FG No. 6

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Lands, Minerals and Petroleum

Field Guide

GEOLOGY AND ECONOMIC DEVELOPMENT OF EARLY CARBONIFEROUS MARINE EVAPORITES, SOUTHEASTERN NEW BRUNSWICK

T.C. Webb

2010

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Cover illustration:	*Stacked algal boundstone mounds and interbedded wackestone of the Gays River Formation (Windsor Group), from Graymont (NB) Inc.'s Samp Hill limestone and dolomite quarry 5 km west of Havelock, southeastern New Brunswick.*
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Hon. Wally Stiles
Minister of Natural Resources

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ABSTRACT

In Atlantic Canada, Early Carboniferous (Early Visean) marine evaporites and associated sedimentary rocks of the Windsor Group have been the subject of considerable study as they host the thickest and most widespread evaporite deposits in eastern North America. Potash, gypsum/anhydrite, rock salt, and limestone have been mined from the Windsor for generations. Over the past thirty years, New Brunswick's economic deposits of potash have been, and continue to be, developed into world class mining and processing facilities. Interest in Windsor evaporites also stems from their underground storage potential for natural gas, compressed air, and carbon dioxide emissions.

The two day field trip outlined in this guide examines the stratigraphic succession of, and addresses several geologic novelties of the Windsor Group in southeastern New Brunswick. Special emphasis is directed at some of the interesting enterprises that make or have made productive use of important Windsor Group mineral resources.

RÉSUMÉ

Au Canada atlantique, les évaporites d'origine marine du début du Carbonifère (début du Viséen) et les roches sédimentaires associées du groupe de Windsor ont fait l'objet de nombreuses études, car elles renferment les gisements d'évaporites les plus épais et les plus étendus de tout l'est de l'Amérique du Nord. On extrait depuis de nombreuses générations de la potasse, du gypse-anhydrite, du sel gemme et du calcaire dans le groupe de Windsor. Au cours des 30 dernières années, les gisements rentables de potasse du Nouveau-Brunswick ont fait l'objet et sont toujours l'objet d'une exploitation minière et d'une transformation de premier rang à l'échelle mondiale. L'intérêt à l'égard des évaporites du groupe de Windsor tient également à leur possibilité de servir de lieu de stockage des émissions de gaz naturel, de l'air comprimé et de dioxyde de carbone.

Cette excursion sur le terrain de deux jours dont rend compte ce guide permet d'examiner la succession stratigraphique et plusieurs des caractéristiques géologiques singulières du groupe Windsor, dans le sud-est du Nouveau-Brunswick. Une attention toute particulière est portée à certaines des entreprises qui utilisent ou ont déjà utilisé de manière productive ces importantes ressources minérales du groupe Windsor.

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ACKNOWLEDGEMENTS

The author is very grateful and indebted to the management of the following mining enterprises and businesses for their cooperation in the preparation of parts of this guide: Jason Downey - Quarry Operations Manager, Brunswick Limestone, Hillsborough, NB; André Van Agten - Plant Manager, Graymont (New Brunswick) Inc., Havelock NB; and Brian Roulston - Engineering Superintendent, Potash Corporation of Saskatchewan Inc. (New Brunswick Division), Penobsquis, NB.

Special thanks to Malcolm McLeod - Manager Geological Surveys Brach South for constructive editorial comments, Terry Leonard and Erin Smith for preparing some of the guide maps and figures, and Erin Smith for her assistance in assembling the document for publication.

SAFETY MEASURES

Note: This guide incorporates visits to key rock exposures on private properties; visits to quarries, mines and associated processing facilities; and visits to several commercial venues. Potential users must therefore make their own arrangements should any attempt be made to duplicate the itinerary and suggested stops in this guide.

For the sake of personal and group safety, all participants in this field trip should read and abide by the safety measures outlined below. The objective of these guidelines is to make the excursion as safe and enjoyable as possible which can only be achieved with everyone's co-operation.

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1. **First Aid/Medical Conditions**: Any participants certified in First Aid are encouraged to identify themselves at the beginning of the trip. A first aid kit should be available in the field trip vehicle(s) and trip leaders should have kits with bandages etc. in their field gear. For precautionary reasons, field trip participants with medical conditions are encouraged to inform the trip leaders in advance of the trip.

2. **Suitable Footwear and Clothing**: Participants are required to have sturdy footwear with good traction to avoid injury in the trenches and during hiking. In addition, because of unpredictable spring weather, participants are to bring proper clothing to protect themselves from the cold (possibly wet) weather (i.e., hat, gloves, rain gear).

3. **Rock Hammers and Picks**: Please use extreme caution when hammering and be aware of those around you. It is strongly recommended that you wear proper eye protection (i.e., safety glasses or goggles) while hammering and while others are hammering around you. The use of hammers and chisels not specifically made for breaking rocks is strictly prohibited because of their potential to splinter and/or break.

4. **Hard Hats**: A supply of hard hats should to be available for participants to use at any time. Participants are encouraged to wear a hard hat when examining cliff exposures and adjacent quarry walls where falling rocks are a potential hazard.

5. **Slippery Surfaces**: Some of the trip requires walking over surfaces that can be extremely slippery; particularly adjacent stream beds and coastal areas. Use extreme caution in areas of moss and seaweed-covered rocks, and exposed tree roots.

6. **Falling Rocks**: Several stops involve examining exposures adjacent a cliff face that may be unstable. Be sure to look over head for any loose rocks before getting too close to the outcrop. Climbing cliff exposures is prohibited as it may be hazardous to you and those around you. When examining the top of a cliff exposure or escarpment, stay well back from the edge and avoid any activity that may be hazardous to people at the base of the exposure.

7. **Hiking Hazards**: Access trails to some field stops require proceeding along cut lines through the forest or walking on partially overgrown paths. Please, watch your step to avoid tripping on small, pointy stumps. Be respectful of those following behind you. Please don't wander off from the rest of the group particularly during traverses in the forest. If it is absolutely necessary to stray from the group, please advise one of the trip leaders before doing so.

8. **Transportation**: While the field trip vehicle is in motion, please remain seated and ensure that all of your belongings (especially rock hammers, chisels, and samples) are safely stowed on the floor and, if possible, beneath your seat.

9. **Roadside Stops**: Some field stops take place along roads where traffic is minimal however, be aware of the occasional passing vehicle on narrow woods roads. Due to time constraints, there may be some impromptu field stops along the highway and secondary roads where traffic may be a concern. In the event that this occurs, please listen for directions from the trip leaders before crossing any road. Also, be aware of traffic at all times and always stay well off to the side of the road.

10. **IN THE UNLIKELY EVENT OF AN EMERGENCY, CALL 911**: Field trip leaders are advised to be equipped with cellular and/or satellite phones. The location of these phones should be disclosed to all participants in the unlikely event of an accident or injury. It may be necessary to seek out a pay/private phone in areas where cellular phone coverage is poor.

USE COMMON SENSE…
…when in doubt, question a field trip leader (s)

ABBREVIATIONS

1 centimetre (cm) = 0.39 inches
1 metre (m) = 39.37 inches or 3.28 feet or 1.09 yards
1 kilometre (km) = 0.62 miles or 3208.84 feet
1 tonne (t) = 1.10 tons
t/d = tonnes per day
t/h = tonnes per hour
t/y = tonnes per year
mt = million tonnes
kcal = kilocalorie
kg = kilogram
kJ = kilojoule
kW-h = kilowatt-hour

GENERAL TRIP ITINERARY

PART 1: from Fredericton

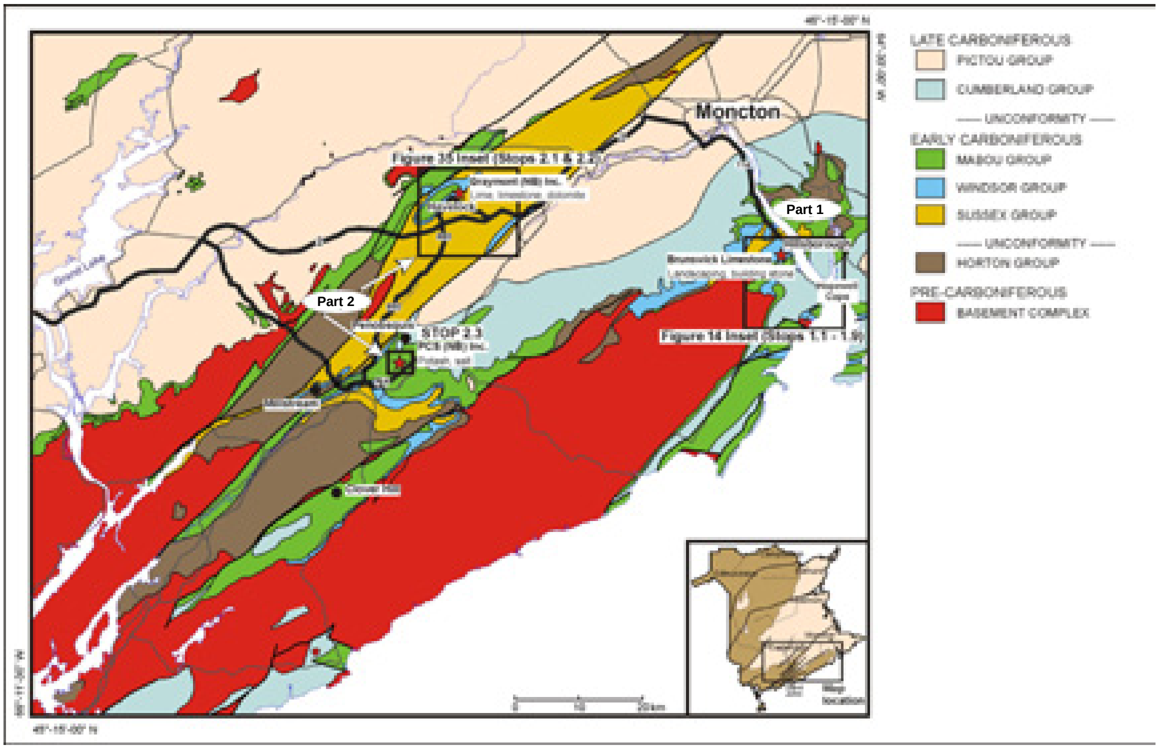
Windsor Group rocks in the western half of the Sackville Subbasin: salt excluded.

- From Fredericton, head east to the Hillsborough area, of southeastern New Brunswick (scenic 2½ hour drive) to view key stratigraphic components of the Windsor Group, a natural stone fabrication facility, and the *Hopewell Rocks*; one of New Brunswick's top tourist attractions
- Return to Moncton (40 minute drive) and overnight in the Magnetic Hill area

PART 2: from Moncton

Windsor Group rocks in the Cocagne and Moncton subbasins: salt included.

- From the Magnetic Hill - Highway # 2 interchange, proceed west to the Havelock area (¾ hour drive) to observe the upper part of the Windsor Group stratigraphic sequence and the lime and limestone processing facility of Graymont (NB) Inc.
- Travel southwest to Sussex (¾ hour drive) and the potash mine and processing operations of Potash Corporation of Saskatchewan (New Brunswick Division) Inc. to examine the internal stratigraphy of Windsor Group evaporites (i.e. the Cassidy Lake Formation) and various operational aspects of this unique underground mine.
- Return to Fredericton (1½ hour drive) and end of field trip



Overview of field trip route in southeastern New Brunswick, Canada.

INTRODUCTION

Although much has been published, the classic work of Gussow (1953) and more recently, that of St. Peter (1993, 2006), provide fairly sufficient introductions to the Carboniferous stratigraphy and structure of New Brunswick. A detailed report by St. Peter and Johnson (2009) has been published and readers are referred to this comprehensive publication for further information. Unless otherwise indicated, the following descriptions are adapted in part from St. Peter (2006). For additional information regarding the regional distribution and composition of Carboniferous rocks in New Brunswick, the reader is referred to the following: New Brunswick Department of Natural Resources (2008 and 2009); Smith (2005; 2006 and 2008); and Smith and Fyffe (2006). This information is available on-line through the New Brunswick Department of Natural Resources Minerals and Petroleum website (http://www.gnb.ca/0078/minerals/index-e.aspx).

During this two-part field trip, Windsor Group lithostratigraphy will be examined at areas in three southeastern New Brunswick Carboniferous subbasins. Part 1 will begin near the western margin of the Sackville Subbasin as most of the formations comprising the Windsor Group in southeastern New Brunswick are visible there. Part 2 will involve traveling north and west into areas of the Moncton and Cocagne subbasins to observe important aspects of the Windsor Group that are not observable in the Sackville Subbasin. To illustrate the economic importance of the Windsor Group, both parts will incorporate visits to commercial enterprises making productive use of the limestone, gypsum/anhydrite, and potash/salt deposits hosted in the Windsor; including the only lime producing facility in Atlantic Canada and an underground visit to a unique potash/salt mine near Sussex.

REGIONAL GEOLOGICAL SETTING

Atlantic Canada and parts of the New England states occur within the northern Appalachian Orogen, a linear mountain belt, extending from the northern tip of Newfoundland along the eastern seaboard of North America. This orogen, characterized by complex folded and faulted assemblages of igneous, sedimentary, and metamorphic rocks, is the product of episodic collision between two of the earth's crustal plates. Several tectonic events affected the Late Neoproterozoic to Early Permian rocks in Atlantic Canada (van Stall 2007). Approximately 350 million years ago, much of Atlantic Canada, including what is now southeastern New Brunswick, lay beneath a 75,000 km^2 terrestrial to marine basin, referred to as the Maritimes Basin (Fig. 1). During the waning stages of the Middle Devonian (400-375 Ma) Acadian Orogeny, several rift related structures formed. As a result of these tectonic events, several northeast-trending uplifted highlands and down-dropped basins formed, including the Cumberland, Sackville, Moncton, and Cocagne subbasins (Fig. 2a). These areas became important depocentres for a host of Late Devonian (375-360 Ma) to Early Carboniferous (345-325 Ma), fine- to coarse-grained clastic sedimentary rocks, evaporites, and carbonates.

GEOLOGY OF LATE DEVONIAN TO EARLY PERMIAN BASINS IN SOUTHEASTERN NEW BRUNSWICK

In New Brunswick, the Maritimes Basin is divided into six major rock groups (Fig. 2b): 1) Late Devonian to Early Carboniferous (Early Tournaisian) clastic sedimentary rocks, including oil-bearing sandstones and shales of the Horton Group; 2) Early Carboniferous (Late Tournaisian) clastic sedimentary rocks and minor evaporites of the Sussex Group; 3) Early Carboniferous (Early to Middle Visean) clastic sedimentary rocks, carbonates, and evaporites of the Windsor Group; 4) Early Carboniferous (Middle Visean to Namurian) clastic sedimentary rocks of the Mabou Group; 5) Late Carboniferous (Namurian to Westphalian) clastic sedimentary rocks of the Cumberland Group; and 6) Late Carboniferous-Early Permian (Westphalian to Asselian) clastic sedimentary rocks of the Pictou Group.

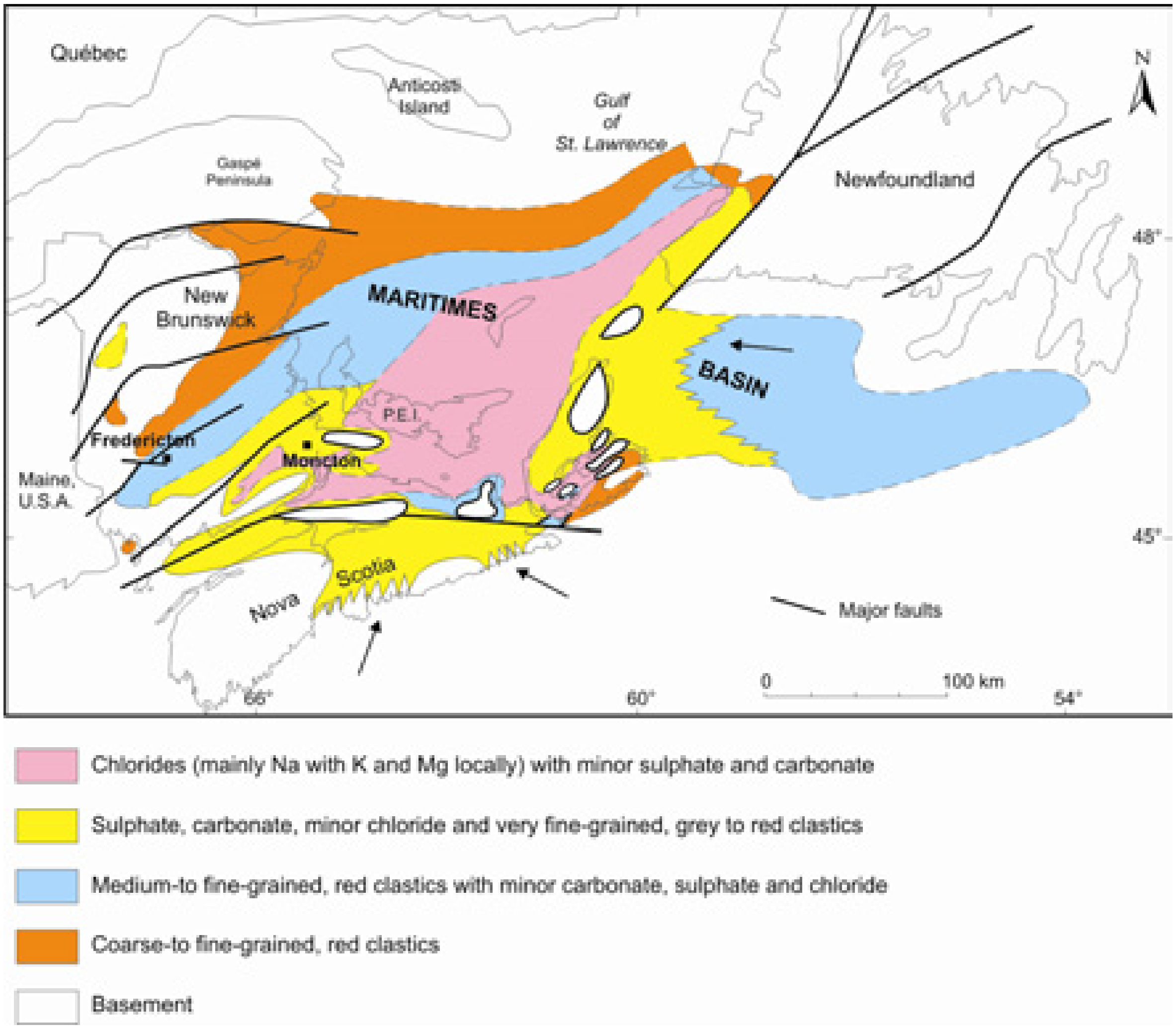


Figure 1. The Maritimes Basin encompasses eastern New Brunswick, parts of central Brunswick, northern and northeastern Nova Scotia, the Îles de la Madeleine in the Gulf of St. Lawrence, and the southwest part of Newfoundland. This map illustrates the paleodistribution of Early Carboniferous (Early to Middle Visean) Windsor Group clastic sedimentary rocks, carbonates and evaporites in the Maritimes Basin (modified from St. Peter 2006 and Howie 1988).

Windsor rocks represent an important marine incursion event in the Maritimes Basin and they have a long exploration and development history in New Brunswick and other parts of Atlantic Canada. They host the thickest and most widespread, evaporite deposits in eastern North America and are currently mined for potash(KCl), halite (rock salt - NaCl), sulphate (gypsum/anhydrite - $CaSO_4 \cdot 2H_2O/CaSO_4$) and carbonate (limestone - $CaCO_3$).

Throughout Atlantic Canada Windsor evaporites, including sulphates and various salts, are commonly preserved in parts of several northeast- and east-trending, fault-bounded depocentres or subbasins, separated from each other by intervening uplifted terrane. In southeastern New Brunswick, these component depocenters are the Cumberland, Sackville, Moncton, and Cocagne subbasins (Fig. 2a). Thinner or condensed accumulations of Windsor strata lie adjacent to these subbasins on the margins of regional uplifts like the Caledonian and Westmorland uplifts and parts of the New Brunswick Platform.

Over the past thirty years, economic deposits of New Brunswick potash have been and continue to be developed into world class mines and processing facilities. Interest in Windsor evaporites also stems from their underground storage potential for natural gas, compressed air, and carbon dioxide emissions.

Horton and Sussex groups

Neoproterozoic and Early Paleozoic basement rocks in the Maritimes Basin are unconformably overlain by Late Devonian to Early Carboniferous rocks of the Horton Group. The Horton consists of coarse- to fine-grained clastic sedimentary rocks, including economically important organic-rich (bituminized) shales and sandstones. Rocks belonging to the Sussex Group unconformably overlie the Horton and although they mostly consist of continental, clastic sedimentary rocks, it also locally contains carbonate and impure deposits of glauberite (a sodium-calcium sulphate) and salt associated with the Gautreau Formation. Potash minerals have not as yet been identified in this formation. Given the non-marine depositional environment proposed for the Gautreau, (St. Peter 2006) it is unlikely potash would be associated with the Sussex Group.

Windsor and Mabou groups

A sequence of Early Carboniferous coarse- to fine-grained, clastics sedimentary rocks, carbonates, and evaporites several hundred metres thick (St. Peter 2006) have been identified by mapping, various geophysical surveys and subsurface drilling throughout southeastern New Brunswick. Collectively these strata are referred to as the Windsor and Mabou groups. Windsor Group rocks represent the only occurrence of marine sediments in the entire onshore portion of the Maritimes Basin in New Brunswick. The contact of the Windsor with underlying Sussex Group and basement rocks is unconformable while its contact with the overlying Mabou Group varies locally from gradational to erosional. Regionally, Cumberland and Pictou group rocks overstep the Windsor Group and all other Carboniferous sequences in the region.

In southeastern New Brunswick, the Windsor Group is divided into several formations (Fig. 3) and, in the Moncton and Cocagne subbasins, the succession consist of the following in ascending order: 1) basal clastic sedimentary rocks of the Hillsborough

Formation; 2) nearshore, platform and basinal carbonates of the Parleeville Formation; 3) Gays River and 4) Macumber formations, which are laterally equivalent; 5) sulphates of the Upperton Formation; 6) chlorides (+/- potash) of the Cassidy Lake Formation; and 7) chlorides, sulphates, carbonates, and clastic sedimentary rocks of the Clover Hill Formation. The Hillsborough, Gays River, Macumber, and Upperton formations are present in the Sackville and Cumberland subbasins. There, overlying chlorides are named the Pugwash Mine Formation, while the carbonates, sulphates, chlorides, and clastic sedimentary rocks capping the sequence are named the Lime-kiln Brook Formation.

