dipping and structurally disrupted sections occur along parts of the southern border of the Creignish Hills near Port Hastings and the Strait of Canso, as well as the Glendale-Melford area near Whycocomagh. Much of the southeastern border of

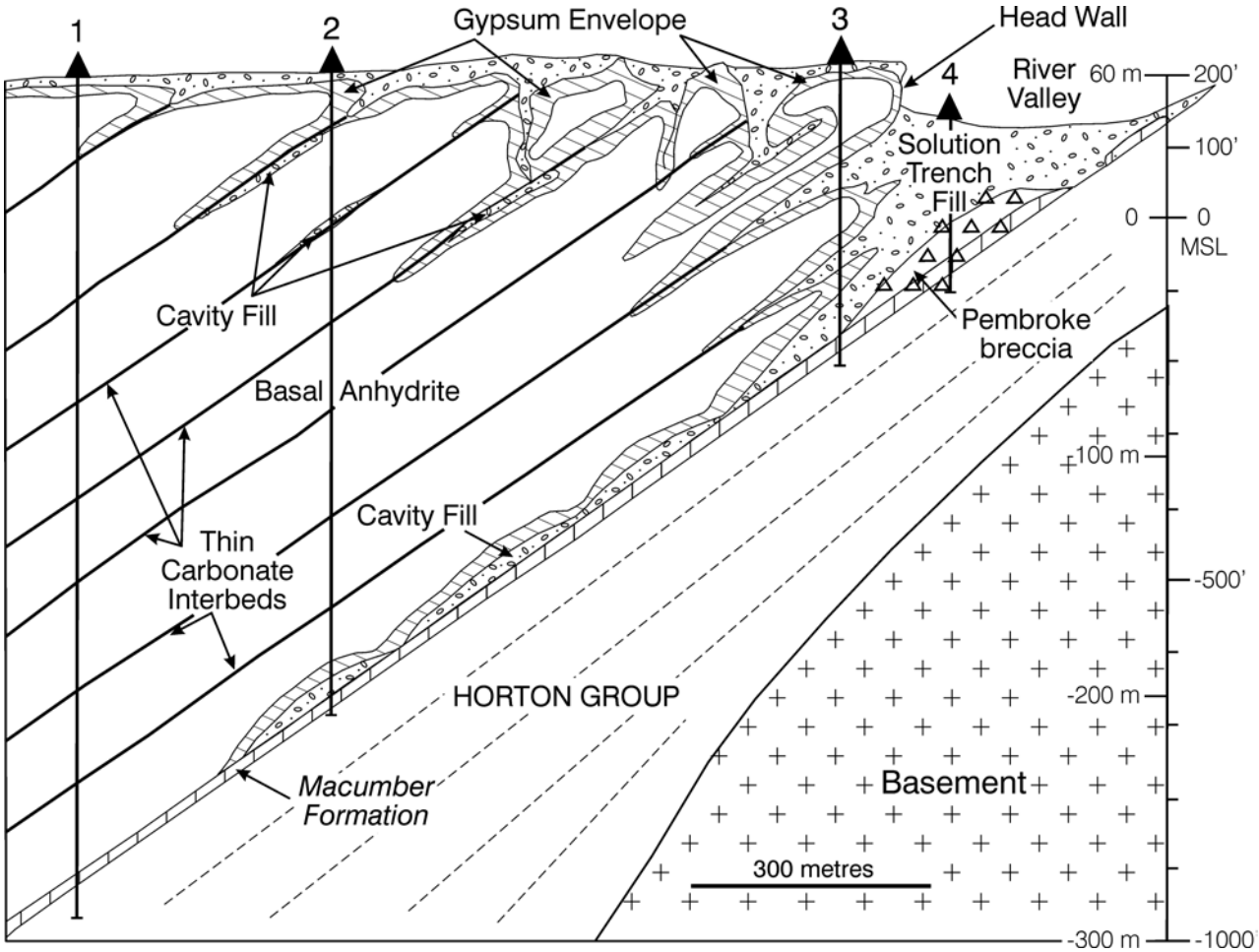

Figure 2. Diagrammatic geological cross-section illustrating karst geology at the Horton Group-Windsor Group contact, south-central Cape Breton Island.

the Creignish Hills, however, is disrupted extensively by faults, including the St. Patricks Channel fault. This is a major northeasterly trending fault (zone) that juxtaposes the middle to upper Windsor Group and possibly Mabou Group with basement and/or Horton Group rocks.