Regionally the thickness, lithofacies, and aeral extent of Windsor strata vary considerably, reflecting diversity in the structural evolution and post-depositional deformation that affected Carboniferous strata throughout the Maritimes. Strata most severely deformed are generally restricted to several narrow subbasin structures striking northeast through southern New Brunswick, east across mainland Nova Scotia and northeast through Cape Breton Island to southwestern Newfoundland. Windsor evaporites are characterized by limited compressive strength and limited structural competence. They are, therefore, particularly susceptible to deformation, typically reacting to stress by being squeezed out of layered depositional sites analogous to squeezing out the contents of a toothpaste tube. This property, combined with lower density and stronger buoyancy compared to that of the surrounding sedimentary rock, often results in highly mobile, semi-fluid evaporite masses moving upward through the overlying sedimentary rock to an equilibrium position forming domes, thickened lenses, diapirs, evaporite cored anticlines, ridges, and walls. The subsurface distributions of Windsor evaporites therefore represent scattered structural remnants of former layered deposits that can often be delineated through hydrologic surface feature observation (e.g., salt springs) or detected indirectly using gravity and seismic geophysical methods.

In New Brunswick, coarse- to fine-grained, clastic sedimentary rocks of the Mabou Group conformably and unconformably overlie Windsor strata and underlie sedimentary rocks of the Late Carboniferous Cumberland and Pictou groups. Typically, the Mabou consists of a coarsening upward succession of reddish brown mudstones to sandstones, capped by conglomerates. The thickness of these rocks is quite variable, ranging up to a few thousand metres in the Sackville and Cumberland subbasins and up to a thousand metres in the Moncton Subbasin, to only a few or tens of metres in areas of the New Brunswick Platform.

Cumberland and Pictou groups

Grey to green, coarse- to fine-grained, terrestrial, clastic sedimentary rocks of the Cumberland and Pictou groups unconformably and disconformably overlie the Mabou. Cumberland and Pictou strata represent the youngest Carboniferous strata in the New Brunswick and are widespread, occupying almost a third of its land mass. The thickness of these rocks is related to tectonic episodes marking the end of Carboniferous deposition in Atlantic Canada. In parts of southeastern New Brunswick, Late Carboniferous strata may exceed thicknesses of a few thousand metres. On the New Brunswick Platform however, the strata provide comparatively thinner cover, seldom exceeding a thousand metres. These rocks are characteristic of a semiarid, non-marine, terrestrial setting. Pictou rocks are known for their associated deposits of coal in the New Glasgow and Sydney areas of northeastern Nova Scotia and in the Chipman-Minto area in south-central New Brunswick.

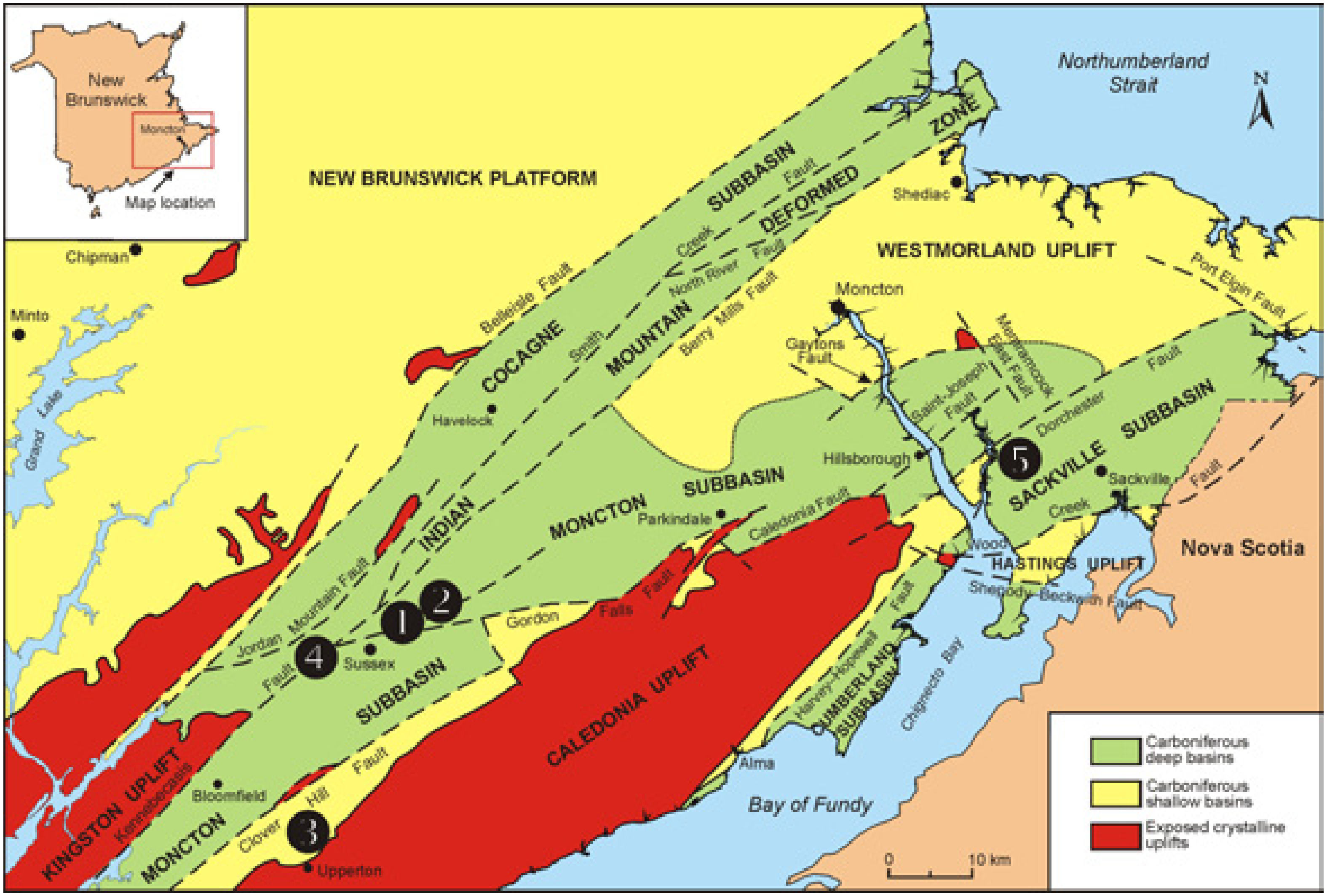
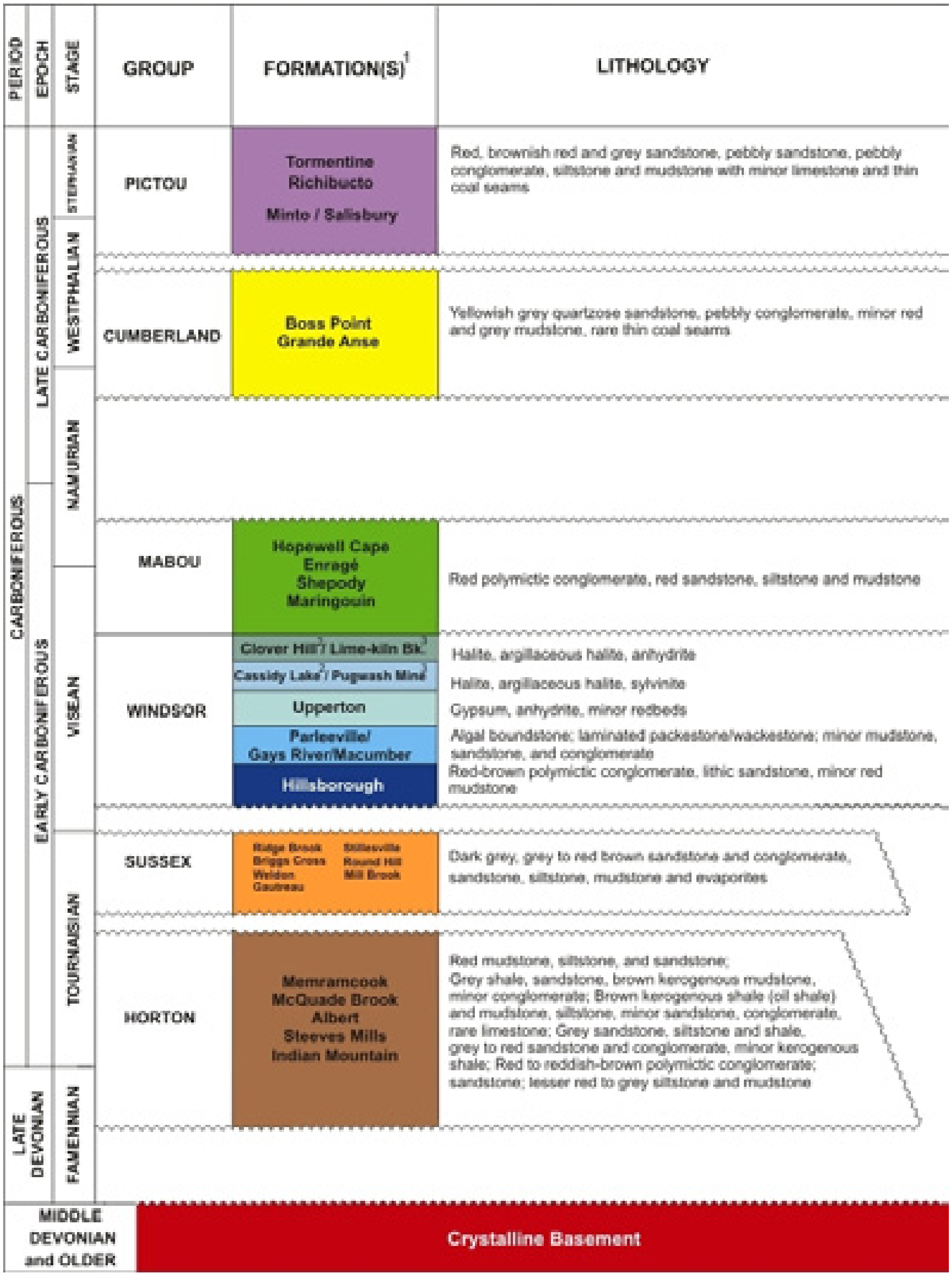


Figure 2a. Late Devonian to Carboniferous subbasins and confirmed deposits of Windsor Group potash and salt in southern New Brunswick (modified from St. Peter 2006): ❶ Potash Corporation of Saskatchewan (New Brunswick Division) Inc.'s Penobsquis potash mine and ❷ their new Picadilly potash mine currently being constructed (2009); ❸ the former Clover Hill potash mine; ❹ the Millstream potash prospect and ❺ the Dorchester salt deposit.



PERIOD	EPOCH	STAGE	GROUP	FORMATION(S)[1]	LITHOLOGY
CARBONIFEROUS	LATE CARBONIFEROUS	STEPHANIAN	PICTOU	Tormentine Richibucto Minto / Salisbury	Red, brownish red and grey sandstone, pebbly sandstone, pebbly conglomerate, siltstone and mudstone with minor limestone and thin coal seams
		WESTPHALIAN	CUMBERLAND	Boss Point Grande Anse	Yellowish grey quartzose sandstone, pebbly conglomerate, minor red and grey mudstone, rare thin coal seams
		NAMURIAN			
	EARLY CARBONIFEROUS	VISEAN	MABOU	Hopewell Cape Enragé Shepody Maringouin	Red polymictic conglomerate, red sandstone, siltstone and mudstone
			WINDSOR	Clover Hill[2] / Lime-kiln Bk.[3]	Halite, argillaceous halite, anhydrite
				Cassidy Lake[2] / Pugwash Mine[3]	Halite, argillaceous halite, sylvinite
				Upperton	Gypsum, anhydrite, minor redbeds
				Parleeville/ Gays River/Macumber	Algal boundstone; laminated packestone/wackestone; minor mudstone, sandstone, and conglomerate
				Hillsborough	Red-brown polymictic conglomerate, lithic sandstone, minor red mudstone
		TOURNAISIAN	SUSSEX	Ridge Brook Briggs Cross Weldon Gautreau Stilesville Round Hill Mill Brook	Dark grey, grey to red brown sandstone and conglomerate, sandstone, siltstone, mudstone and evaporites
			HORTON	Memramcook McQuade Brook Albert Sleeves Mills Indian Mountain	Red mudstone, siltstone, and sandstone; Grey shale, sandstone, brown kerogenous mudstone, minor conglomerate; Brown kerogenous shale (oil shale) and mudstone, siltstone, minor sandstone, conglomerate, rare limestone; Grey sandstone, siltstone and shale, grey to red sandstone and conglomerate, minor kerogenous shale; Red to reddish-brown polymictic conglomerate; sandstone; lesser red to grey siltstone and mudstone
LATE DEVONIAN		FAMENNIAN			
MIDDLE DEVONIAN and OLDER			Crystalline Basement		

Figure 2b. Late Devonian to Carboniferous stratigraphic chart for southern New Brunswick (modified after St. Peter 2006; St. Peter and Johnson 2009). NOTE: see New Brunswick Department of Natural Resources (2009) for detailed descriptions of individual formations.

1. no stratigraphic order implied; regional distribution of formations varies
2. western end of the Moncton Subbasin
3. Sackville and Cumberland subbasins

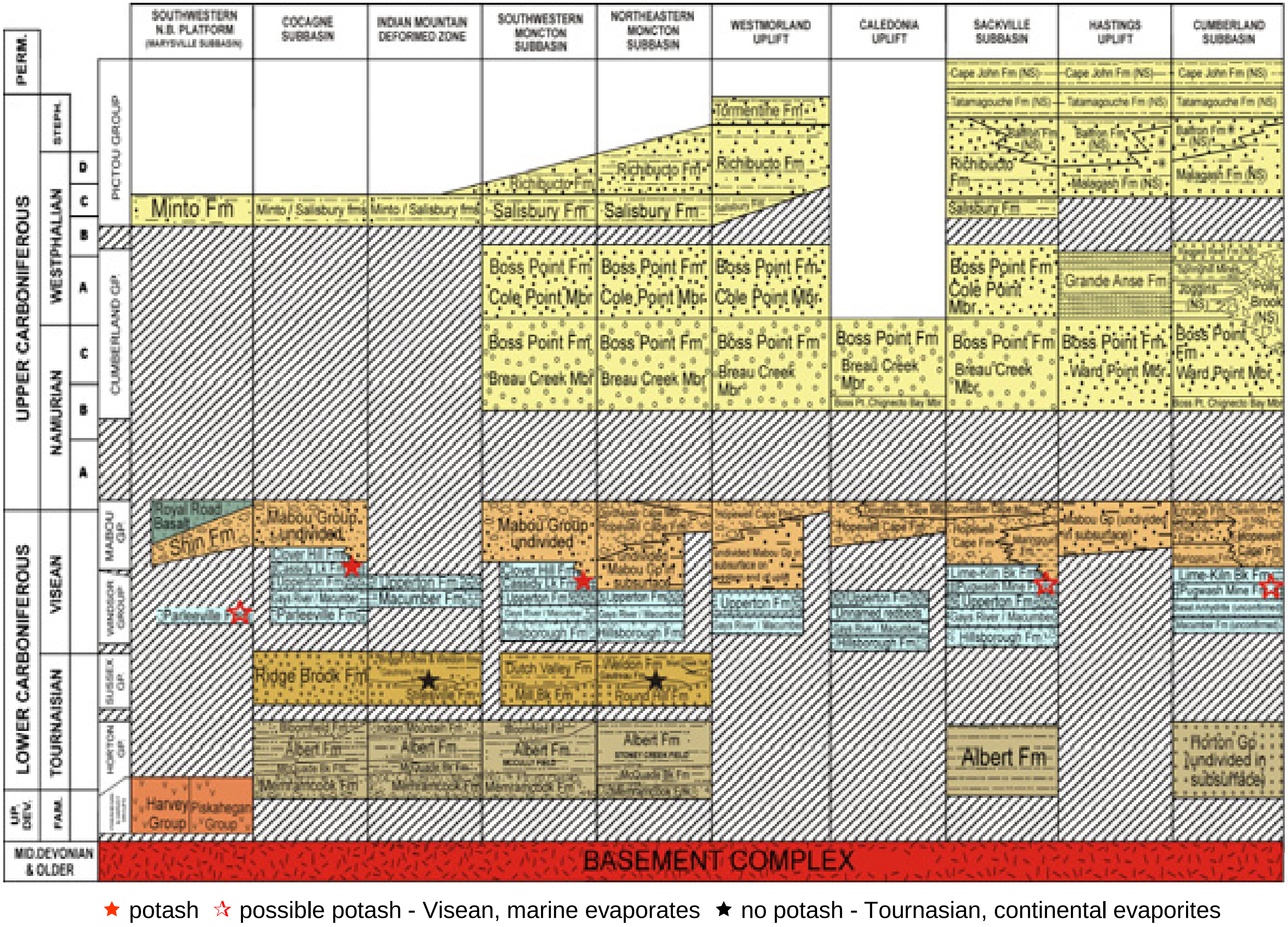
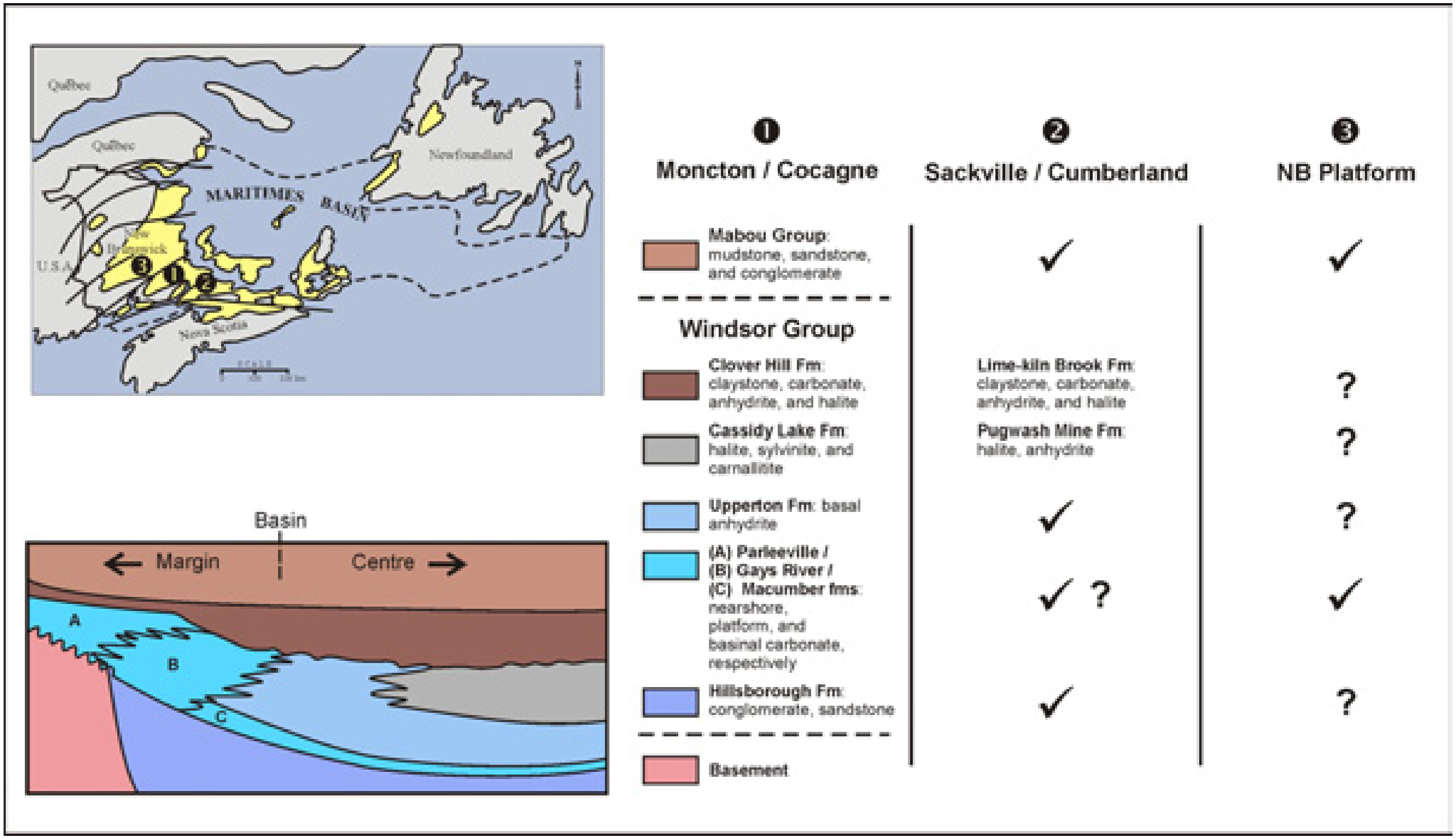


Figure 3. Table of formations for subbasins and uplifts in the Maritimes Basin of southeastern New Brunswick and adjacent Nova Scotia summarizing the regional relationships between Upper Devonian to Permian strata and Upper Carboniferous Windsor Group evaporites, carbonates and clastic sedimentary rocks (modified after St. Peter 2006).



	❶ Moncton / Cocagne	❷ Sackville / Cumberland	❸ NB Platform
▨	**Mabou Group**: mudstone, sandstone, and conglomerate	✓	✓
	Windsor Group		
▨	**Clover Hill Fm**: claystone, carbonate, anhydrite, and halite	**Lime-kiln Brook Fm**: claystone, carbonate, anhydrite, and halite	?
▨	**Cassidy Lake Fm**: halite, sylvinite, and carnallitite	**Pugwash Mine Fm**: halite, anhydrite	?
▨	**Upperton Fm**: basal anhydrite	✓	?
▨	**(A) Parleeville / (B) Gays River / (C) Macumber fms**: nearshore, platform, and basinal carbonate, respectively	✓ ?	✓
▨	**Hillsborough Fm**: conglomerate, sandstone	✓	?
▨	**Basement**		

Figure 4. Windsor facies relationships and lithostratigraphy in the Moncton, Cocagne, Sackville, and Cumberland subbasins and in the New Brunswick Platform.

LITHOSTRATIGRAPHY OF THE WINDSOR GROUP IN NEW BRUNSWICK

Windsor Group strata are variably found in all of New Brunswick's major Carboniferous basins. Due to differing structural development in individual subbasins, the distribution of key lithologies varies regionally. For areas of southeastern New Brunswick, Windsor facies relationships and lithostratigraphy are illustrated in Figures 3 and 4 and summarized below.

Hillsborough Formation

Coarse-grained, clastic sedimentary rocks of the Hillsborough Formation form the stratigraphic base of the Windsor Group in New Brunswick. The Hillsborough clastic sequence was assigned to the Windsor by St. Peter on the basis of its upper and lower contact relationships which "quite obviously [indicate it as] the initial part of the Windsor depositional cycle [in New Brunswick]" (St. Peter 1993). Typically comprised of red conglomerates and coarse-grained to gritty sandstones with minor mudstones, Hillsborough strata rest unconformably on deformed, non-marine, clastic sedimentary rocks and minor evaporites of the Sussex Group, or locally near basin margins, overstep Horton Group clastic sedimentary rocks, or lie directly on Neoproterozoic basement. The upper contact with the overlying Macumber Formation is conformable.

A typical Hillsborough exposure consists of thick to amalgamated beds of conglomerate and coarse-grained sandstone with thin interbeds of fine-grained sandstone and mudstone (Fig. 5a, b). St. Peter (2006) describes the Hillsborough as "coarse, mass-flow, water lain deposits" with clast sizes and compositions comparable to the fairly localized provenance of basement and other rocks. A grain-supported texture for most

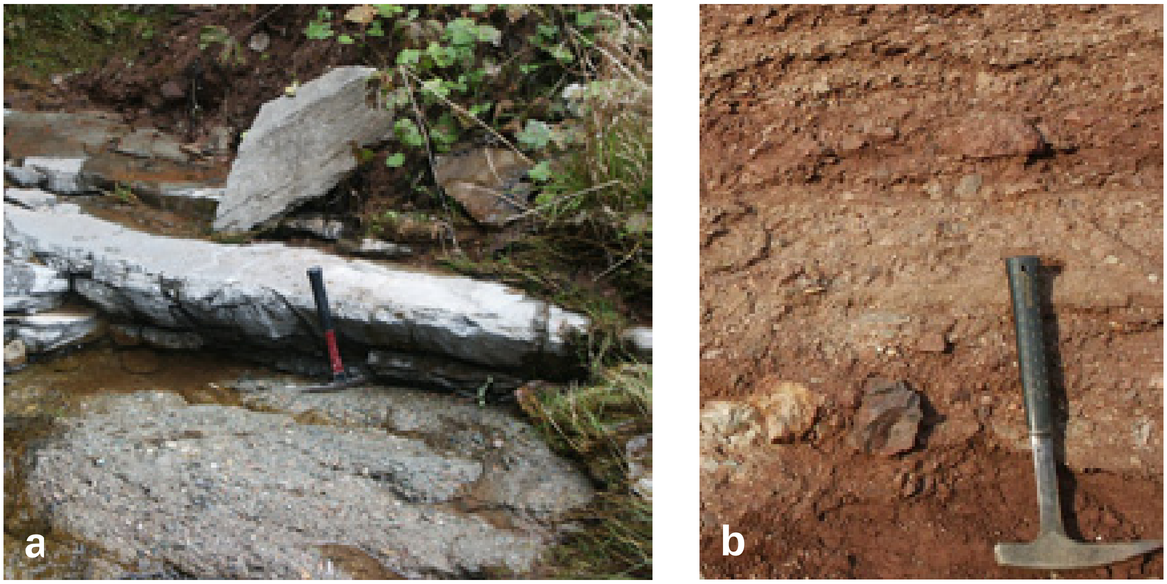


Figure 5a. Early Carboniferous, red to grey, polymictic, angular pebble and cobble conglomerate of the terrestrial Hillsborough Formation (in lower part of photo) disconformably overlain by grey laminated, allochthonous marine limestone of the Macumber Formation (in the upper part of photo), south of Hillsborough, southeastern New Brunswick. **5b**. Typical Early Carboniferous, red, polymictic, angular pebble and cobble, proximal conglomerate of the Hillsborough Formation in the Sackville Subbasin.

conglomerates and primary sedimentary structures, including tabular cross beds and cut and fill channelling, suggest the formation is primarily the product of braided stream deposition from the medial areas of alluvial fan complexes (St. Peter 1993, 2006).

Macumber, Gays River, and Parleeville formations

In New Brunswick, the carbonates near the base of the Windsor Group are laterally equivalent and consist of three main lithofacies: 1) a deep basinal, sublittoral facies of the Macumber Formation that progresses up-dip to 2) a platform or reef facies of the Gays River Formation that continues to 3) the basin-margin or shallow, nearshore, mixed carbonate-siliciclastic facies of the Parleeville Formation (Fig. 4). The Macumber, Gays River, and Parleeville are conformably overlain by, and in part laterally equivalent to, the Upperton Formation.

The Macumber Formation typically occurs in the medial parts of several of New Brunswick’s Carboniferous subbasins. Considered a basinward, allochthonous facies equivalent to the Gays River and Parleeville formations, it concordantly overlies the Hillsborough Formation. Typically, Macumber strata consist of thin, laminated wackestones and packstones (Fig. 6a, b) comprised of various sized, eroded algal intraclasts and pellets. An intraformational breccia usually develops near its up-dip contact with the reef rocks of the Gays River. Folding, a result of gravity induced slippage and slumping of unlithified material on steep sloping surfaces (plastic deformation), is not uncommon. Surface exposures of the Macumber are up to 18 m thick, however; deep basinal borehole intersections indicate thicknesses are seldom greater than 30 m.

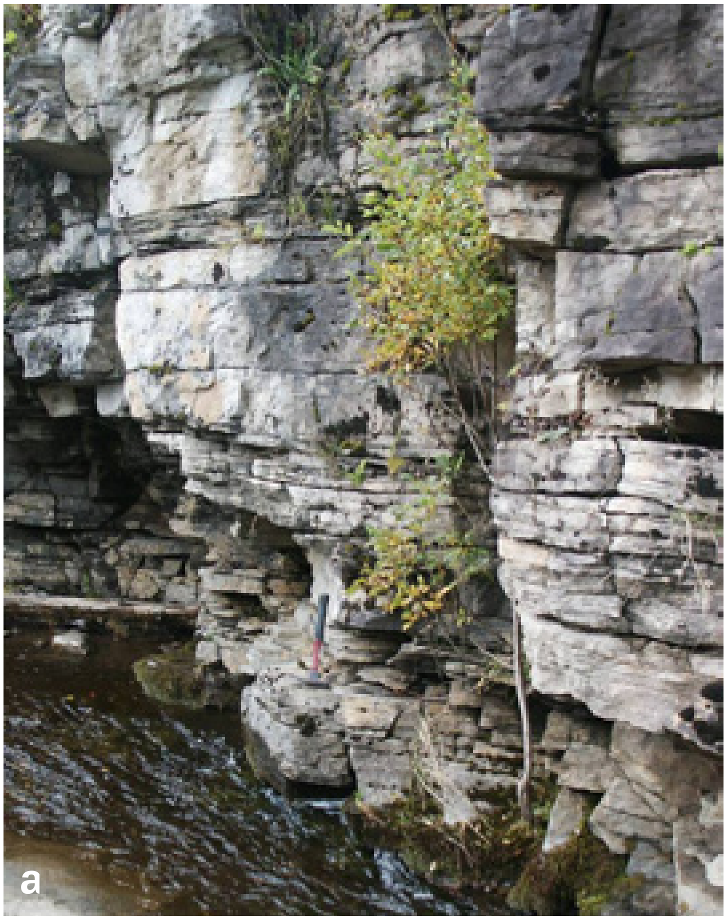


Figure 6a. Parallel-laminated, even-bedded packstone (limestone) of Early Carboniferous, marine (basinal) Macumber Formation, south of Hillsborough, Albert County, southeastern New Brunswick. **6b**. Close up of the exposure shown in 6a with bedding-parallel and rare, cross-cutting, dark grey stylolites.

Up-dip and shoreward of the Macumber are the platform carbonates of the Gays River Formation. Gays River strata consist of shallow water, thick- to massive-bedded algal boundstones with thin interbedded, bioclastic wackestones and packstones, often found in the interstitial spaces between adjacent stacked mounds of algal material (Fig. 7a, b). The strata represent basin margin reef material (algal mounds) deposited in a wave active environment and range in thickness from a few metres, near Hillsborough in the western part of Sackville Subbasin, to tens of metres at Havelock in the eastern part of the Cocagne Subbasin. This formation is of one of the few in the Windsor that locally supported a shelly, benthic community of brachiopods and pelecypods, and various species of foraminifera, and rare gastropods.

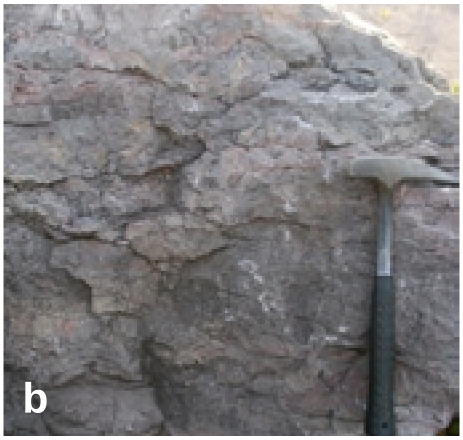


Figure 7a. Grey algal boundstone (limestone) of the Early Carboniferous, marine (platform) Gays River Formation, southeast of Albert Mines, Albert County, southeastern New Brunswick. **7b**. Close up of the exposure shown in 7a, interpreted as platform stacked, reef algal mounds.

The Parleeville Formation is a mixed assemblage of interbedded carbonates, similar to the Gays River, and fine- to coarse-grained calcareous siliciclastic rocks characteristic of a nearshore or intertidal depositional environment (Fig. 8). The thickness and ratio of carbonate to clastic rock within the formation is quite variable. The Parleeville is best exposed in the Cocagne Subbasin, where it consists of variably sized, mostly small algal boundstone mounds intermixed with wackestones, packstones, sandstones, and mudstones in thicknesses up to 22 m (St. Peter 2006). Fossils similar to those found locally in the Gays River are also found in the Parleeville.

Figure 8. Early Carboniferous, marine (nearshore) Parleeville Formation from the type section, west of Sussex at the southwestern end of the Cocagne Subbasin in south-central New Brunswick. Parleeville rocks typically consist of greyish red and olive-grey to black algal boundstone, siliciclastic floatstone, pelletoidal packstone to grainstone (limestone), with calcareous to non-calcareous sandstone and minor mudstone.

Upperton Formation

Sulphate of the Upperton Formation typically consists of stratiform, replacive, and displacive anhydrite found near the medial parts of several Carboniferous subbasins in southeastern New Brunswick. Macumber carbonates typically host Upperton sulphates, however; greenish grey claystone (mudstone) also serves as a suitable host. The anhydrite is typically hard, fine-grained to cryptocrystalline, and varies from steel grey to dark grey to light grey (Fig. 9). The gradational nature of the contact between the Upperton and underlying and adjacent Windsor carbonates often masks the exactness of the contact between the two contrasting lithologies.

Surface exposures of the Upperton are characterized by white to greyish white gypsiferous rocks (Fig. 10a, b). In areas of limited exposure, well developed karst topography (see page 39) provides near surface evidence of variably eroded, subsurface sulphate. Such areas are associated with fault zones. The upward and outward movement of formational water along fault planes and into adjacent fractured sulphate (anhydrite) has hydrated localized zones subsequently formed high quality gypsum resources of variable lateral extent and thickness. Drilling indicates the Upperton ranges in thicknesses from 40 to 110 m, however; it is noted that true thicknesses are often modified by structural thickening and thinning associated with stratigraphic repetition (Wilson et al. 2006). McCutcheon (1981) concluded the Upperton is an accumulation of sulphate in a subaqueous, deep-basin depositional setting.

Figure 9. Hard, fine-grained to cryptocrystalline, grey to light grey to banded, even-bedded anhydrite of the Early Carboniferous Upperton Formation, southwest of Hillsborough, Albert County, southeastern New Brunswick.

Figure 10a. Sulphate of the Upperton Formation, locally consisting of bedded gypsum with porphyroblasts of singular and radiating crystals of smoky selenite in a former quarry near Albert Mines, Albert County, southeastern New Brunswick. **10b**. Close up of the exposure shown in 10a.

Cassidy Lake and Pugwash Mine formations

Chlorides of the Cassidy Lake Formation (restricted to the Cocagne and Moncton subbasins) and its stratigraphic equivalent, the Pugwash Mine Formation (in the Sackville and Cumberland subbasins) are in part conformably underlain by and laterally equivalent to the Upperton sulphates (Anderle et al. 1979; McCutcheon 1981). Cassidy Lake chlorides are known only from exploration boreholes and from underground development associated with potash exploration and mining activity near: 1) Sussex, at the Potash Corporations of Saskatchewan (New Brunswick Division) Inc.'s Penobsquis mine and their new Picadilly mine, which is currently under construction; 2) Potacan Mining Company's former Clover Hill mine; and 3) Millstream, formerly explored by BP Exploration Canada Limited (Fig. 2). Pugwash Mine chlorides have been intersected in a few boreholes near Dorchester in the Sackville Subbasin.

In the Moncton and Cocagne subbasins, Cassidy Lake chlorides are subdivided into four members (Roulston et. al. 1995) comprising: 1) a basal halite-claystone; 2) a middle halite-claystone; 3) a potash; and 4) an upper halite-sylvinite-carnallitite[1]. At Penobsquis and Clover Hill, the basal Cassidy Lake member is a predominantly clean, medium- to coarse-grained halite (> 98% NaCl) (Fig. 11). Anhydrite or anhydritic claystone laminae, averaging 1 mm in thickness, occur locally. The estimated maximum true thickness of this member is 200 m. At Millstream, the basal Cassidy Lake member is an anhydritic to marly, reddish brown claystone with only minor halite, with a thickness of only 28 m. Halite is present as isolated hopper crystals and upward-pointing chevron structures, and as narrow, coarse-grained, recrystallized veins disseminated throughout the argillaceous material. Up to 80 m of argillaceous halite, belonging to the middle halite-claystone member, overlies the basal halite at Penobsquis and Clover Hill and the lower claystone at Millstream, where it is up to 350 m thick. It consists of reddish brown to greyish brown, medium- to coarse-grained halite with interstitial or bedded, greenish grey to dark grey claystone. The volume of claystone in the total lithology varies from about 5 % at Penobsquis and Clover Hill to about 20% at Millstream where it is commonly found in deformed beds up to several metres thick.

The potash member, up to 50 m thick, overlies the middle halite-claystone member. It represents the main potash "ore zone" that mined at Penobsquis and Clover Hill. This "ore zone" member is generally comprised of sylvinite, a fine- to medium-grained red sylvite (KCl) in a matrix of dark brown to light orange halite with minor grey clay (Fig. 11). Halite beds of variable thicknesses are also present, particularly at Millstream, a feature reflected by lower than average potassium values at this location compared to those at Penobsquis and Clover Hill.

A distinct, heterogeneous interval, the upper halite-sylvinite-carnallitite member, overlies the potash "ore zone" (Fig. 11). At Penobsquis and Clover Hill, this sequence, which exceeds 100 m in thickness, is comprised of interbedded orange, brown, and clear fine-grained, clean and argillaceous halite, red fine-grained sylvinite, minor carnallite, reddish brown claystone, and grey anhydrite laminae. Individual sylvinite beds at Penobsquis and Clover Hill range from a few centimetres to 6 m in thickness but represent a relatively minor component of the total lithology. However, this is not the case at Millstream where four separate sylvinite beds and three zones of carnallitite have been intersected. The sylvinite beds range in thickness from 4 to 38 m and average between 22.4% and 27.5% K_2O (Webb 1994).

At Penobsquis, the top of the upper halite-sylvinite-carnallitite member is composed of thin, seldom exceeding 5 cm, beds of inclusion-rich, vertically oriented halite crystals draped with thin anhydrite laminae and scattered lenses of sylvite mineralization. At Clover Hill, this sequence may have been deposited, but the beds have been suberoded. The situation at Millstream differs markedly as the uppermost beds are massive and carnallitic. Another distinct feature of the heterogeneous upper halite-sylvinite-carnallitite member is the common and widespread occurrence of borate

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[1] Carnallite ($KCl.MgCl_2.6H_2O$) intermixed with halite (NaCl) is referred to as "carnallitite"

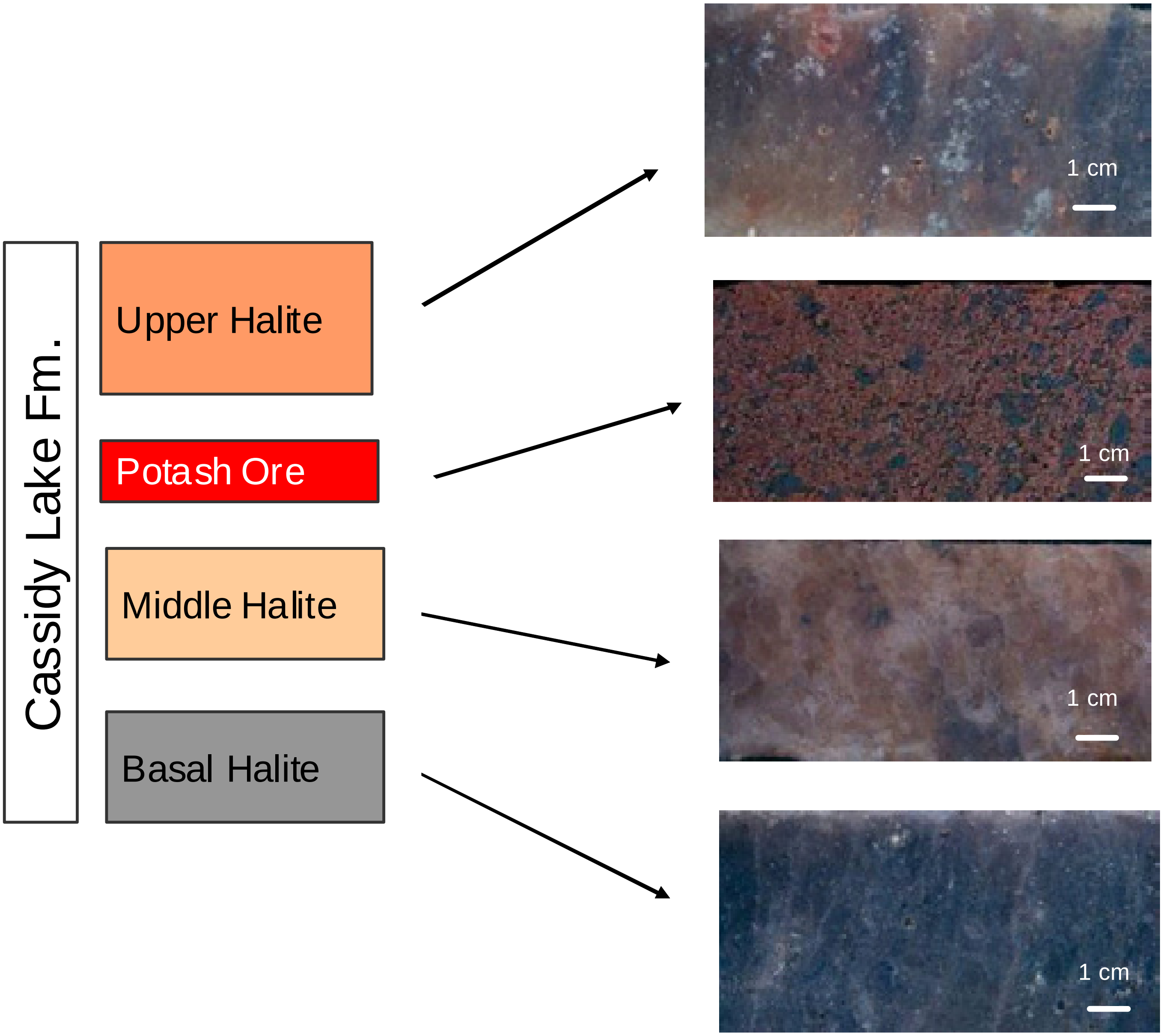


Figure 11. Chloride members of the Cassidy Lake Formation from the western half of the Moncton Subbasin, southern New Brunswick.

minerals. To date, fourteen mostly sodium enriched borates, have been identified and they generally occur in clusters ranging from a few millimetres to more than 5 cm in diameter. In contrast, an overlying sequence of sulphates, chlorides, and fine-grained clastic sedimentary rocks of the Clover Hill Formation mark the termination of Cassidy Lake chlorides in the Moncton and Cocagne subbasins.

The Pugwash Mine has only been intersected in three boreholes, two near Dorchester, and one at Copper Mine Hill. At Dorchester, 10 km east of basal Windsor exposures near Hillsborough, about 975 m of halite was intersected in a 1949 borehole drill by Shell Oil Company. Another borehole drilled in 1960 by Imperial Oil Limited 3 km to the south, intersected 795 m of halite with minor anhydrite and shale. St. Peter and Johnson (2009) suggest that comparable thickness in the two wells indicate a more or less tabular salt body in this area. Within the New Brunswick portion of the Cumberland Subbasin, the only subsurface evidence of the Pugwash Mine is a linear east west trending gravity low on the southern part of the Maringouin Peninsula (Gussow 1953; Chandra et al. 1982). At Copper Mine Hill, about 7 km east of Dorchester, a Columbia Natural Resources Canada Limited borehole, drilled in 2000, intersected 177 m of Pugwash Mine colourless to pink halite with zones of sulphate and claystone. This drilling indicates that the Pugwash Mine chlorides consist almost entirely of colourless to white halite salt with only minor crystals and thin stringers of sulphate. The halite is locally interbedded with minor red or reddish brown and lesser grey shales commonly containing halite hopper crystals, very rare grey and reddish brown sandstone, massive, fine- to medium-grained anhydrite, and rare dolomite. Due to the paucity of borehole control, the exact distribution and regional variation in thickness of the Pugwash Mine is a puzzle yet to be solved.

Both the upper and lower contacts of the Pugwash Mine in the Sackville Subbasin are interpreted to be gradational St. Peter and Johnson (2009). The formation conformably overlies Upperton sulphate and conformably underlies either the sulphate-chloride and claystone sequence of the Lime-kiln Brook Formation or the fine-grained clastic sedimentary rocks of the Mabou. As indicated previously, the chlorides and associated rocks of the Pugwash Mine occupy a stratigraphic position analogous to that of the Cassidy Lake in the western parts of the Moncton and Cocagne subbasins. The latter formation is presently being mined for its thick beds of potash-bearing chlorides (mainly sylvinite), which could imply that somewhere within the Sackville and Cumberland subbasins the Pugwash Mine may also contain potash.

Clover Hill and Lime-kiln Brook formations

Both the Cassidy Lake and Pugwash Mine formations are overlain, disconformably to conformably, by a mixed sequence of laterally equivalent, fine- to coarse-grained clastic sedimentary rocks, carbonates, sulphates, and chlorides. The distribution, thickness, and lithologies represented in this sequence are quite variable and imperfectly defined. In the western half of the Moncton and Cocagne subbasins, these rocks are referred to as Clover Hill Formation. Stratigraphically analogous rocks in the Sackville and Cumberland subbasins are referred to as the Lime-kiln Brook Formation.

In the Moncton Subbasin, the Clover Hill is quite variable from place to place. Having been intersected by several boreholes associated with potash exploration in the Sussex area, it is predominantly defined from subsurface data, and its distribution is considered “spotty” as it is completely absent in some boreholes. This “spotty” distribution is perhaps a function of non-deposition, or more likely, suberosion. Where it does exist, its thickness varies from 2 to 55 m (St. Peter 2006).