The concordant sedimentary contact between the Windsor Group and underlying Horton Group and/or basement rocks is reasonably well documented in outcrop and drill core. Adams (1991) and Boehner and Giles (1993) described and illustrated the basic concordant stratigraphic contacts associated with the base of the Windsor Group. Where the Horton - Windsor contact strata occur in an undisturbed and moderately to gently dipping succession, there is virtually ubiquitous development of an evaporite solution trench of varied scale and composition. Depending upon the extent of infill and depth of burial, the surface expression may be a well developed linear karst valley landform with extensive sinkholes, gypsum outcrop and modern river drainage (e.g. Washabuck River) or there may little or only very subtle elevation, landform or modern drainage expression at all (e.g. Sugar Camp). The complex age and history of this contact solution trench environment was described by Boehner and Giles (1993). The infill material is heterogeneous, including locally derived (*in situ*) or transported material, and may be lithified or unconsolidated. The unconsolidated material is typically not recovered or only partially recovered in the diamond-drilling process. Locally developed, lithified carbonate breccias of complex age and origin (karst/residual accumulation, solution collapse, tectonic, synsedimentary, etc.) are referred to as Pembroke breccia. The age of

development, based upon the age of the infilling material, ranges from latest Carboniferous, through Cretaceous to Quaternary and Recent.

Morphology of the solution trench is controlled mainly by the down-dip dissolution of relatively soluble anhydrite and gypsum of the thick (300 m+) basal anhydrite. Dissolution occurs preferentially at the contact with the relatively insoluble basal carbonate immediately overlying siliciclastics of the Horton Group, along the boundaries of thin carbonate interbeds with the basal anhydrite, and as discordant fracture zones. The contrasting physical and chemical character of the strata across the basal carbonate/basal anhydrite contact provide a favourable zone for fracturing, faulting, groundwater penetration and circulation. This zone of enhanced primary and secondary porosity and permeability is necessary to develop stratabound evaporite karst systems of varying scales and depths.

The parent anhydrite strata may be hydrated to gypsum as well as dissolved by groundwater. Areas of basal anhydrite with deep hydration may result in economic gypsum deposits with characteristic high grade and whiteness/brightness. Relatively insoluble carbonate that occurs as thin interbeds or inclusions in the anhydrite may be in part dissolved or accumulate in the bottom of karst cavities as residual debris (e.g. lithified depris such as the Pembroke breccia). The basal anhydrite may be 10 to 15% carbonate as thin interbeds, nodules and inclusions, with 20% or more near the basal contact with the Macumber Formation. External sediment may have been washed or foundered down into the cavity system and remained as accumulated infill material (generally unconsolidated) that can be dated by paleontological methods (e.g. Late Carboniferous, Early Cretaceous).

The surface zone of the evaporite karst may range from a width of a few metres to 300 metres and extend along strike for kilometres. Examples include the Washabuck River-Plaster Ponds area near Jubilee and Little Narrows, and the James River-Sylvan Valley area near Antigonish (Boehner and Giles, 1993). The downdip extent of karst development in the basal Windsor Group, based upon limited drilling data, indicates that cavity development (or gypsum as a contact-oriented hydration precursor) rarely occurs below a vertical depth of 300 m. The trench geometry is basically a downdip tapering wedge, bounded at its base by the upper surface plane of the basal carbonate (e.g. Macumber Formation). The upper contact is more irregular and discordant to varying degrees. It is a low-angle curvilinear truncation of the overlying anhydrite strata at their updip extremity.

The basic form of the trench at the surface, where maturely developed, may have a headwall face of gypsum and anhydrite (tens of metres high) at the updip face of the basal anhydrite (hanging wall). This headwall area may contain isolated vertical sinkholes and ponds, and probably represents the complex expansion and interconnection of deep sinkholes developed along the strike trend of the linear contact. Complex cavities, both as discordant and stratabound fissures, may occur in the headwall area of the basal anhydrite. Concordant cavity zones may be associated with thin carbonate interbeds as downdip, horizontal to near-horizontal cavities. Variations of the solution trench karst geometry occur at the Jubilee Zn/Pb deposit where a domal uplift of the Horton Group is defined by a sub-circular ring zone (moat) of partially exposed evaporite karst. In addition, there is an associated discordant karst along a northwest-trending faulted zone (Jubilee Fault) that hosts base metals in the Macumber Formation (basal carbonate) and carbonate breccias. All of these have varying degrees of interconnection and hydraulic connectivity, including open subterranean watercourses connected with surface drainage.