The Clover Hill contains up to three informal members, all of which are affiliated with the Penobsquis salt and potash deposit (Roulston et al. 1995). These members comprise: 1) a lower anhydrite; 2) a medial halite with anhydrite laminae; capped by 3) greyish green claystone. Since these rocks grade upward into fine-grained, terrestrial, clastics redbeds of the overlying Mabou Group, it appears the Clover Hill represents a marine, shallowing upward sequence (McCutcheon 1981). The Clover Hill-Mabou contact varies from conformable to unconformable because the Clover Hill has been suberoded to various degrees throughout the Moncton Subbasin. As a result, all members are not everywhere represented and its stratigraphic position may locally be occupied by “caprock”, a solution-collapse breccia comprised of angular anhydrite fragments, gypsum, and grey and red claystone in a grey and red, muddy matrix most likely derived from the dissolution and collapse of soluble members of the Clover Hill (Wilson et al. 2006).

In the Cocagne Subbasin, rocks in the same stratigraphic position as the Clover Hill in the Moncton Subbasin are exposed in the Petitcodiac and Havelock areas and have been intersected in boreholes at Millstream. North of Petitcodiac, the Clover Hill is represented by a 30 to 50 m thick unit of orangey brown to white, schistose, alabaster gypsum collapsed on an underlying, 150 m thick unit of white, massive Upperton gypsum and anhydrite. The absence of Cassidy Lake chlorides in this area is apparently due to dissolution (Webb 2001). Several kilometres northwest at Samp Hill near Havelock, strata equivalent to the Clover Hill are represented by an 8 to 10 m interval of interbedded carbonate wackestones, claystones, and fine-grained sandstones. The basal component of this interval is a muddied, intraformational conglomerate comprised of wackestone clasts in a mudstone to sandstone matrix, which McCutcheon (1981) termed the “Samp Hill beds”. He interpreted this interval as a Windsor (Cassidy Lake chlorides and Upperton sulphates) dissolution zone and argued that the dissolution subsequently caused Clover Hill strata to collapse on the underlying Gays River. However, a nearby northeast-trending, normal fault and the presence of adjacent dolomite indicated this zone could also represent a locally developed fault breccia accompanied by the dissolution of evaporites at depth. Upward migration of magnesium enriched brines along the proposed fault plane could account for replacement deposits of dolomite in porous and fractured Gays River carbonates adjacent the fault structure. St. Peter (2006) suggested McCutcheon’s “Samp Hill beds” term be abandoned and evaporite recommended including these rocks in the Clover Hill because they clearly overlie algal carbonates of the Gays River and are conformably succeeded by fine-grained redbeds of the Mabou.

At the Millstream potash deposit, the Clover Hill is comprised almost entirely of claystone and anhydritic claystone. At Penobsquis, it is comprise of basal anhydrite, medial halite, and claystone members overlying Cassidy Lake chlorides. It is unclear if the absence of anhydrite and halite at Millstream is due to non-deposition or chloride dissolution and weathering of basin-margin carbonate and sulphate deposits (Roulston et al. 1995). The upper claystone member is a common Clover Hill feature throughout southeastern New Brunswick and it marks the end of Windsor evaporite deposition in the Moncton and Cocagne subbasins.

The Lime-kiln Brook Formation is found in the Sackville and Cumberland subbasins of southeastern New Brunswick. It is stratigraphically analogous to the uppermost Clover Hill strata of the Moncton and Cocagne subbasins but, it is considerably thicker. In New Brunswick, the Lime-kiln Brook generally consists of predominantly non-marine, coarse- to fine-grained clastic sedimentary rocks with lesser amounts of marine carbonates (dolomite and limestone) and evaporites (sulphate and chloride). St. Peter and Johnson (2009) suggest the Lime-kiln Brook has a true thickness of 365 m.

There is no completely exposed section of the Lime-kiln Brook in New Brunswick. However, the upper part of the formation, a section of coarse-grained clastic sedimentary rocks and overlying carbonates, is exposed at Hopewell Cape near the Hopewell Rocks (Fig. 12a, b, c). Parts of the formation are also exposed on the west coast of Cape Maringouin (selenitic gypsum, carbonate, and fine-grained, clastic sedimentary rock) and near Hillsborough (gypsum and carbonate). The formation has also been intersected in boreholes in the Dorchester area where it consist of claystones, carbonates, sulphates, and chlorides conformably overlying chlorides of the Pugwash Mine Formation.

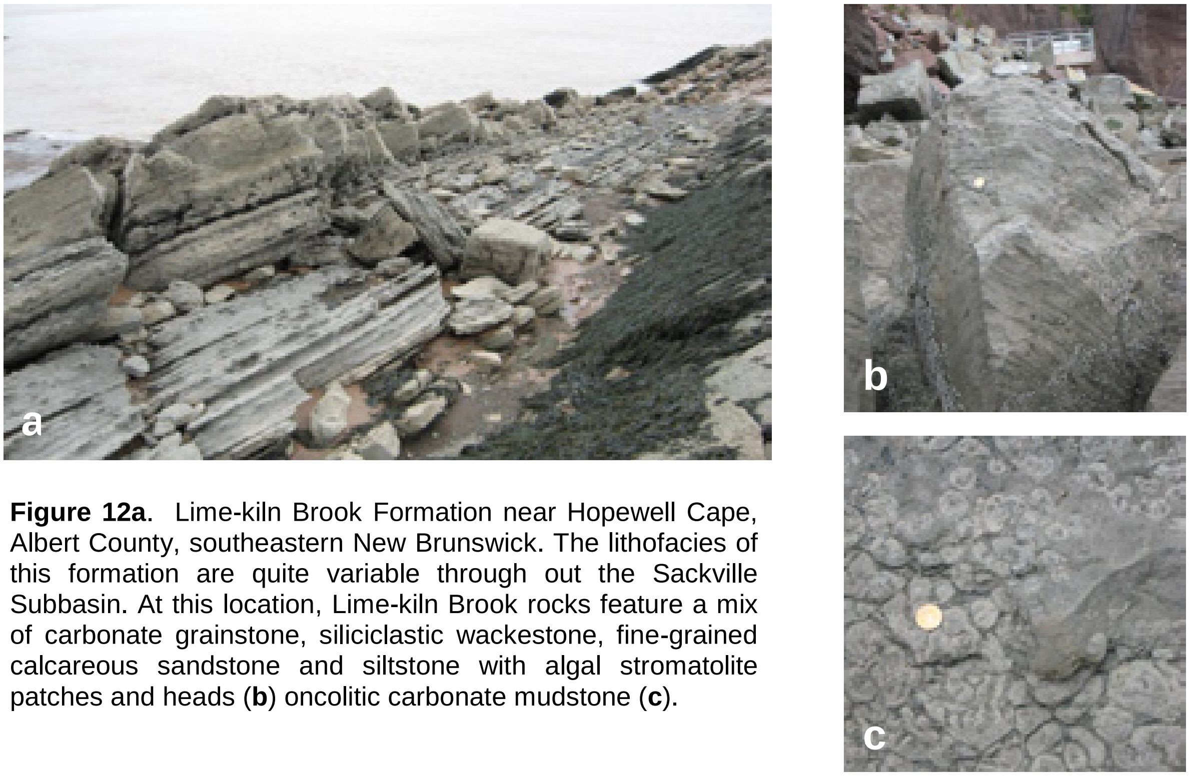


Figure 12a. Lime-kiln Brook Formation near Hopewell Cape, Albert County, southeastern New Brunswick. The lithofacies of this formation are quite variable through out the Sackville Subbasin. At this location, Lime-kiln Brook rocks feature a mix of carbonate grainstone, siliciclastic wackestone, fine-grained calcareous sandstone and siltstone with algal stromatolite patches and heads (**b**) oncolitic carbonate mudstone (**c**).

St. Peter and Johnson (2009) have divided the Lime-kiln Brook into three informal members in New Brunswick: 1) white to grey, massive to granular sulphates with minor carbonates (dolomite) and minor, very fine- to coarse-grained, clastic sedimentary rocks; 2) reddish brown and rare greyish green, coarse- to very fine- to medium-grained clastic sedimentary rocks; and 3) buff to light brown, grey fine- to coarse-grained fossiliferous, siliciclastic carbonates with reddish brown to greyish red and grey fine- to coarse-grained clastic sedimentary rocks, locally containing stromatolite heads.

In places, the Lime-kiln Brook is represented by a chaotic mix of brecciated carbonates and contorted sulphates suggesting local dissolution of chlorides and subsequent collapse of overlying strata (Fig. 13). The formation is gradationally overlain by coarse alluvial clastics sedimentary redbeds of the Hopewell Cape Formation (Mabou Group) and this relationship is best viewed at the south end of Hopewell Rocks. It is conformably underlain by evaporites of the Pugwash Mine. Similar to rocks of the Clover Hill in the Moncton and Cocagne subbasins, subsurface data suggests Lime-kiln Brook strata are not present everywhere and apparently give way laterally to and interfinger with fine-grained clastic sedimentary rocks of the Maringouin Formation (Mabou Group). It appears that the Lime-kiln Brook represents one or more Windsor marine cycles separated by terrestrial, clastic sedimentary rocks in this part of New Brunswick.

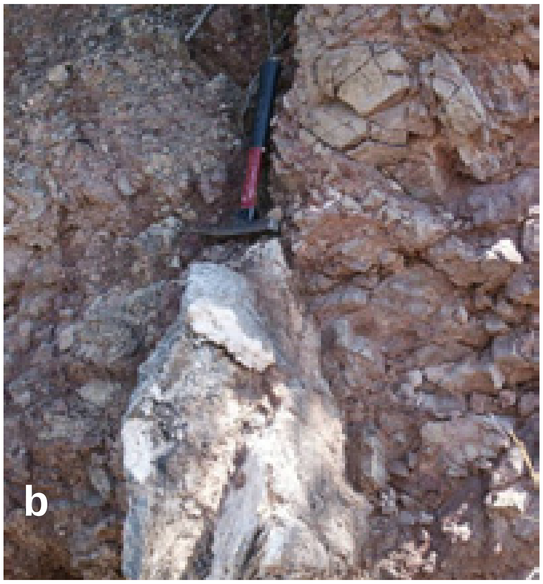


Figure 13. Brecciated, white to grey, massive to bedded sulphate with selenite porphyroblasts and grey massive micro-crystalline carbonate (dolomite) of the Lime-kiln Brook Formation. The deformed nature of these rocks suggest upward movement and dissolution of underlying salt of the Pugwash Mine Formation and subsequent collapse of the Lime-kiln Brook on Upperton Formation sulphates.

Photo **a** is from the west end of the former King quarry, southwest of Hillsborough, Albert County, southeastern New Brunswick and photo **b** is from the west coast of Cape Maringouin, Westmorland County, southeastern New Brunswick.

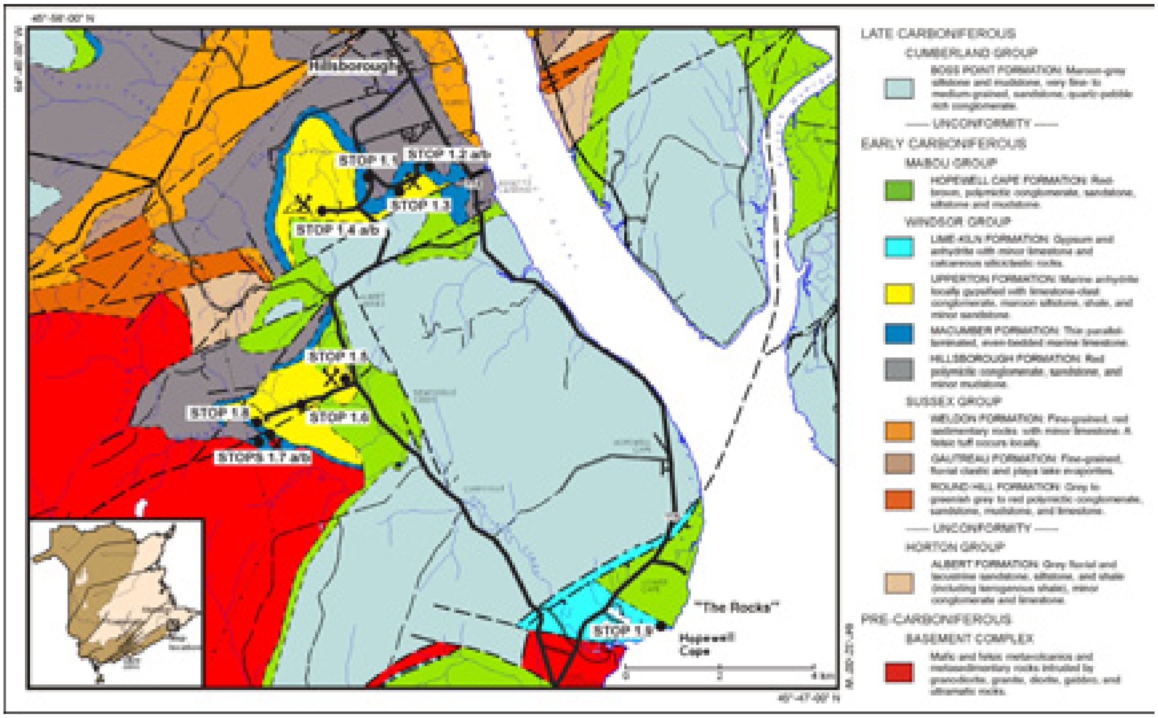


Figure 14. Geology of and Part 1 field trip stop locations in the Hillsborough-Hopewell Cape area, southeastern New Brunswick (geology after St. Peter and Johnson 2008).

STOP DESCRIPTIONS

Part 1: Windsor Group in the Sackville Subbasin…salt excluded (Fig. 14)

Stop 1.1: **Grant's Pass mini-covered bridge, 17th Hole, Hillsborough Golf Course - Hillsborough and Macumber formations**

Lat: 45 54' 02"N
Long: 64 38' 57"W

Total driving time from Fredericton to Stop 1.1 should be just under 2 hours (~210 km). From Fredericton head east on Highway 2 to the Moncton area (~150 km) and take exit 446 for Highway 128 to Riverview. At 6.9 km, turn left to merge onto Highway 15 and head west (~3 km) to the roundabout. At the roundabout, keep to the right and take the 2nd exit to cross the causeway to Riverview (~1 km). Proceed under the overpass and take the off ramp to Highway 114 and Fundy National Park (Hillsborough Road). Turn right on Highway 114 and proceed east-southeast (~25 km) to Hillsborough and the intersection of Highway 114 and the Golf Club Road (across from Railway Museum). Turn right onto the Golf Club Road and proceed to a fork in the road (~1 km). Grant's Pass mini covered bridge is on the right. Park at the intersection and walk to the bridge area (~3 minutes).

Cautionary Note: As guests of the golf course, please avoid walking on the putting surface and be respectful of play. Please, be careful and do not to get to close to the edge of the small cliff.

This Stop represents the bottom of the ancestral Windsor Sea. The base of the Windsor Group is very well exposed at this stop (Fig. 5a, 6a). The section dips to the north and basal, polymictic conglomerates of the Hillsborough Formation are overlain by laminated carbonates of the Macumber Formation.

The Hillsborough rocks exposed here are comprised of maroon, pebble to cobble conglomerates and minor coarse-grained to pebbly arkosic sandstones. The rocks are typical of an alluvial fan/braided stream depositional setting and the pebble and cobble compositions indicate a proximal source area, likely the Neoproterozoic basement terrain to the west. Including this terrestrial, coarse-grained, clastic sedimentary unit in the predominantly marine Windsor Group may appear to be misplacement. However, at this stop, the conformable contact with overlying Macumber strata clearly indicates the Hillsborough strata represent the early stages of a subsiding ocean basin, a fundamental component of the Windsor depositional cycle in New Brunswick (St. Peter 1993). Elsewhere in the Sackville Subbasin, Hillsborough strata either rest unconformably on and overstep older Carboniferous rocks or rest directly on basement.

About 4 m of Macumber carbonates overlie the Hillsborough at this stop and comprise thin, grey and dark grey, parallel-laminated to thin-bedded, allochthonous, siliciclastic wackestones and intraclastic to pelletoidal packstones. Fossils are rare but minor amounts of bioclastic debris (including fragmented brachiopod shells), foraminifera, and ostracods are visible in the packstone lithology. Macumber strata probably represent a deep-water, intertidal to sublttorial depositional setting below an active wave base. Platform and reef carbonates of the up-dip and laterally equivalent Gays River Formation are likely the source of the allochthonous, intraclastic carbonates and related bioclastic material.

Stop 1.2a: Brunswick Limestone Ltd. - Macumber Formation

Lat: 45 54’ 10”N
Long: 64 38’ 18”W

From Stop 1.1, proceed east (~1.4 km) on the King Quarry Road to the limestone quarry and fabrication facilities of Brunswick Limestone Ltd. near the eastern end of the former King gypsum quarry (Fig. 21).

Cautionary Note: Please wear your hard hat and eye protection. Watch your step and watch for moving equipment.

The uniquely laminated bedding style and colour variations of the Macumber carbonates make them a functional, desirable building and general purpose landscape stone. This stop features the stone processing facility of Brunswick Limestone Ltd. (Fig. 15). Specializing in limestone, flagstone, and related products, Brunswick Limestone Ltd. has operated a limestone quarry and processing facility since 2000. The company produces a wide range of natural stone products including: split and bed-sawn building stone; random shaped, square, and rectangular cut flagstone in various sizes (Fig. 16a, b, 17); random dry wall-stone and flagstone; and wall copping, stepping, stair tread, and armour stone. The products are marketed in two main colors: antique red (a variegated mix of dark red and greyish green stone) and antique green (a greyish green stone with tints of yellow and black). The products are tested to ensure they meet or exceed several key ASTM standards and certify their suitability for many applications.

Figure 15. Landscape and building stone fabrication facility (foreground) and quarry (background) of Brunswick Limestone Ltd. near Hillsborough, Albert County, southeastern New Brunswick.

Figure 16. The laminated even bedded nature and durability of Macumber Formation limestone make it a very suitable natural material for a wide range of construction stone products. Photo **a** shows pallets of processed flagstone and wall-stone typically used in landscaping and various building application. Photo **b** shows stone typically used for stepping stones, stair treads, and armour stones.

Brunswick's products are marketed throughout the Maritimes, eastern Canada, and parts of the United States. To ensure efficient, timely responses to product demand and to keep sufficient inventory on hand, the company operates year round. The company prides itself in total resource development and even utilizes the grout material from its processing plant as aggregate or agricultural lime. For more information on Brunswick Limestone Ltd., product specifications and related technical data, photo galleries, and contact information, please visit the company's website: http://brunswicklimestone.com.

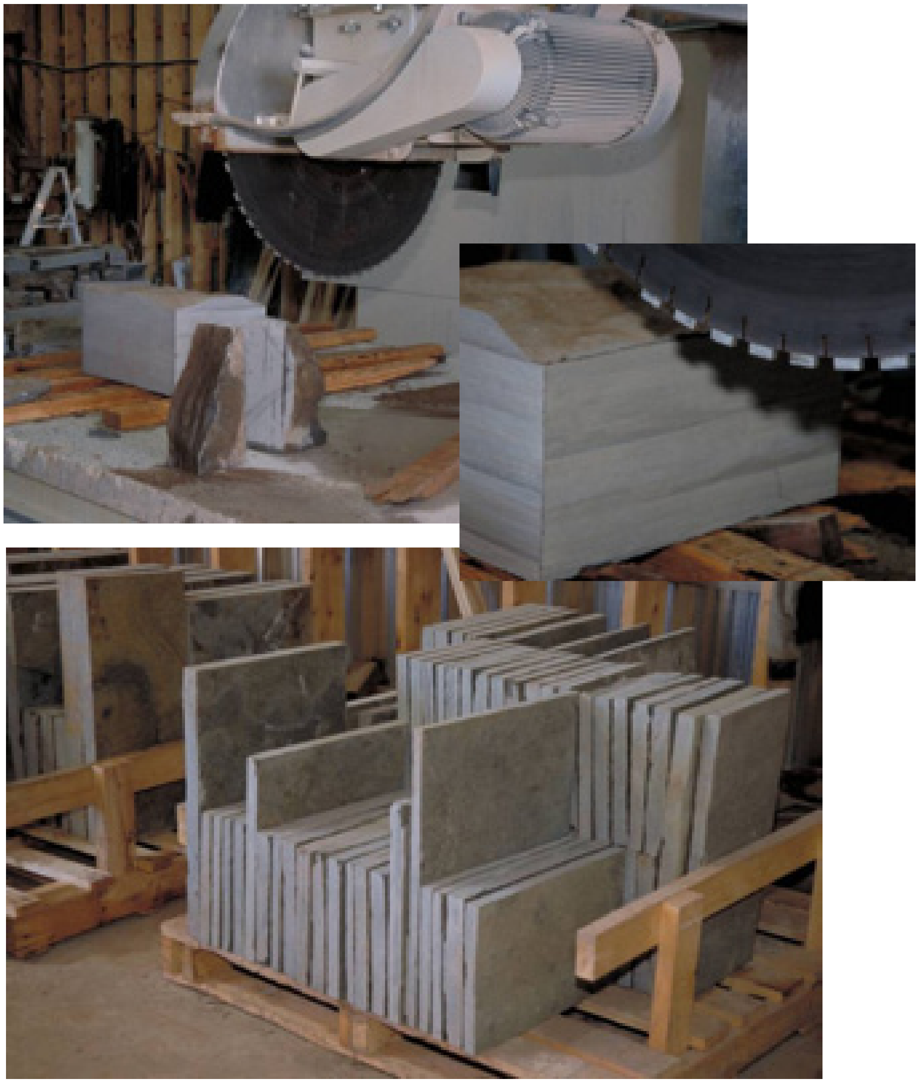


Figure 17. Using a selection of custom stone cutting and shaping equipment, including a computerized diamond rotary saw and hydraulic stone splitters, Brunswick Limestone Ltd. produces several cut and guillotined stone products in addition to variously sized, randomly shaped products.

Stop 1.2b: Former King gypsum quarry - Upperton Formation

Lat: 45 54’ 09”N
Long: 64 38’ 36”W

From stop 1.2a, proceed west (~200 m) from the Brunswick Limestone fabrication plant and observe (on the left) the reclaimed hanging wall of the former King gypsum quarry (Fig. 21).

Along the reclaimed wall of the former King gypsum quarry, immediately south of the Brunswick Limestone processing facility, remnants of white, red mud-stained gypsum and anhydrite of the Upperton Formation are visible. The distribution of these sulphate deposits throughout the Hillsborough area is quite variable. Anhydrite at this stop is generally dark bluish grey to light grey and is characterized by massive, laminated to nodular textures. In places, the anhydrite is extensively fractured and often filled with clear, selenitic gypsum. In other places, the anhydrite interfingers with gypsum.

The remnant gypsum deposits along the quarry walls are very white to light grey and typically massive to nodular with selenite crystals distributed throughout. The Upperton sulphate deposits in the Hillsborough area are the product of chemical precipitation in a shallow- to deep-marine basin setting (Fig. 18). The sulphate resources at this stop are a blend of primary gypsum and anhydrite, and secondary gypsum (derived from hydrated primary anhydrite) and limited recrystallization. It is suggested that, calcium sulphate crystals forming via evaporation would have gradually settled on the sea floor forming primary, very fine-grained, bedded to massive gypsum deposits in shallow water, coupled with thick sequences of laminar anhydrites in deeper water. A primary gypsum precipitate is not stable in a deeper water (i.e., elevated salinity and temperature) setting. Areas of gypsum containing randomly distributed selenite crystals appear to represent transitional zones between gypsum and anhydrite. In these transitional zones, the setting was deep enough to allow the formation and growth of selenite crystals, which subsequently sank to the bottom and were preserved in a finer grained “mush” of gypsum and anhydrite. Considerable portions of the gypsum resources in the Hillsborough area are secondary (Webb 2002a, b). The structural development of the Hillsborough area, with respect to syn- and post-Windsor faulting and associated fracturing, had a direct impact on the effectiveness of the hydration process and the spatial relationship between the gypsum and anhydrite deposits (Fig. 19).

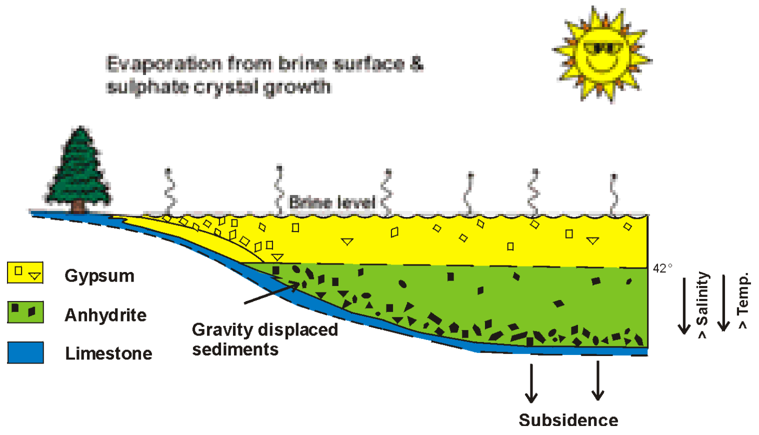
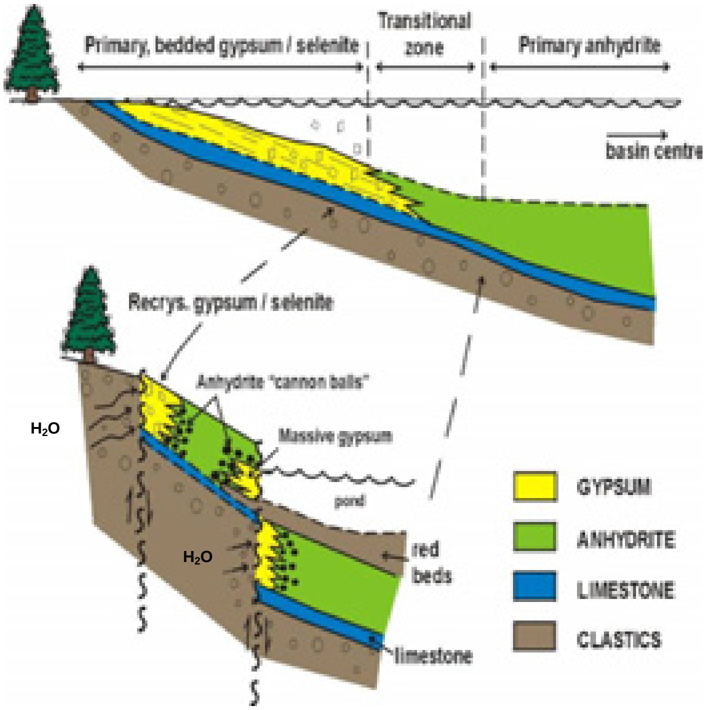


Figure 18. Proposed depositional model for primary calcium sulphate (gypsum/anhydrite) deposits, in the Hillsborough area, Albert County, southeastern New Brunswick (after Webb 2002a, b).

Figure 19. Proposed model for the formation of secondary gypsum deposits in the Hillsborough area of southeastern New Brunswick is, in part, linked to active fronts of hydration developed along fault planes and related fracture structures. Anhydrite "cannon balls" generally mark the outer limit of hydration zones (after Webb 2002a, b).



Stop 1.3: Former King gypsum quarry - Lime-kiln Brook (?) Formation

Lat: 45 54' 06"N
Long: 64 38' 48"W

From Stop 1.2b, head west (~0.6 km) to a rubble and boulder pile near the western end of the former King gypsum quarry (Fig. 21).

Cautionary Note: Please wear eye protection and watch your step. If you hammer the rocks, please be mindful of others in the vicinity. These anhydritic (with selenite crystals) and dolomitic rocks are very brittle and their brecciated nature supports many rough, jagged edges.

A mixed sulphate and carbonate exposure, atypical of the Upperton in the Hillsborough area, is exposed at the west end of the former King gypsum quarry. It consists of a rare anhydrite and dolomite breccia, occurring in a matrix of clear to white gypsum with abundant selenite crystals and veins (Fig. 20). The stratigraphic significance of this lithology is unknown and only generalizations can be made in regard to its distribution. One interpretation is that the breccia is a result of the dissolution of an underlying rock salt unit (Pugwash Mine Formation) and the subsequent collapse of an overlying, regressive, sulphate-dolomite sequence (Lime-kiln Brook Formation) onto a sulphate unit (Upperton Formation). In other words, the sulphate rocks in the King quarry are really the accumulation primary and secondary gypsum from two separate Windsor Group sulphate-bearing formations.

Figure 20. A mixed sulphate (anhydrite) and carbonate (dolomite) breccia, with abundant primary selenite crystals and secondary veins. These rocks are considered part of the Lime-kiln Brook Formation, and are found in the former King gypsum quarry, about 1 km west of Edgetts Landing, Albert County, southeastern New Brunswick.

The complex sulphate stratigraphy at this quarry resulted in various development challenges. The King Quarry (Fig. 21) was the last gypsum excavation in the Hillsborough area worked by the Canadian Gypsum Company and was plagued with several grade control issues and high quarrying and production costs. Grade inconsistency, a consequence of anhydrite contamination and elevated chloride levels in the gypsum feedstock, which in turn lead to considerable imperfections in the board product, resulted in high reject-to-product ratios and high manufacturing cost for a nearby wallboard plant. In the early 1980s, after nearly 130 years of almost continuous operation, Hillsborough's plaster and wallboard industry folded due to deteriorating market conditions and other logistical challenges.

Figure 21. The former King quarry, the last gypsum quarry to operate in the Hillsborough area, is about 1 km west of Edgetts Landing. (circa. 1978)

Stop 1.4a: Exposed underground workings of a former gypsum mine - Upperton Formation

Lat: 45 53’ 48”N
Long: 64 39’ 34”W

From the Stop 1.3, head west (~1 km) back to the Golf Club Road, turn left and proceed to intersection with the New Road (~0.8 km). Keep heading west (~400 m). The former quarry workings are on the left just past the gated barrier. Stop 1.4a is < 200 m west and south of quarry road.

Cautionary Note: Stay close to designated pathway. Watch where you walk and be aware of small depressions, open cracks and other obstacles. Ground conditions may be unstable after the spring thaw.

In the early mining days, gypsum was generally extracted from exposed hillside locations. Eventually, operations expanded into areas requiring the removal of several metres of overburden in order to expose the gypsum ore. Given the lack of portable, earth moving equipment with the capability to efficiently remove thick overburden; other methods of extraction were pursued. The massiveness and thickness of the gypsum resource made it suitable for underground mining using a basic “room and pillar” recovery method whereby basic hand tools and “black powder” explosives extracted gypsum ore from open stopes. The stopes varied in size but generally consisted of 50 to 100 m^2 rectangular rooms several metres high separated by circular to square pillars of ore that supported the roof or “hanging wall” (Fig. 22). Old mine plans for this area indicate that attempts were made to arrange rooms and pillars in regular patterns. Numerous cave-ins and related accidents occurred due to the instability of the roof rocks. By the 1940’s, mishaps were minimized with the introduction of rock bolting, a process that reinforced the roof’s structural integrity. When equipment availability increased after World War II, improved mining equipment replaced hand tool and “black powder” explosive extraction practices.

Quarrying on top of former underground operations coupled with freeze-thaw cycles in areas of thin cover occasionally resulted in roof or “crown collapse” into underlying mined rooms (Fig. 22). A collapse feature and partial underground network of mined-out rooms and gypsum pillars are observable at this stop. Several collapse structures, varying in diameter from a few to several tens of metres, are present in this area. Sometimes, they remain dry and are in-filled with collapsed rock, glacial till, and vegetation. Other times, they are filled with surface water run-off or with ground water flowing through the old underground workings.

Stop 1.4b: “Fore!” A former gypsum quarry reclaimed to a signature golf hole (14th) at the Hillsborough Golf Course - Upperton Formation

Lat: 45 54’ 08”N
Long: 64 39’ 43”W

From Stop 1.4a, return to the parking spot and proceed north (< 100 m) on the golf course access road, past the gate, then left to the 14th tee.

This stop features a unique reclamation symbolizing the heritage of former gypsum mining activities in the Hillsborough area. Established in the “gut” of a former gypsum excavation, the 14th hole presents golfers with a very picturesque challenge (Fig. 23). This hole is one of several on this 18-hole layout that effectively incorporates natural and man-made exposures of gypsum into one of the most scenic golf courses in this area of New Brunswick.

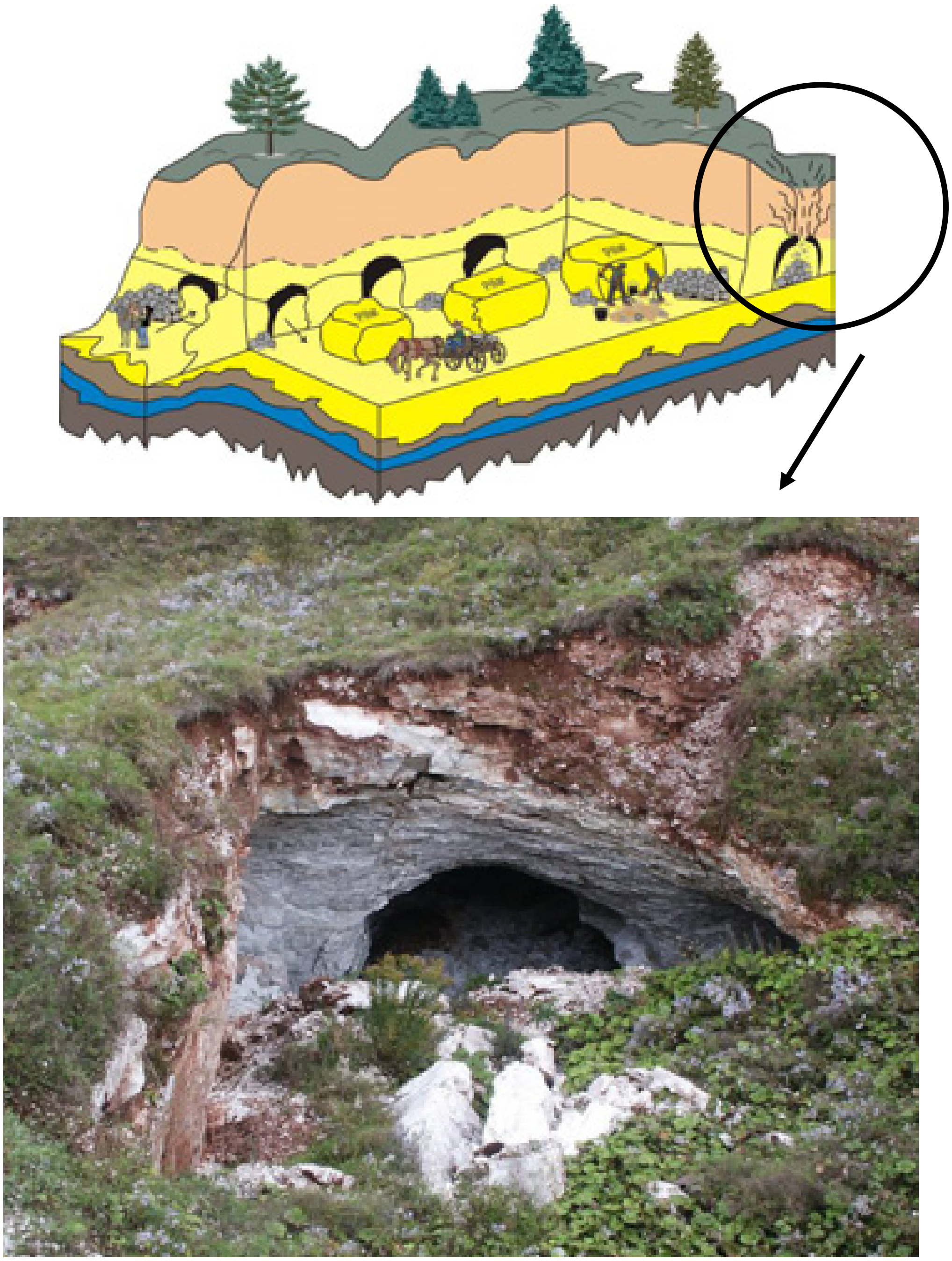


Figure 22. Partial crown collapse, exposing supportive pillars over former underground gypsum workings near Hillsborough, Albert County, southeastern New Brunswick

Figure 23. This signature golf hole, the 14th at the Hillsborough Golf Course, has been established in the “gut” of a former, reclaimed gypsum quarry.

Stop 1.5: Former Canadian Gypsum Company Demoiselle Quarry - Upperton Formation

Lat: 45 51’ 54”N
Long: 64 39’ 47”W

From parking area of Stop 1.4b, head back to the intersection the quarry road make with New Road, turn right, and proceed to the Albert Mines Road. Turn right and proceed to the gate of the former Demoiselle quarry (~2.75 km).

Cautionary Note: Please wear eye protection and watch your step as you move about the quarry. If you hammer the rocks, please be mindful of others in the vicinity.

This quarry stop features white, alabaster gypsum and bedded anhydrite of the Upperton Formation. Note the selenite occurring as secondary veins, as tabular and radiating crystal porphyroblasts, and as "rosette" crystal aggregates distributed randomly throughout the exposure (Fig. 24). Selenite mineralization and massive gypsum are likely the result of scattered primary gypsum deposition and the subsequent hydration of primary anhydrite along two east west tending fault zones.

Figure 24. Gypsum rosettes consisting of intergrown, thin-bladed selenite crystals radiating outward from a central core. Crystal aggregates are set in a matrix of massive alabaster gypsum, at the former Demoiselle gypsum quarry.

Stop 1.6: Anhydrite cliff section along Wilson Brook - Upperton Formation

Lat: 45 51’ 33”N
Long: 64 40’ 53”W

Return to the gate at Stop 1.5, turn right, and proceed ~300 m. Turn right onto the Underground Lake Road. Proceed ~1.1 km until white sulphate cliffs come into view on the left side of road. Park and hike ~0.5 km through light forest to Wilson’s Brook and its adjacent white escarpment.

Cautionary Note: Due to potential instability of the cliff face, it is imperative that all participants wear their hard hats at all times and remain on the north side of Wilson Brook. Participants are also asked to respect the fact that this stop is within the Wilson Brook Protected Natural Area… no sample collecting, please.

The white cliff marking the western bank of Wilson Brook is an excellent example of a structurally controlled hydration front. The sulphate rocks of the cliff face are variable mix of primary anhydrite and secondary gypsum (Fig. 25).

The anhydrite is generally dark bluish-grey to light grey and is typically bedded with nodular zones a few metres thick. Nodules, referred to as cannonball structures (see page 39), range from a few centimetres to a few metres in diameter (Fig. 25, 26). These structures frequently occur in a gypsum matrix and are interpreted to indicate: 1) the outer limits of a hydration front (where anhydrite has been incompletely converted to gypsum) and 2) proximity to a structural feature (a fault or related zone of fracturing).

The variable distribution of gypsum and anhydrite in the Wilson Brook area is reflected in the development of unique landscape features collectively referred to as “karst” (see page 39). The irregular, hummocky topography is characterized by many closely spaced depressions (sinkholes), cave systems (including a 240 m^2 underground lake), stream-less valleys, and disappearing streams and springs. All of these features are a result of surface and ground water interaction with the soluble sulphates and related carbonates. The karst at this stop and reports of an unusual collection of arctic vegetation on the cliff face warrant the site’s inclusion within the Wilson Brook Protected Natural Area.

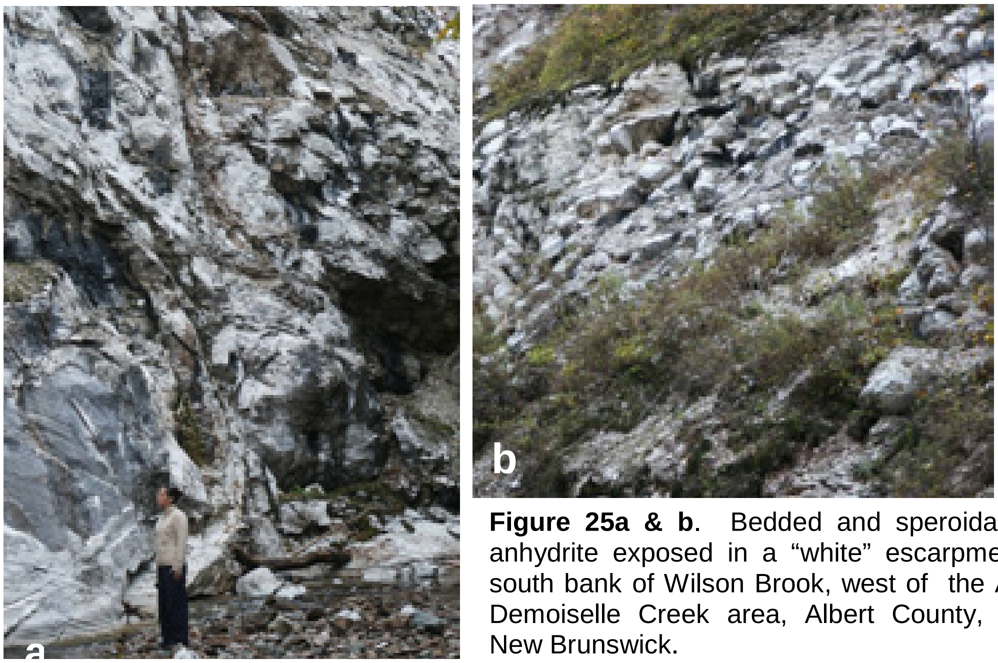


Figure 25a & b. Bedded and speroidal gypsiferous anhydrite exposed in a “white” escarpment along the south bank of Wilson Brook, west of the Albert Mines-Demoiselle Creek area, Albert County, southeastern New Brunswick.

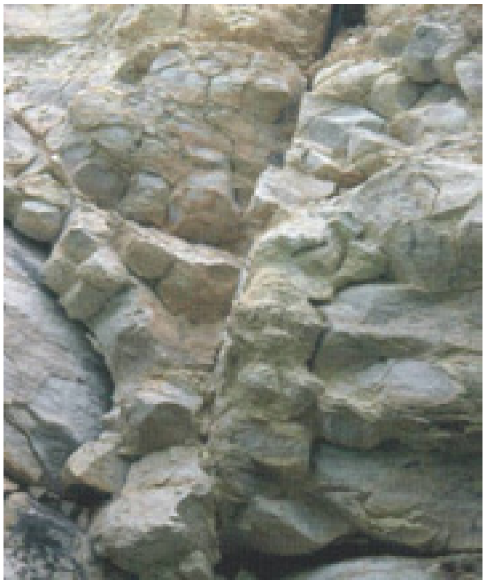


Figure 26. Cannonball sulphate structures comprised of anhydrite cores surrounded by an exfoliated gypsum crust. An in depth explanation for the formation of these peculiar structures is presented on page 39.

Figure 27. The formation of spherical sulphate (anhydrite/gypsum) structures, referred to as cannonballs, results from the subsurface chemical weathering (hydration) of anhydrite. Concentric shells of hydrated gypsiferous rock are successively loosened and separated from a block of anhydrite as water penetrates bounding joints or fracture systems and attacks the block from all sides. These structures indicate proximity to significant water bearing fault zones and mark the outer limit of hydration fronts in the Wilson Brook-Demoiselle Creek area, Albert County, southeastern New Brunswick (after Webb 2002a, b).

Stop 1.7a: Former aggregate quarry in the Wilson Brook area - Gays River Formation

From Stop 1.6, proceed west (~0.7 km) to a sharp right turn on the Underground Lake Road (Lat: 45 51’ 28”N / Long: 64 41’ 14”W). Park and follow a south blazed property line, which merges into a trail, for ~450 m. You will cross two small brooks on this route. Several metres past the second brook walk up the steep embankment to the former quarry (Lat: 45 51’ 15”N / Long: 64 41’ 08”W).

Cautionary Note: When walking the property line, please watch your step. Moss covered rocks and surficial tree roots are slippery and easy to trip over. Watch out for the remnants of a barbed wire fence. Please, stay together as a group.

Algal boundstones and thinly bedded wackestones of the Gays River Formation unconformably overlie Neoproterozoic granitoid rocks in this former aggregate quarry. A thin basal regolith breccia containing abundant granitic clasts marks the contact. The boundstones contain laterally linked, low domal stromatolites whose vuggy porosity is characteristic of an intertidal depositional environment. Numerous vugs are filled with a tar-like kerogen (Fig. 28) likely derived from down-dip, basinal Macumber Formation carbonates or from the older hydrocarbon-rich Horton Group rocks. Minor copper mineralization and anomalous amounts of lead and zinc are reported from this exposure.

Figure 28. Stacked algal mounds of the Gays River Formation, resting on a pinnacle of basement at a former quarry in the Wilson Brook area, west of the Albert Mines-Demoiselle Creek area, Albert County, southeastern New Brunswick

Stop 1.7b: Unnamed Wilson Brook tributary - Gays River and Macumber formations

Lat: 45 51’ 15”N
Long: 64 41’ 08”W

From Stop 1.7a, backtrack to brook and head up-stream to a fork in the stream bed (~70 m). Take the right-hand fork and continue to the mini-canyon and “Lost Brook Cave” system (~75 m).

Cautionary Note: Please, watch your step. The rocks in the stream bed and on adjacent banks are very slippery. Stay back from the edge of “Lost Brook Cave” canyon.

The facies relationship between platform Gays River algal boundstones and basinal Macumber carbonates is clearly displayed in the 9 m high cliff walls of this 79 m long “Lost Brook Cave” system (Arseneault et al. 1997). As you move up section, the carbonates at the base are overstepped by algal boundstones. Thick intraformational breccias and wackestones containing debris shed from the algal build-ups are interlayered with the carbonates down-dip from the boundstones.

Stop 1.8: Remnants of a former field kiln - Macumber Formation

Lat: 45 51’ 15”N
Long: 64 41’ 08”W

From Stop 1.7b, return to the parking area of Stop 1.7a and follow a southwest-trending trail through an old apple orchard to a small stream (~350 m). The former field kiln is < 50 m upstream.