Karst development processes were not confined to the base of the Windsor Group, and extended to varying degrees and depths in all of its evaporitic sections. The connection of the origin of gypsum deposits to evaporite-salt karst and solution-generated karst was outlined by Boehner *et al.* (2002).

Basal Windsor Group - Horton Group Drillholes

The subsurface nature of solution trench features

are documented mainly in mineral exploration drill holes. Example drillholes and source references illustrating the trench geology in south-central Cape Breton Island are described in four categories (diagramatically represented as a composite model in Fig. 2). These represent the extremities from unaltered basal anhydrite to near-surface solution trench sections where the basal anhydrite is entirely absent due to dissolution/weathering. Depending upon depth and development history, the cavities may be open, partially filled, or completely filled with a variety of lithified and unconsolidated surficial material ranging from mud and sand to gravel and boulders.

Type 1 drillholes (Unaffected Sections) are located downdip from significant groundwater penetration. They are characterized by thick, relatively undisturbed and stratigraphically complete sections through the basal anhydrite. These have an intact contact with the underlying basal carbonate (Macumber Formation) which rests concordantly on Horton Group siliciclastics. The depth to the base of the Windsor Group in these drillholes typically exceeds 250 m to 300 m. There is no significant hydration of the basal anhydrite at the contact with the Macumber Formation. There typically is a very thin hydration zone (a few metres) on the upper surface of the basal anhydrite at the contact with the overlying unconsolidated surficial deposits. Representative drillholes include: SJL97-1, SJL97-3 (Jubilee Joint Venture, 1998), JLN-1, JLN-3 near Jubilee/Little Narrows (Westminer, 1993), CB9 and CIB2 near Malagawatch (Chevron Standard Ltd., 1978), SCL-88-11 and SCL-12 near Sugar Camp (Westminer Canada Limited, 1993) and the Bestwall deep hole (NSDNR Record # 4957) near Big Brook.

Type 2 drillholes (Deep Karst Cavity Sections) intersect the deepest extension of karst/hydration development located updip from the unaltered basal anhydrite sections. These are characterized by thick, relatively unaltered sections of the basal anhydrite with gypsum hydration and small karst stratabound cavities. The cavities (filled to open) are developed at the contact with the underlying basal carbonate (Macumber Formation), which rests concordantly on Horton Group siliciclastics. The depth to the cavity zone in these drillholes rarely exceeds 250 m to 300 m, and typically occurs at depths of 250 m or less. There is minor hydration of the basal anhydrite at the cavity contact with the Macumber Formation. Representative drillholes include: PH-1-91 (247-276 m) in the Sugar Camp area (Scotia Prime Minerals Incorporated, 1992), IR-3-74 (275 m+) near the superb karst of the Plaster Ponds in the Jubilee/Iona Rear area (Texas Gulf, 1978).

Type 3 drillholes (Shallow Trench Cavity Sections), which intersect the core of the karst development zone, occur updip from Type 2 and extend downdip from the headwall of the solution trench near the outcrop limits of the basal anhydrite. These drilled sections are typically less than 150 m deep and are characterized by thick, variably hydrated and karsted sections through the basal anhydrite. There is locally extensive gypsum hydration and karst cavity development including: stratabound and discordant fissures, sinkholes-dolines, valley sinks, pinnacles and haystack hills along the hanging wall of the basal anhydrite and at the contact with the underlying basal carbonate. The cavity zone depth in these drillholes rarely exceeds 40 m and typically occurs at depths less than 150 m. Hydration of the basal anhydrite to gypsum occurs in an envelope that extends around the overhanging headwall of the basal anhydrite. The stratigraphy of these drillholes appears to be unusual; they typically have the following section downhole: overburden, gypsum, anhydrite, gypsum, trench cavity fill, basal carbonate, Horton Group. In fact, there may be multiple cavities and gypsum zones in the basal anhydrite section above the main solution trench zone. Representative drillholes include: S1 (107-114 m) near Sugar Camp (Rio Tinto Canadian Exploration Ltd., 1974), 141-3 (118-158 m) near Washabuck Bridge/ Little Narrows (St. Joseph Explorations, Ltd., 1974a) and 139-2 (93-158 m) near River Denys (St. Joseph Explorations, Ltd., 1974b).