Cautionary Note: Please, watch your step. The rocks in the stream bed and on adjacent banks are very slippery.

This stop features the remnants of a late 19th - early 20th century field kiln made from nearby Macumber limestone. This kiln (Fig. 29a) is a very good example of how the early farming community utilized local limestone resources for building purposes (mortar, plaster and whitewash), as an amending agent to control soil acidity (lime), and for sanitation purposes. This type of kiln was built, using available fieldstone, into a hillside and generally had a wagon path to its top. Alternating layers of wood, or other fuel, and hand-crushed limestone (the “charge”) were loaded into the top of the kiln, forming successive, dome-shaped layers on basal grate bars above the “eye” adjacent the draft or draw tunnel (Fig. 29b). After loading, the kiln bottom was lit and the fire gradually spread up through the charge. After burning for several hours to few days, and after sufficient liberation of carbon dioxide (CO_2) from the limestone, a crude lime product filtered through the basal grate to the hearth below. The lime was then drawn out of the tunnel and often hydrated.

This type of field kiln was often hazardous. Workers had to be cautious and avoid slipping and falling into them, and being asphyxiated by the deadly CO_2 fumes. Kilns were common on small farms in areas underlain by limestone. Many operated until the late 1800s when large commercial kilns near Saint John began mass producing and transporting lime throughout southern New Brunswick and the northeastern United States.

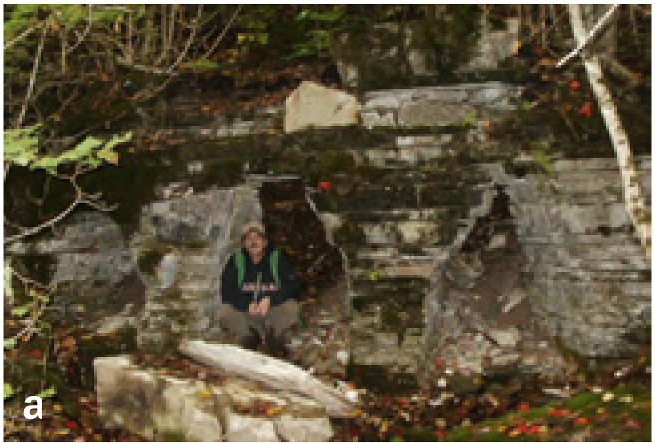
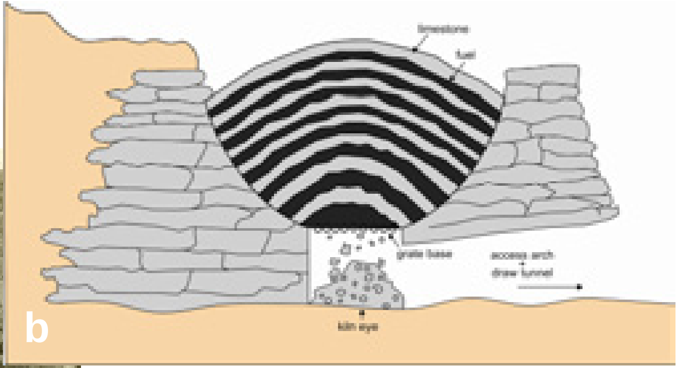


Figure 29a. Remnants of a late 19th - early 20th century field kiln in the Wilson Brook area, west of Demoiselle Creek, Albert County, southeastern New Brunswick.
29b. Sketch illustrating how a field kiln, like the one in shown in 29a, operated.
29c. The kiln operated in Wilson Brook area was probably a similar set up to this one near Wapanucka, Oklahoma (circa. 1909) (after Krukowski 2007).



Stop 1.9 Hopewell Rocks Ocean Tidal Interpretive Centre - Lime-kiln Brook Formation

Lat: 45 51’ 15”N
Long: 64 41’ 08”W

From stop 1.8, return to the parking area of Stop 1.7a and head back to the Albert Mines Road near Demoiselle Creek. Turn right and proceed (~8 km) to its intersection with Highway 114 near Cape Station. Turn left on to Highway 114 and follow signage to the parking lot of the Hopewell Rocks Ocean Tidal Interpretive Centre (~13 km). From the main parking area, make way to the shuttle station for transport to the beach access area. Several flights of well-constructed stairs provide time saving access to the beach area. Although use of these stairs is restricted in late fall and winter, the beach remains accessible at the north end of a lower parking area or by hiking a trail to Demoiselle Beach. Once on the beach, hike south (~0.9 km) to the “Ledges”. ***Note****: during the spring and summer months, a reasonable admission fee is charged to access beach and the grounds and services associated with the interpretive centre.*

Special Note: This stop is only accessible at low tide. Check appropriate tide table data to ensure its availability during the field trip itinerary. Please refer to Hopewell Rocks (2008) for more information.

Cautionary Note: Rocks often fall from the steep cliff face. Stay back from the face as much as possible and do not walk inside the cordoned-off areas.

This stop features several contrasting lithologies of the Lime-kiln Brook Formation (the upper most strata of the Windsor Group in southeastern New Brunswick) and the Formation’s contact relationship with the overlying, predominantly coarse-grained, clastic rocks of the Hopewell Cape Formation (Mabou Group). The “flower pot” rocks observable here, more commonly known as the Hopewell Rocks, are assigned to the Hopewell Cape Formation. For more information on this unique natural wonder, please refer to the following: Trenhaile et al. (1997) and Hopewell Rocks (2008).

The following description of the Windsor rocks at Hopewell Cape is adapted primarily from St. Peter (2003).

The Hopewell Cape section on the west shore of Shepody Bay lies within a fault block on the western margin of the Sackville Subbasin. A major regional fault, the Harvey-Hopewell Fault, defines the ancestral margin of the Subbasin several kilometres to the northwest. The Carboniferous succession in the fault block comprises the Lime-kiln Brook Formation of the Windsor Group and conformably overlying Hopewell Cape Formation. The strata at the Hopewell Cape section strike at 110 and dip 30 to the northeast, almost at right angles to the interpreted ancestral basin margin.

The oldest beds of Lime-kiln Brook Formation within the fault block are sulphates (gypsum and anhydrite), associated minor red mudstones, and marlstones. Sulphates are found in a northeast-trending wedge, on the northwest side of the block, bound by the Harvey-Hopewell Fault and a related parallel splay. Although they are not exposed, sulphates probably occur down-section as well, southwest of Hopewell Cape. Low, marshy ground in the area, and an extrapolation of similar stratigraphy several km southwest of Shepody Marsh, support this interpretation.

Although the contact is not exposed, it is interpreted that the sulphates in this area are overlain by predominantly red, coarse-grained, clastic sedimentary rocks. These sediments are exposed at the south end of the Hopewell Cape section and consist of reddish brown, polymictic, pebble-cobble, sandy-matrix conglomerates; reddish brown, medium-grained to granular and pebbly lithic sandstones; minor fine reddish brown, to medium-grained, parallel- and ripple-laminated sandstones; minor greyish green to grey siltstones and mudstones (Fig. 12a). These clastic rocks are conformably succeeded by two tongues of grey rocks, predominately marine limestone. An intervening unit of coarse-grained, red clastics, indistinguishable from the underlying clastic unit, separates the two limestone tongues.

A reddish brown and greyish green (at the top), very fine-grained sandstone to mudstone with minor granule to pebble conglomerate marks the base of the lower limestone tongue, which at this point in the section has a thickness just over 2 m. These clastics are conformably followed by an 80 cm interval of very thinly bedded, grey, siliciclastic limestone with minor oolite and ostracod fragments, which is followed by a calcareous sandstone and kerogenous siltstone capped by thin unit of olive-grey mudstone. The top of the olive-grey mudstone marks the top of the lower limestone tongue.

A few tens of metres east and along the strike of the above section, the lower limestone tongue’s thickness is increased, three-fold. There, the section contains mostly carbonate grainstones and wackestones with some calcareous siliciclastic sandstones and siltstones. Wave-formed ripples and spectacular patches and heads of algal stromatolites are quite common (Fig. 12b, 30). The lower limestone tongue is overlain by several metres of interbedded, reddish brown, course- and fine-grained, clastic sedimentary rocks. These sediments are conformably overlain by an upper unit, which on the tidal platform is about 12 m thick, comprised of grey non-calcareous sandstones, dark grey, siliciclastic wackestones and grainstones with algal stromatolite masses and wave-formed ripples, and grey, oncolitic carbonate mudstone (McCutcheon 1981). The limestone tongues and intervening clastic rocks are among the youngest Windsor Group strata exposed in southeastern New Brunswick (St. Peter 2003).

The upper grey unit is conformably overlain by reddish brown, coarse-grained, clastic sedimentary rocks of the Hopewell Cape Formation. The Hopewell Cape is comprised of reddish brown, pebble to large cobble, polymictic conglomerates, coarse-grained to pebbly lithic sandstones, and minor finer grained sandstones and red mudstones. The conglomerates are mainly clast-supported, with a sandy or gritty matrix. The clasts are predominantly plutonic rocks; granite, granodiorite, and gabbro. Conglomerate and sandstone beds are commonly lenticular, and cut-and-fill structures are abundant. Sandstone beds terminate abruptly and are often surrounded by conglomerate.

Figure 30. Stromatolites, sometimes called "cabbage heads" are among those enduring structures recording some of the earliest evidence of life on Earth. They are not fossils of living creatures but are instead traces of structures created by living algal organisms. These peculiar structures are typically preserved as layered carbonate rock in the form individual and linked domes and cylinders of variable size. They are essentially composed of thin, sticky layers or mats of algae that have frequented shallow, warm bays and inlets throughout geologic time. Their sticky substrate often trapped particles of carbonate and other terrestrial sediment from waters flowing across their surface eventually obscuring sunlight, a very necessary component of photosynthesis, a process on which its survival depended. This build up required the algae to grow up and through carbonate mush forming a new sticky algal mat on top. The repetition of this process has resulted in the sizeable layered and inter linked domes and inverted pyramidal structures seen here at Hopewell Cape.

THE BAY OF FUNDY EXPERIENCE - POINTS OF INTEREST

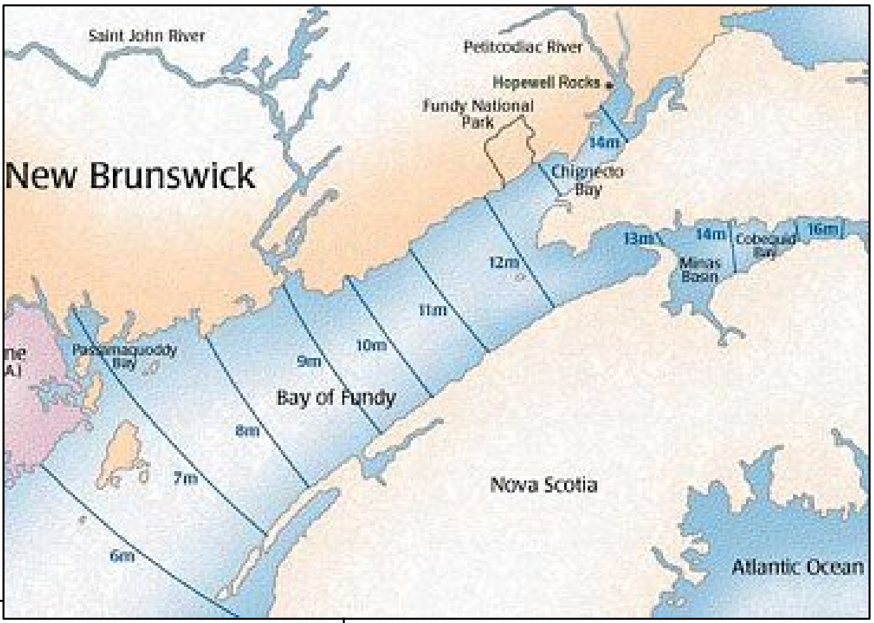
Walking on the ocean floor - the world's highest tides

Field trip participants are reminded that they are literally walking on the sea floor at Stop 1.9. In 8 to 9 hours, the rocks there the will be submerged under several metres of sea water. Tides are generated by the Earth's rotation and the gravitational pull of the sun and moon. Two unique Bay of Fundy characteristics combine with those forces to generate the world's highest tides. The first is topography; the second is the rhythmic movement of water.

The Bay trends northeast over a distance of 290 km and its mouth, up to 100 km wide, varies in depth from 120 to 215 m gradually narrowing and shallowing to the northeast. Near Hopewell Cape, the Bay is about 2.5 km wide and a 14 m deep, at low tide. The gradual narrowing and shallowing constricts the water flowing into the bay thereby causing a notable rise in the tide (Fig. 31a, b). Bay tides rise and fall between 10 and 14 m, the average height of a four story building, and are 14 times greater than the world average. At Stop 1.9, you can watch the tide rise up to 2 m/hour as nearly 100 billion tonnes of salt water flows in and out of the bay with force equal to that exerted by 8000 locomotives or 25 million horses. The powerful rise and fall, ebb and flow, action of this twice-a-day, daily routine has eroded the Hopewell Cape Formation conglomerates and sandstones forming the abovementioned "flower pot" rocks, which are curiously named "Mother-in-Law", "Lover's Arch", "ET", "Bear", "Apple", and "Diamond".

Every basin of water has its own natural rhythm. The time it takes the tide to flood the Bay of Fundy is roughly equal to the time it takes the tide to come in from the North Atlantic Ocean via Gulf of Maine to the southwest. Analogous to the wave action produced by sloshing water back and forth in a bathtub, the match between the ocean rhythm and the Bay rhythm amplifies the tide.

Figure 31a. Illustration marking the high tide ranges (in metres) from southwest to northeast for the Bay of Fundy in Atlantic Canada (after Hopewell 2008).



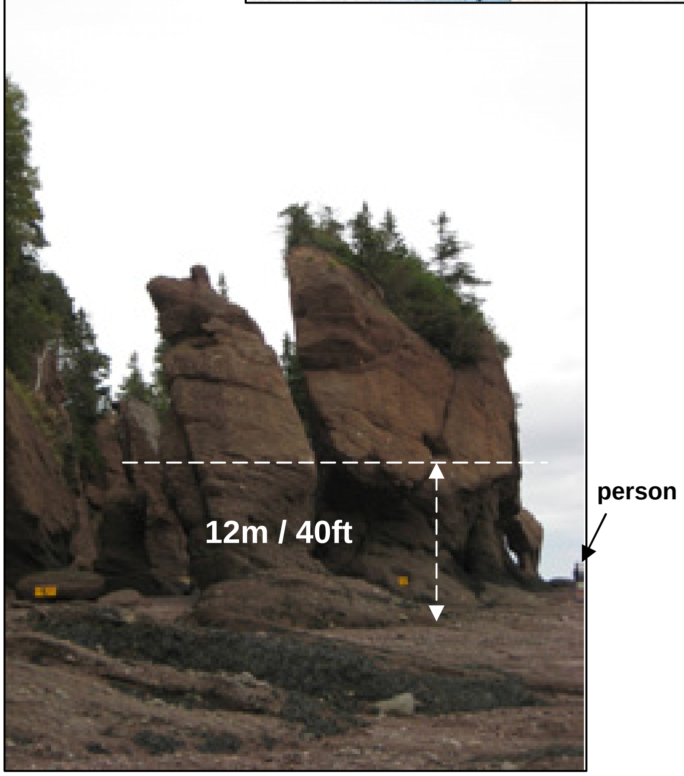


Figure 31b. The gradual tapering and shallowing of the Bay of Fundy to the northeast constricts its tidal flow, causing water to rise from the global average high tide of 1 m to the 16 m tidal range commonly recorded near the head of the bay. Note the person for scale.

Chocolate waters

The Bay of Fundy’s “chocolate” waters (Fig. 32) are another feature unique to the area. For millions of years, moving water has eroded the reddish mudstone, sandstone, and conglomerate cliffs along the upper reaches of the Bay. Small particles of sand and mud, rust-stained by iron compounds originally binding them together as rock, have accumulated on beaches and at the mouths of numerous river systems discharging their suspended, sediment-laden loads in the northeastern part of the Bay. With each rise and fall of the tide, the rust-stained accumulations of sediment swirl and mix in shallow, nearshore waters and form an almost permanent, suspended mix of rust-stained, mud-laden water.

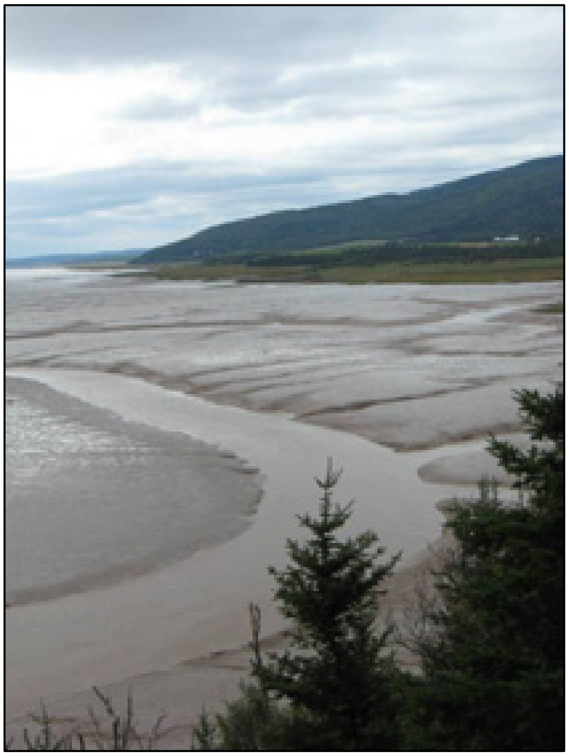


Figure 32. A view of the Hopewell mud flats and adjacent chocolate brown waters of Shepody Bay at Hopewell Cape, near the head of the Bay of Fundy, southeastern New Brunswick

The soft, coastal, sedimentary rock exposures that line the upper reaches of the Bay succumb to the solutioning and freeze-thaw affects of water, dissolving and cracking quite easily. This is readily witnessed at Hopewell Cape where the rocks have been shaped into rather bizarre “flower pots”. In this part of New Brunswick, crustal rebound, in the aftermath of the last regional glacial event, is a major contributing force to a fast rate of erosion and local coastal instability.

Karst topography

Very irregular land surface features, collectively referred to as "karst", are common throughout the eastern half of New Brunswick's Albert County. This unusual topography (Fig 33.) is a result of surface and ground water interaction (solution and erosion) with the extensive gypsum (sulphate) and limestone (carbonate) deposits underlying the area and is best observed adjacent the road to Albert Mines north (~1.5 km) of the Albert Mines Road-Highway 114 intersection, west (~3 km) of the Hopewell Rocks Ocean Tidal Exploration Site. Interconnected, underground caverns of variable size and extent have formed. The cavern roofs are usually formed of rock able to resist the solvent action of the water; however, they occasionally collapse, and typically create funnel-shaped depressions or sinks (sinkholes). These sinks eventually fill with debris or serve as collection sites for ground water thereby forming circular-shaped, ponds.

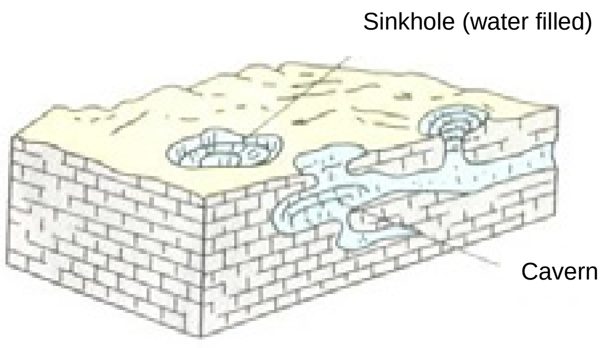


Figure 33. Water-filled and dry sinkholes and networks of underground caverns are common features of karst landscapes.

Cannonball structures

The formation of anhydrite/gypsum cannon-ball structures (A) is analogous to a form of exfoliation. This process (Fig. 34), which involves the formation and separation of successive, concentric layers of hydrated (gypsiferous) material around an anhydrite core, frequently occurs in rock cut by intersecting joints and fracture systems adjacent fault structures. Joints and fractures provide avenues for the movement of water, which slowly attacks separate fractured- or joint-bound blocks of anhydrite from all sides (B). The moisture penetrating these fragmented masses of anhydrite remains long enough for hydration and the subsequent formation of gypsum. Because the depth of hydration is greater at corners and edges than it is along flat surfaces (C), a spherical-shaped shell of gypsum is formed (D). Hydration is accompanied by an increase in rock volume. This sets up forces within the rock that cause gypsiferous layers to separate from the main anhydrite mass. A fresh hydration surface is established and the gypsification (anhydrite hydration) process is repeated again and again until equilibrium in pressure is established between the inner hydrating anhydrite core and the perimeter of the cannon-ball structure. Each successive layer surrounding the anhydrite becomes more spheroidal than its outer neighbor, until the original anhydrite block is transformed into an onion-like structure of concentric shells of residual gypsiferous material (D).

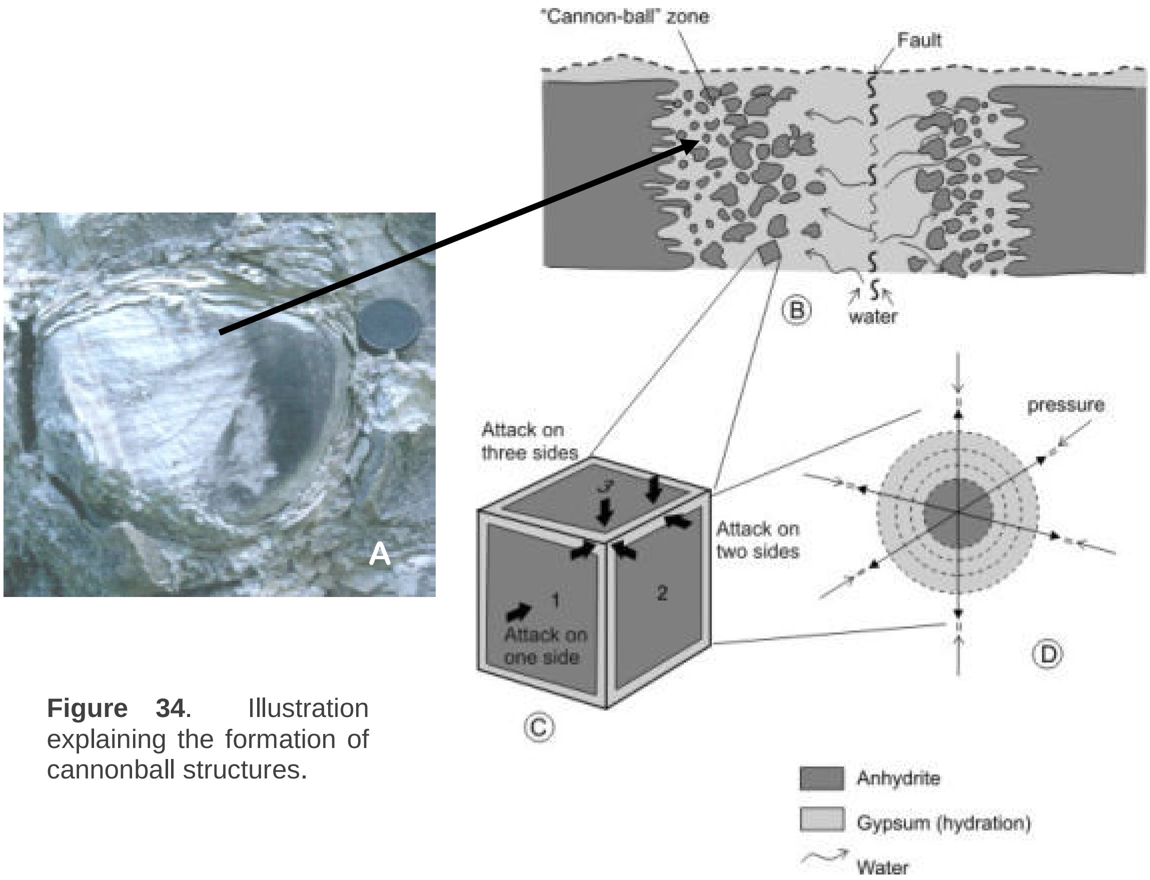


Figure 34. Illustration explaining the formation of cannonball structures.