Type 4 drillholes (Solution Trench Sections) occur updip from Type 3, and are essentially entirely within the solution trench updip and beyond the outcrop limits (headwall) of the basal anhydrite. These drilled sections are typically less than 100 m deep, but may reach 150 m. They are characterized by the absence of *in situ* anhydrite or

gypsum of the basal anhydrite, with only unconsolidated surficial karst infill deposits directly overlying the basal carbonate. The cavity zone in the Type 4 drillholes progressively becomes enlarged at the outcrop limits to widths that may exceed 300 m. These wide (hundreds of metres) and elongate (kilometres) landform features, often topographic lows, are the location for major parallel surface drainage in the region (e.g. Washabuck River, and Big Brook/River Denys). Representative drillholes include: JBL97-1 (0-78 m) near Upper Washabuck/Little Narrows (Kaoclay Resources Inc., 1997), 139-1 (0-93 m) near River Denys (St. Joseph Explorations, Ltd., 1974b) and RD-2 (0-73 m) near Melford/Upper River Denys (Texas Gulf, 1977).

Conclusions

The Horton Group - Windsor Group and basement contact is a favourable and prospective zone for mineralization because the basal Windsor carbonate is a chemically and physically receptive host that lies on top of siliciclastics of the Horton Group or crystalline basement, which serve as hydrogeological sources for metals and conduits for mineralizing fluids. The impermeable anhydrite overlying basal carbonate served as a seal to confine and focus fluid flow at the Horton - Windsor contact, and comparisons may be made to source, reservoir and seal rocks in a petroleum system.

This contact is geologically complicated due to post-depositional and syn- to post-mineralization tectonics and evaporite karst processes that have preferentially affected the Horton-Windsor contact zone. Evaporite karst development occurred in multiple episodes controlled by regional and local tectonics and erosional events in the late Paleozoic, Mesozoic, and Cenozoic eras.

The subsurface nature of solution trench karst features at the base of the Windsor Group is documented mainly in mineral exploration drilling and to a lesser extent in mine/quarry workings. The diagrammatic cross-section in Figure 2 and the example drillholes, illustrate the interpreted trench geology in south-central Cape Breton Island in four categories. Type 1 drillholes are unaffected sections. Depth to the base of the Windsor Group in these drillholes typically exceeds 250 m to 300 m. There is no significant hydration of the anhydrite or karst cavity development. Type 2 drillholes include deep karst cavity sections in the deepest extension of karst/hydration development. These have limited gypsum hydration and small karst stratabound cavities at depths rarely exceeding 250 m to 300 m, and typically at depths of 250 m or less. Type 3 drillholes intersect shallow trench cavity sections that define the core of the karst development zone. This occurs immediately downdip from the headwall of the solution trench near the outcrop limits of the basal anhydrite. These drilled sections are typically less than 150 m deep and are characterized by variable and generally extensive hydration and karstification of the basal anhydrite. Type 4 drillholes are essentially entirely within the solution trench updip and beyond the outcrop limits (headwall) of the basal anhydrite. These drilled sections are typically less than 100 m deep and are characterized by the absence of *in situ* anhydrite or gypsum of the basal anhydrite, with only unconsolidated surficial karst infill deposits directly overlying the basal carbonate.

Underground and surface mining operations in the basal Windsor Group at Walton, Gays River, and to a lesser extent Loch Lomond, encountered unstable ground conditions in the hanging wall. Large volumes of karst and fracture system controlled groundwater infiltrated to mine depths exceeding 300 m.

The geological features that were favourable to host these mineral deposits were also conducive to later structural disturbance and subsequent preferential evaporite karst development in the near-surface environment. Karst development and associated groundwater infiltration and hydration of anhydrite is integral to the origin of economic high-grade gypsum deposits in south-central Cape Breton Island (e.g. Big Brook, Sugar Camp, Little Narrows). The karst process history also may be important in the development of the late Paleozoic basin petroleum system.

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