STOP DESCRIPTIONS

Part 2: Windsor Group in the Cocagne and Moncton subbasins…salt included

The Carboniferous Cocagne and Moncton subbasins, west of Moncton, are the focus of Part 2 (Fig. 2, 35). The Cocagne Subbasin contains Early Carboniferous, clastic sedimentary rocks, carbonates, and evaporites (including potash) of eroded Windsor Group rocks. The Cocagne trends northeast-southwest, has an estimated strike length over 100 km, and a width up to 10 km (St. Peter 2006). Its northwest margin is marked at its contact with Early to Late Carboniferous rocks of the New Brunswick Platform along the Belleisle Fault. To the southeast, its margin is less clearly defined but St. Peter (2006) suggests a series of northeast-trending faults serve as convenient break in stratigraphy between the Cocagne and the adjacent Moncton Subbasin.

With the exception of basal, clastic sedimentary rocks and carbonates at Havelock, Windsor surface exposures in the Cocagne are quite limited. The Havelock area is important because it is the only place in New Brunswick where the contact relationship between the Windsor and overlying clastic sedimentary rocks of the Mabou Group is exposed. In a limestone quarry 5 to 6 km southwest of Havelock, platform and reefal, algal carbonates of the Gays River Formation, are overlain by carbonaceous, fine-grained sediments of the Clover Hill Formation (Samp Hill Beds), which transition upward into fine- to medium-grained, clastic sedimentary rocks of the Mabou Group.

The Havelock excursion will include a visit Graymont (NB) Inc., a leading producer of lime and related limestone products in Atlantic Canada. The trip will then proceed southwest, crossing into the Moncton Subbasin, to observe of the internal stratigraphy and structure of the Cassidy Lake Formation (Windsor Group) in the underground workings of the only potash mine and processing facility on the east coast of North America, the Potash Corporation of Saskatchewan Inc. (New Brunswick Division) about 10 km west of Sussex.

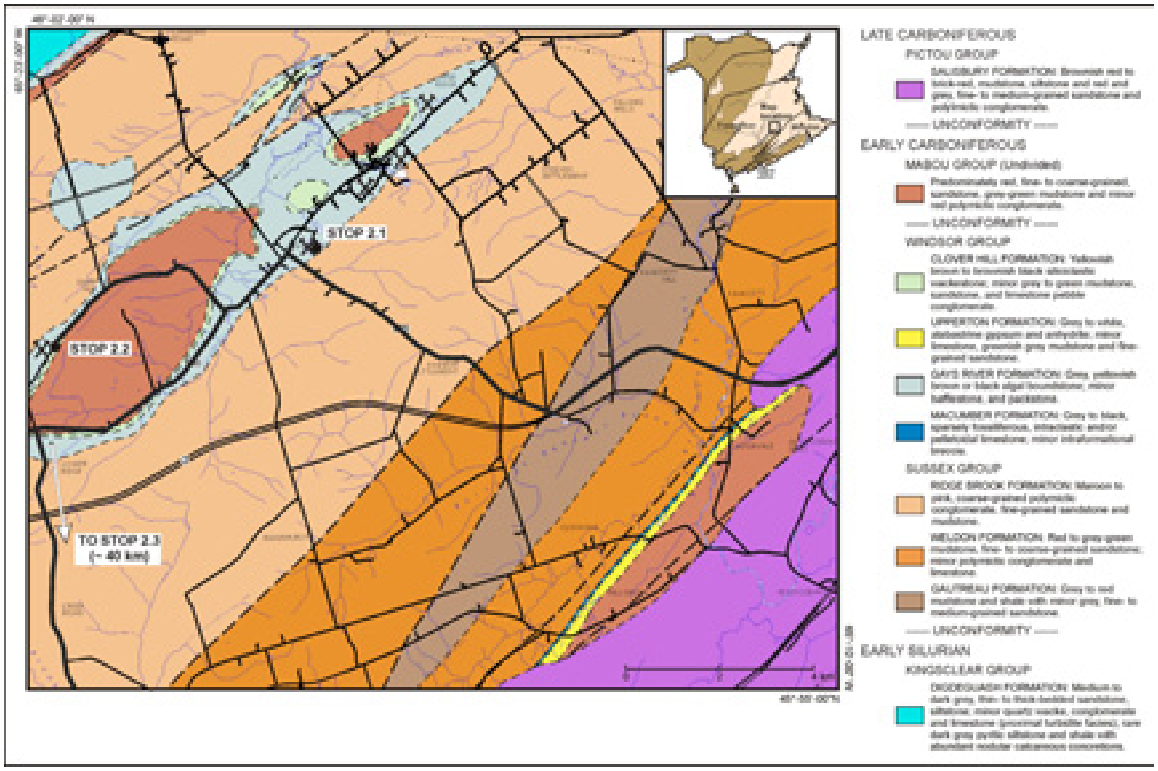


Figure 35. Geology of and Part 2 field trip stop locations in the Havelock area, southeastern New Brunswick (geology after St. Peter et al. 2005 and Smith 2007).

Stop 2.1: Graymont (NB) Inc.

Lat: 45 00’ 08”N
Long: 65 19’ 13”W

From Moncton’s Magnetic Hill area, proceed to the Highway 2 on-ramp heading west to Sussex and Fredericton. Continue to the Havelock-Petitcodiac exit 414 (~37 km). At the intersection with Highway 885, turn right and continue northeast to Havelock and the intersection with Highway 880(~7 km). Turn right and proceed to Graymont (NB) Inc.’s lime and limestone processing facility (~0.6 km, on the right).

> **Cautionary Note**: Safety measures and related information will be discussed by Graymont officials prior to entering the site. It is recommended that participants wear their hard hats and safety glasses at all times, particularly in the vicinity of the kiln.

Graymont (NB) Inc. (Fig. 36) is a subsidiary of Graymont Inc., a North American company focused on high calcium and dolomitic lime, and value added lime based products like specialty hydrates and precipitated calcium carbonates. It is also involved in the aggregate and pulverized stone business.

Graymont Inc. is the third largest producer of lime in North America. In Canada, its lime operations comprise 10 subsidiary production facilities along with 4 dedicated distribution terminals extending from its Havelock lime plant in New Brunswick to operations in Quebec, Manitoba, Alberta and British Columbia. In the United States, 8 lime plants and 11 distribution terminals operate mostly in the northern states of New York, Massachusetts, Ohio, Pennsylvania, North Dakota, Wisconsin, Washington, Oregon, and Montana, and in the mid-western and coastal states of Utah, Nevada, and California.

Figure 36. The processing facilities of Graymont (NB) Inc, at Havelock, Kings County, southeastern New Brunswick;a leading producer of lime and limestone products in Atlantic Canada.

Note: the following description is adapted from information prepared by Mr. André Van Agten, Operations Manager at Graymont (NB) Inc.

"…Graymont (NB) Inc. is the leading supplier of lime and limestone products throughout Atlantic Canada and the State of Maine. The quarrying and processing of various limestone related products from the Havelock area has been an ongoing enterprise for over 70 years. The operations meagre beginnings go back in time to 1938 when local Havelock resident, Mr. Roy Alward, with $5.00 in his pocket, set out to buy 20 tons of agricultural lime from a local producer. The machinery they were working with was in such poor condition and production was so slow, Roy was told it might take up to two years before his lime order could be filled. Apparently, that was too long to wait, so Roy offered to buy the whole operation. The next day he found himself the proud owner of a lime business and a $1500 debt.

The first year, working with two men hired at $1.35 a day, Roy managed to crush one hundred eighty-six tons of aglime (agricultural lime) worth about $500. Of course, Roy got the first 20 tons. For the first few years, the limestone was quarried using only a crowbar, no explosives. The rock was loaded on a drag and hauled with one horse to a 4x6 inch jaw crusher. When the rock was broken down, it went through a small hammer mill, was put into one hundred and fifty feed bags, and then hauled by truck to the customer.

The Operation continued in this fashion, gradually purchasing necessary equipment to make production easier until a more efficient aglime plant was erected at Havelock in 1945. There were soon 15 persons on the payroll crushing four tons of aglime per hour. That year the operation managed to crush 1000 tons.

Aglime demand continued to increase during the 1950's and every effort was made to keep pace through the purchase of new equipment, buildings for inventory and better methods to deliver product to the customer.

A major expansion took place in 1964 when a new plant was opened to produce high-calcium mineral supplements and fertilizer fillers. With this expansion, Havelock Lime could produce 60 ton of lime products per hour, more than the total yearly production in 1945, in one day. The business continued to prosper and in 1970, another milestone was achieved with the construction of a rotary lime kiln to produce a new lime product, burnt or calcined lime.

Limestone ($CaCO_3$), when burned at high temperatures (2500°F) for up to two and half hours, produces calcined lime (CaO), which was used extensively by the Province's pulp and paper industry at the time. A hydrator was also installed at this time to produce hydrated lime for use by the mining industry to treat runoff waters from various ponded mine tailings.

In those early days, it seemed like a new application for lime product came into being almost daily ranging from various treatments of water and sewage to the manufacture of glass, carpet backing, tooth paste, and plastics. The list kept growing and so did Havelock Lime.

Another unique difference between calcined lime and limestone is that calcined lime requires a specialized trucking system to handle it. Moisture has to be kept out of the product and, because hydrated lime is an extremely fine material, pneumatic tanks were the preferred mode of transportation. Additional investment went into an efficient, just-in-time transportation and delivery system allowing Havelock Lime to provide superior customer service on a twenty-four hour basis, second to none.

In 1985, the Alward family sold the business to, Dickenson Mines Ltd. of Toronto, Ontario. Dickenson continued to expand and improve operations at Havelock by investing over $12 000 000 in an upright, 300 t/d annular-shaft kiln (completed in 1989) (Fig. 37), to improve fuel economy, provide increased production capacity, and provide long-term market competitiveness. A new 10 t/h hydrator further contributed to improved production efficiency. Later in 1991, a wash plant was commissioned, providing better quality stone feed to the kiln…"

In 1989, Goldcorp Inc. gained control of Dickenson Mines and its affiliated companies including Havelock Lime. Five years later (1994) the assets of Goldcorp, Dickenson and two other companies were reorganized into a new corporate structure. At that time, Havelock Lime's company name was modified to reflect the new corporate identity - Havelock Lime (a division of Goldcorp Inc.).

In 1996, Havelock Lime's reputation as a marketer of quality lime products was enhanced by its qualification for the internationally recognized ISO 9002 quality assurance accreditation.

To assist funding requirements pertaining to the redevelopment of its Red Lake gold mine in northwestern Ontario, Goldcorp announced, late in 1999, that it was selling the Havelock Lime operation to its present owner, British Columbia-based Graymont Ltd. The Havelock facility, renamed Graymont (NB) Inc., is closely associated with Graymont's three other eastern Canadian lime plants and related quarries in the Province of Québec.

At present, Graymont (NB) has the capacity to produce in excess of 100 000 t of calcined (hydrated) lime products annually. In addition, a few hundred thousand tonnes of limestone is processed from a nearby quarry each year into several products including agricultural lime, rip rap, pulverized high calcium stone, screened high calcium stone and, hydra-lime +, a unique, blended agricultural liming material , featuring three source of calcium, each with differing solubilities. The company's commitment to value added, product research and development assist in making it an aglime leader in Atlantic Canada's agricultural community.

In addition to the wide variety of lime and limestone products the company manufactures, it continues to provide its long established commitment to customer service through flexible product handling and transportation equipment, which includes pneumatic tankers, and flat bed and bulk dump trailers. Graymont's Havelock operation employs between 30 and 40 people.

How is lime made?

A typical lime making process involves the burning of calcium and/or magnesium carbonates at temperatures between 900 and 1500 C. Such temperatures are high enough to liberate carbon dioxide and obtain the derived calcium oxide CaO, referred to as "quicklime", via the following chemical reaction:

$$CaCO_3 + \text{heat} \rightarrow CaO + CO_2\uparrow$$

High purity limestone is quarried nearby and transported to Graymont's Havelock lime processing plant , where it is crushed, screened, graded to appropriate kiln feed size and then washed. Washing the kiln feed material assists in removing impurities like silica, clay, and very fine particles of limestone. Washing also creates free space between the stones for air circulation, thus reducing the amount of excess air and energy required for the burning process. The kiln feed limestone is stored in outdoor stockpiles.

Many different fuels are used in lime kilns. Choosing an appropriate fuel is a key component of the lime manufacturing process. It provides the necessary energy to calcine (burn) the limestone to a suitable lime product. The cost of fuel per tonne of lime may represent 40 to 50% of the production cost so an inappropriate fuel has a major impact on operating costs and the overall economics of the lime making process. It can also influence the quality of the lime, notably the residual carbon dioxide level, the reactivity, and the sulphur content. In addition, the choice of fuel can affect carbon dioxide, carbon monoxide, smoke, dust, sulphur dioxide, and oxides of nitrogen emissions levels, all of which have an environmental impact. At Graymont (NB) Inc., heavy fuel oil is the primary fuel.

The Fuller Beckenbach upright annular shaft kiln

At the Havelock lime plant, a Fuller Beckenbach upright annular shaft kiln is used in the lime manufacturing process (Fig. 37). It has been in service for over two decades and was the first of its kind to operate in North America. The following, a general description of its characteristics and typical operation has been adapted from information supplied by Graymont's predecessor Havelock Lime Ltd.

The kiln is charged automatically by bucket with (1) a seal system (2) to control infiltrated air. The feed to be burned passes through the charging hopper (3) at the top of the kiln into the annular shaft. This shaft is formed by refractory lining of the kiln shell (4) and two concentrically arranged inner cylinders (5,6). The limestone then passes, through a preheating zone (PZ) to the firing zones. Two burner levels (7,8) each, depending on the size of the kiln, having 4 or 5 cylindrical combustion chambers (9,10) located radially and distributed symmetrically around the kiln, divide this section of the kiln into two firing zones operating in counter-flow (UFZ, MFZ), and one zone operating co-currently (CCZ).

In the cooling zone (CZ) following the co-current zone (CCZ) the quicklime gives off its heat in counter flow to the lime cooling air induced by the exhaust gas fan and is discharged at the bottom of the CZ by a hydraulic push rod system (11) on a table (12) into a hopper (13) located below the shaft. A vibrating feeder (14) empties the hopper at required intervals.

The upper and lower combustion chambers (9,10) as well as the circulating gas inlets (15) located in the inner cylinder between the co-current and the cooling zone are arranged offset to one another, ensuring uniform gas distribution the whole cross section of the annulus.

Above every combustion chamber exit, a bridge (16) made of refractory material arches from the outer shell to the inner cylinder. The gases coming out of the combustion chambers penetrate into the filling of the feed to be burned through the hollow spaces formed under the bridges appropriate to the natural angle of repose, and are at the same time evenly distributed over the whole width of the annulus.

The inner cylinder consists of a suspended upper section (5), through which the required volume of exhaust gas for preheating the driving air is induced to the recuperator, and the lower section (6), which contains openings and ducts for circulating the gas.

The double-walled steel shell of the upper and lower cylinder is lined with refractory brickwork and air cooled. The hot air leaves the lower cylinder through the cooling beams (17) located in the bridges, is collected in a ring main (18) and fed to the burners (20) as preheated secondary air. The excess shell-cooling air is discharged, as is the shell-cooling air exiting the upper cylinder.

The driving air induced by a blower is discharged to the recuperator where it is preheated by means of exhaust gas. Exiting from the recuperator the preheated driving air discharges to a ring main from where it is distributed to the injectors (19) and, in the case of oil firing, as atomising air for the oil burners (20).

The co-current flow gas is, in conjunction with the lime cooling air coming from the cooling zone, conveyed by the injectors through the circulating gas inlets (15) in the inner cylinder and drawn into the circulating gas mains (21), which are located in the upper bridges and lead outwards, and is then, together with the injector driving air, fed to the lower combustion chambers (10).

In the lower combustion chambers (10) the fuel is completely burned, with a supply of excess air, prior to entry into the bed of the feed to be burned.

The gases coming from the lower combustion chambers (10) split up into two gas flows, one of which is forced downwards by the injectors (19) through the co-current zone (CCZ), while the other is drawn off by the exhaust gas fan upwards through the middle firing zone (MFZ) located between the burner levels.

The gas flow drawn downwards in co-current flow is constantly reduced in temperature as heat is given off to the decarbonated lime and is, at the end of the co-current flow zone, drawn off together with the lime cooling air into the inner cylinder by means of injectors (19).

In the upper combustion chambers, (9) the fuel is burned with deficient air. The incompletely burned gases emerging from the upper combustion chambers (9) penetrates the bed of feed to be burned beneath the bridges where they meet the excess air coming from below, thereby allowing complete combustion. In this section (U-FZ) of the firing zone, the lime is partially decarbonated and this burning has no effect on the quality of lime, nor any detrimental effect on the refractory brick lining.

The exhaust gas from the preheat zone (PZ) is collected in an annular ring (22) and sent to the inlet of the exhaust gas fan and dust collection equipment. The exhaust gas from the recuperator is also treated by this exhaust gas fan and dust collection equipment.

The kiln is fitted with safety and control equipment. All temperatures and gas volumes, etc. required for operation at the plant are continuously monitored and recorded as necessary.

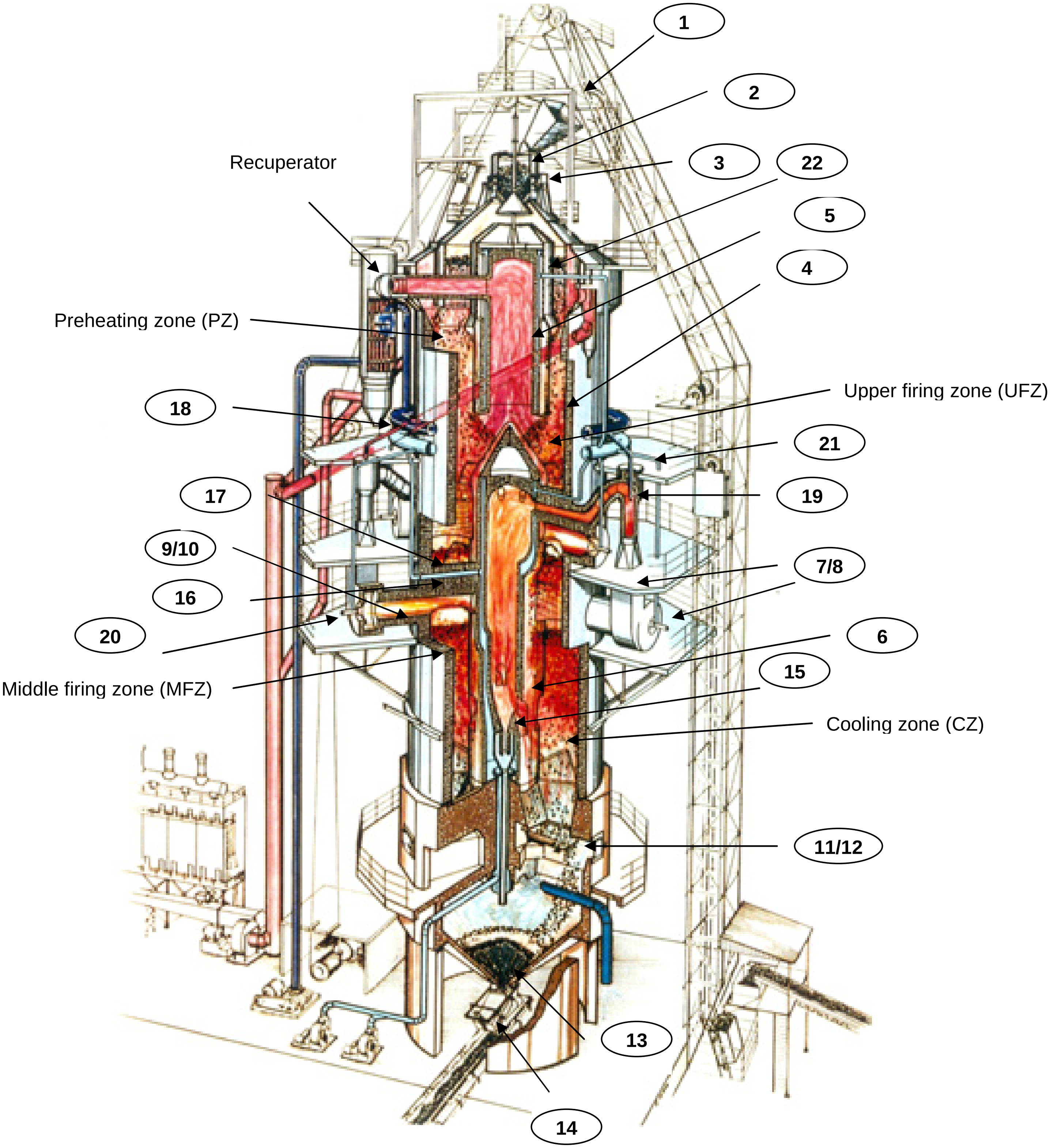


Figure 37. Operation of the Fuller Beckenbach upright annular shaft kiln and the lime calcination process at Graymont (NB) Inc. *(Caption continues on facing page.)*

Figure 37 *(cont'd)*. Legend key for and listing of selected operational characteristics of the Fuller Beckenbach upright annular shaft kiln

1. Feed hopper
2. Sealing system
3. Charging hopper
4. Kiln shell (refractory brick+)
5. Upper inner cylinder
6. Lower inner cylinder
7. Upper burner platform
8. Lower burner platform
9. Upper combustion chamber
10. Upper combustion chamber
11. Hydraulic push rod
12. Table
13. Hopper
14. Vibrating feeder
15. Bridge over combustion chamber
16. Circulating gas inlets
17. Cooling beams
18. Ring main
19. Injectors
20. Oil burners
21. Circulating gas mains
22. Annular ring

Kiln capacity: 300 mt of lime per day.

Heat consumption: At nominal kiln capacity, <900 kcal/kg of kiln product.

Power consumption: Dependent on the feed size and shape (i.e. power consumption for stone sized 5 to10 cm is about 20 kW-h/mt of lime).

Feed size: Between 5 and 20 cm.

Quality of feedstock: $CaCO_3$ content of 82-99%, typical impurities: SiO_2, Al_2O_3, and Fe_2O_3 not detrimental to the refractory lining.

Brick lining: Refractory repairs to bridge arches, combustion chambers and the upper part of the preheating zone may not be necessary until approximately 4 to 5 years of operation. Balance of refractory repair often in excess of 15 years.

Maintenance availability: The kiln is operated under a vacuum system which allows maintenance work without stopping the kiln operation and without loss of production or quality.

Fuel: Operated with nearly all solid, liquid, and gaseous fuels. Heavy fuel oil used at Graymont.

Personnel: One operator for the control room required per shift, and during the day shift, a second person is required for general maintenance and clean-up work.

From quick to hydrated lime

The quicklime product from the kiln is generally directly transferred to an adjacent hydrating plant where it is reacted with a carefully controlled amount of water to produce a fine dry powder according to the following chemical reaction:

$$CaO + H_2O \rightarrow Ca(OH)_2 + heat\uparrow$$

A strong exothermic reaction takes place generating 1140 kJ/kg CaO. The heat release causes a vigorous boiling action creating a partially fluidized bed. The average residence time in the hydrator is about 15 minutes.

The quantity of water added is about twice the stoichiometric amount required for the hydration reaction. The excess water is added to moderate the temperature generated by the heat of reaction by conversion to steam. The steam, which is laden with particulates, passes through abatement equipment prior to discharge. After hydration, the product is conveyed to storage silos. From there, it is either discharged to bulk transport or transferred to a packing plant to be packed in sacks or intermediate bulk containers.

Who uses lime?

Quicklime and hydrated lime are used by many industries and in many manufacturing processes. Mining, mineral processing, sugar milling, paper making, water treatment, bio-solid management, soil and road stabilization, alumina refining, steelmaking, flue gas scrubbing, and construction are just a few examples.

Stop 2.2 Graymont (NB) Inc. Samp Hill quarry - Gays River and Clover Hill Formations

Lat: 45 58’ 47”N
Long: 65 22’ 32”W

From Stop 2.1, turn left onto Highway 880 and proceed to its intersection with the Samp Hill Road on the right (~2.6 km). Head north on Samp Hill Road to the Samp Hill Quarry gate (~2.8 km). Proceed past the gate on the lowest quarry lift (~300 m). The exposure of particular interest is in a cut on the left.

Cautionary Note: Due to potential instability of the quarry wall, it is imperative that all participants wear their hard hats at all times and refrain from getting too close to the wall.

Readily visible in a drainage excavation near the quarry’s east end, this stop is one of the few places in New Brunswick where the contact between the Windsor Group and overlying Mabou Group is observable. The quarry is also intriguing because it is the only area in the Cocagne subbasin where Windsor carbonates are variably dolomitized. The relationship between Windsor and Mabou strata in the Samp Hill quarry section is illustrated in Figure 38 and summarized below.

Gays River rocks in the quarry are comprised of four distinct carbonate lithofacies partly obscured by a recrystallized texture (McCutcheon 1981; Noble and Webb 1982). Collectively, the four lithofacies are up to 30 m thick. Figure 39 illustrates their typical spatial relationships.

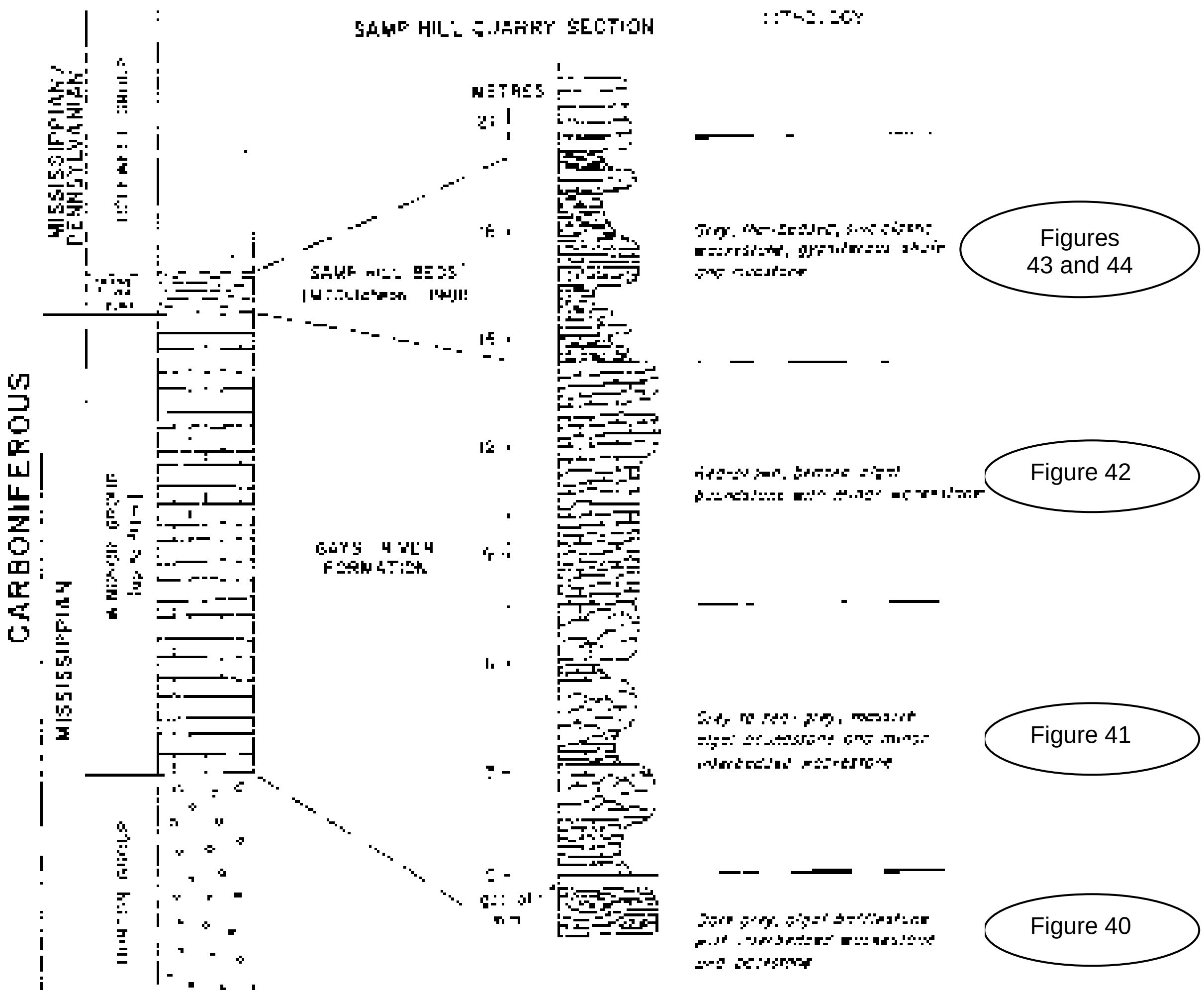


Figure 38. Summary of Windsor Group carbonates and associated strata and the Windsor Group contact with overlying Mabou Group sedimentary clastic rocks at the Samp Hill quarry near Havelock, Kings County, southeastern New Brunswick (after Noble and Webb 1982).

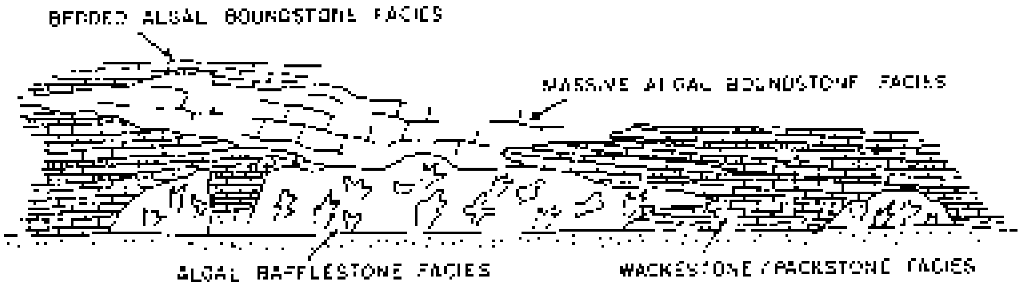


Figure 39. Typical spatial relationship between various lithofacies of the Gays River platform carbonates at the Samp Hill quarry near Havelock, Kings County, southeastern New Brunswick (after Noble and Webb 1982).

The first facies, generally visible in the north wall of the quarry, consists of dark grey algal bafflestones that (Fig. 40) conformably overlie steeply dipping conglomerates and sandstones of the Hillsborough Formation (exposed to the north beyond the quarry wall). The mottled appearance and vertical algal fabric produced by the coalescing, irregular, crustose, and digitate (branching) mounds of algal material are the dominant characteristics of this facies. The mounds are often steep-sided, varying in height from 30 cm to over 1 m and range from circular structures of slightly less than 1 m in diameter to large elongate structures with an axis of 6.5 m or more. The mounds often interfinger with thin-bedded wackestones. Large cavities, abundant within the algal framework, are frequently lined with a crust of fibrous calcite and filled with wackestone and mudstone sediments. Indigenous fauna associated with this facies include brachiopods, gastropods, and foraminifera. Digitate algae associated with normal marine fauna, rapid lateral facies change from bafflestones to thin-bedded wackestones, and the absence of fenestrae all suggest a shallow, subtidal to intertidal, low-energy depositional environment of normal salinity.

The second facies is represented by massive, algal boundstones with minor very thin- to thin-bedded argillaceous wackestones and packstones (Fig. 41). Fossils associated with these rocks are generally very small, thin-shelled brachiopods, ostracods, minor foraminifera, and rare bryozoa. The local occurrence of intraclastic wackestone, silt, hematite and mica, and disarticulated brachiopod shells indicate a possible allochthonous origin. The wackestone dominates this facies and it generally interfingers with the algal mounds of the bafflestone facies. As a result, the depositional environment is interpreted to be similar to that of the algal bafflestone facies (low-energy, shallow, and subtidal).

The third, and probably most extensive and economically important, facies consists of massive, porous, non-parallel beds of algal boundstone with minor thin-bedded wackestone visible in the south wall of the quarry. These boundstones occupy the cores of large mounds that collectively formed thick, tabular to wavy coalescing masses. Individual mounds are difficult to discern, except where this facies occurs in transition with a facies containing more prevalent bedding features like the wackestone-packstone facies, are commonly 60 to 90 cm in diameter, 19 to 30 cm high, and are curved upward. These boundstones contain cryptalgal and partially recrystallized, intraclastic wackestones and are often vuggy, with a dominant, "spongy" cryptalgal texture. Locally, a late diagenetic leaching has enlarged vugs, produce good porosity. Dolomitic limestone is associated with this facies, but its distribution is variable, often restricted to suitable strata adjacent northeast-trending, post- and syn-depositional faults. Locally, hematite and fluorite are present in the vugs indicating mineral-bearing fluids moved through this porous rock.

Coarsely fenestrate limestones with cryptalgal fabrics are typically intertidal. The coarse fenestrae would have formed from pustular algal mats (Playford and Cockbain 1976). The presence of soft-sediment fractures, interpreted as dehydration cracks, and dolomite support the concept of an upper intertidal to supratidal depositional environment for the massive algal boundstone facies.

Bedded, reddish brown, algal boundstones, with minor wackestones, and locally developed breccias interfingering with the massive algal boundstone facies, represent the fourth Gays River facies at Samp Hill (Fig.42). Bedding, 3 to 5 cm thick, is commonly irregular, wavy or lensoidal. Algal tube molds and large irregular fenestrae are generally filled with blocky, sparry calcite cement give the stone a clotted fabric similar to, but not as well developed as, the massive algal boundstone facies. Fenestrae are also partly filled with sediment. Minor quartzose silt and thin, irregular clay seams are disseminated throughout the facies. Widely separated, low amplitude, domal stromatolites occur locally. Stromatolites, abundant fenestrae, intraformational breccia, and red interstitial sediment all suggest a supratidal to upper intertidal depositional environment associated with relatively high energy and oxidizing conditions.

Figure 40. Dark grey, mounded, algal bafflestone with minor packstone and wackestone from the Gays River Formation, Samp Hill quarry near Havelock, Kings County, southeastern New Brunswick.

Figure 41. Grey to red grey, massive algal boundstone with minor interbedded wackestone from the Gays River Formation, Samp Hill quarry near Havelock, Kings County, southeastern New Brunswick.

Figure 42. Grey to red grey, bedded algal boundstone and dark grey mounded algal bafflestone from the Gays River Formation, Samp Hill quarry near Havelock, Kings County, southeastern New Brunswick.

Figure 43. Grey, thin-bedded, silicicalstic wackestone, gypsiferous shale, and mudstone from the Samp Hill Beds, Samp Hill quarry near Havelock, Kings County, southeastern New Brunswick.

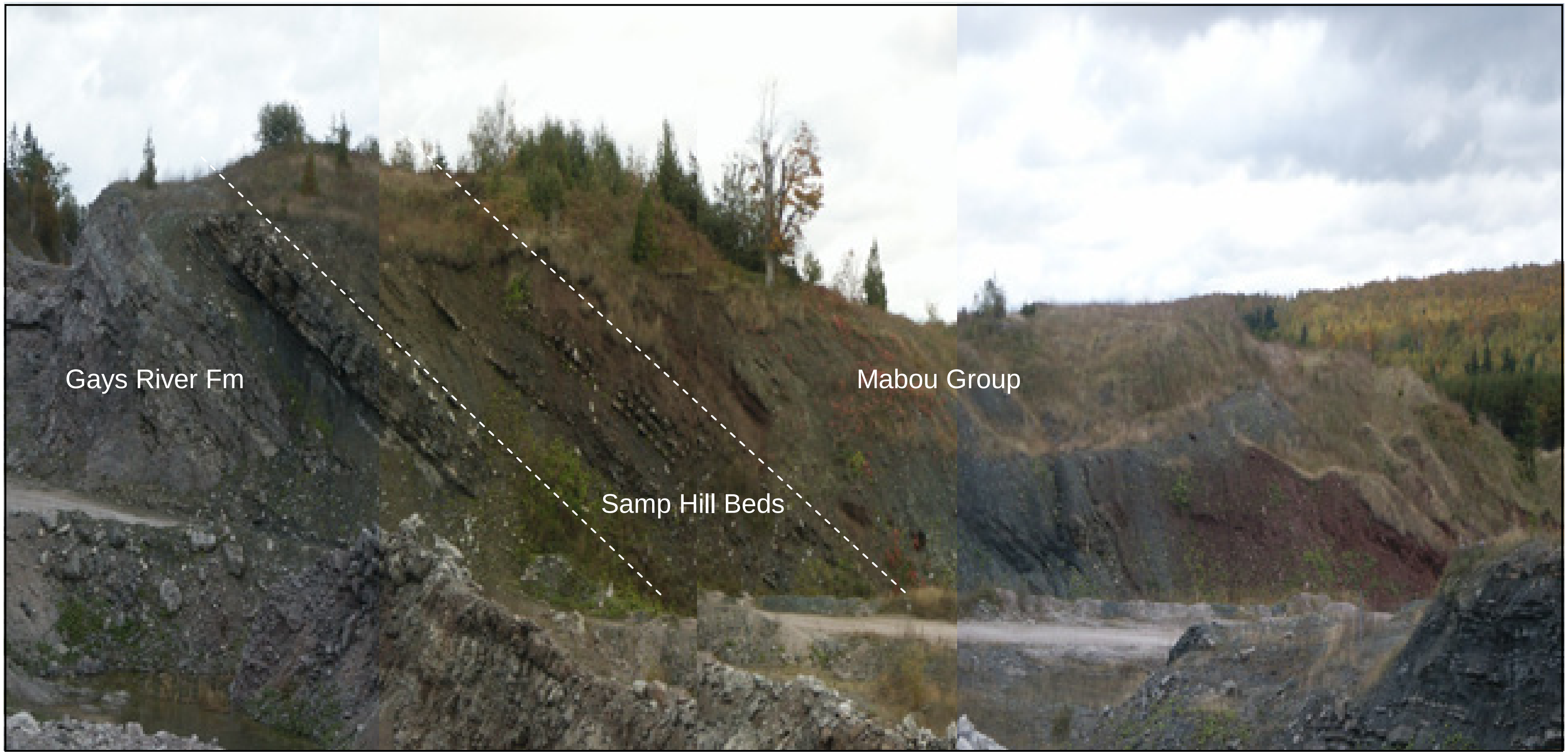


Figure 44. South-dipping section near the east end of the Samp Hill quarry featuring the upward transition from carbonates of the Gays River (Windsor Group) to carbonates and siliciclastics of the Samp Hill Beds to overlying siliciclastics of the Mabou Group.

The upper contact between the Gays River and overlying greenish grey clastic sediments and brownish black, thinly laminated, carbonate wackestones of the Samp Hill Beds (Clover Hill Formation) (McCutcheon 1981) is exposed in a cut that runs perpendicular to the south wall of the quarry (Fig. 43, 44). The contact is marked by an intraformational breccia consisting of disrupted beds of wackestone in a mudstone-sandstone matrix.

There, the Clover Hill is only about 8 m thick. Its upper contact with clastic Mabou sediments is placed at the top of the stratigraphically highest wackestone. The basal brecciated zone is perhaps a result of dissolution of evaporites (salt?) however; the limited amount of disruption indicates the evaporites, if actually present, were thin. Greenish grey, fine- to medium-grained sandstones and mudstones, containing plant detritus, overlie the uppermost Clover Hill wackestones. These rocks gradually grade upward into red, fluvial sedimentary rocks of the Mabou Group.

Post- or syn-depositional faulting has had a significant impact on both the mineralogical and textural properties of the Gays River Formation. Faults serve as conduits and allow various mineral-bearing solutions to penetrate some of the more porous limestone rocks. Depending on the solution's geochemistry, the location of fault structure(s) within the Havelock area, and the primary textural properties of the limestone, rock near a fault zone may be recrystallized, dolomitized, or mineralized with manganese, hematite, or fluorite. Altered (dolomitized) limestone is observable along a northeast-southwest-trending fault evident along the long axis of the quarry. Rocks near fault zones are generally avoided during quarry development because kiln feedstock comprised of such material is unsafe for use in the standard calcination process. At the Samp Hill quarry, the bedded, algal boundstone facies (third facies) exposed along the south wall has historically provided favourable grades of high-calcium limestone with microtextural properties preferred for calcination and the manufacture of lime.

Stop 2.3: Potash Corporation of Saskatchewan Inc. (New Brunswick Division)

Lat: 45 45’ 14”N
Long: 65 25’ 14”W

From Stop 2.2, return to the Samp Hill Road–Highway 880 intersection. Turn right and proceed to Lower Ridge-Creek Road intersection (~5 km). Turn left (south) onto Creek Road (note: Creek Road merges with Highway 890) and proceed to Highway 1 at Sussex (~30 km). Proceed under the Highway 1 overpass, turn left taking the east bound on-ramp to Moncton, then take exit 198 (~2.5 km). Turn left onto Highway 111 (note: Highway 111 merges into Highway 114). Turn left onto McCully Road (~5 km) PCS(NB) is visible on the left at ~4.2 km. Turn left at the PCS(NB) entrance and proceed to the parking area and check-in point. Total driving time from Stop 2.2 to PCS(NB) should be about 40 minutes (~45 km).

Cautionary Note: Safety measures and related information will be discussed by PCS(NB) officials prior to going underground. No full-face beards are permitted underground. Hard hats and eye protection are mandatory. The descent underground is ~0.9 km. It is not cold (20 C+/-) or wet. Participants will be driven to most points of interest and must be careful getting on and off the vehicles in the dimly lit conditions. Please, do not hesitate ask questions regarding the safety measures.

Potash is the term generally applied to the naturally occurring salts of potassium. In New Brunswick, potash ore (sylvinite) is comprised of a mix of potassium chloride (sylvite, KCl) and sodium chloride (halite, NaCl) (Fig. 45). The commercial products produced from sylvinite are referred to as muriate of potash (KCl). Equivalent percentage potassium oxide (K_2O) is the common industry standard for comparing potassium content. Marketable potash contains about 60% K_2O = 95% KCl. Canada is the world's leading producer and exporter of this important product.

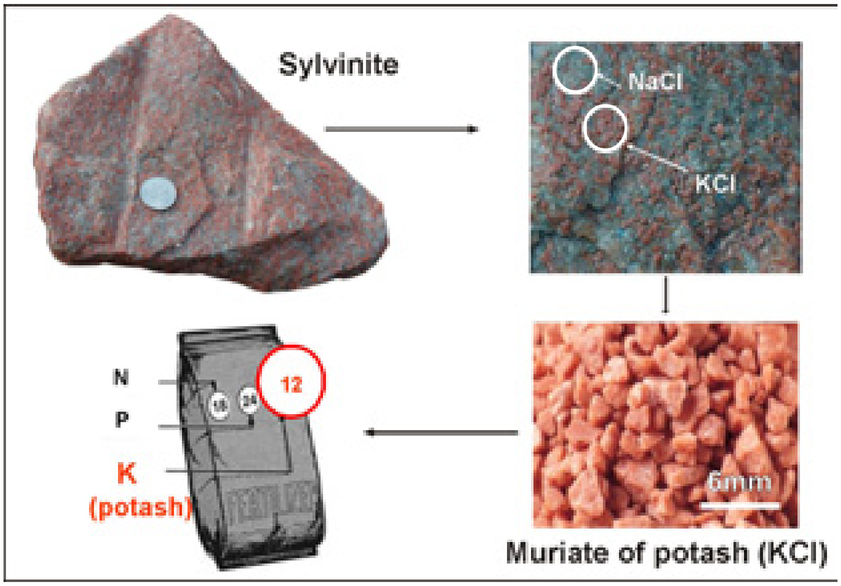


Figure 45. In New Brunswick, potash ore (sylvinite) is primarily a mix of potassium chloride (sylvite, KCl) and sodium chloride (halite, NaCl). The commercial products produced from sylvinite ore are referred to as muriate of potash or KCl. Virtually all potash production finds its way into the agricultural sector in the form of a major fertilizer ingredient symbolized as the “K” ingredient on most commercial bags and containers.

Virtually all potash production finds its way into the agricultural sector as a key component to most fertilizers. Remaining quantities are used by manufacturers of goods like detergent, soap, glass, pharmaceuticals, furnace fluxes, de-icing agents, water softeners, and explosives. Potash is a strategically important resource because it is produced in only 13 countries and consumed in over 150 countries.

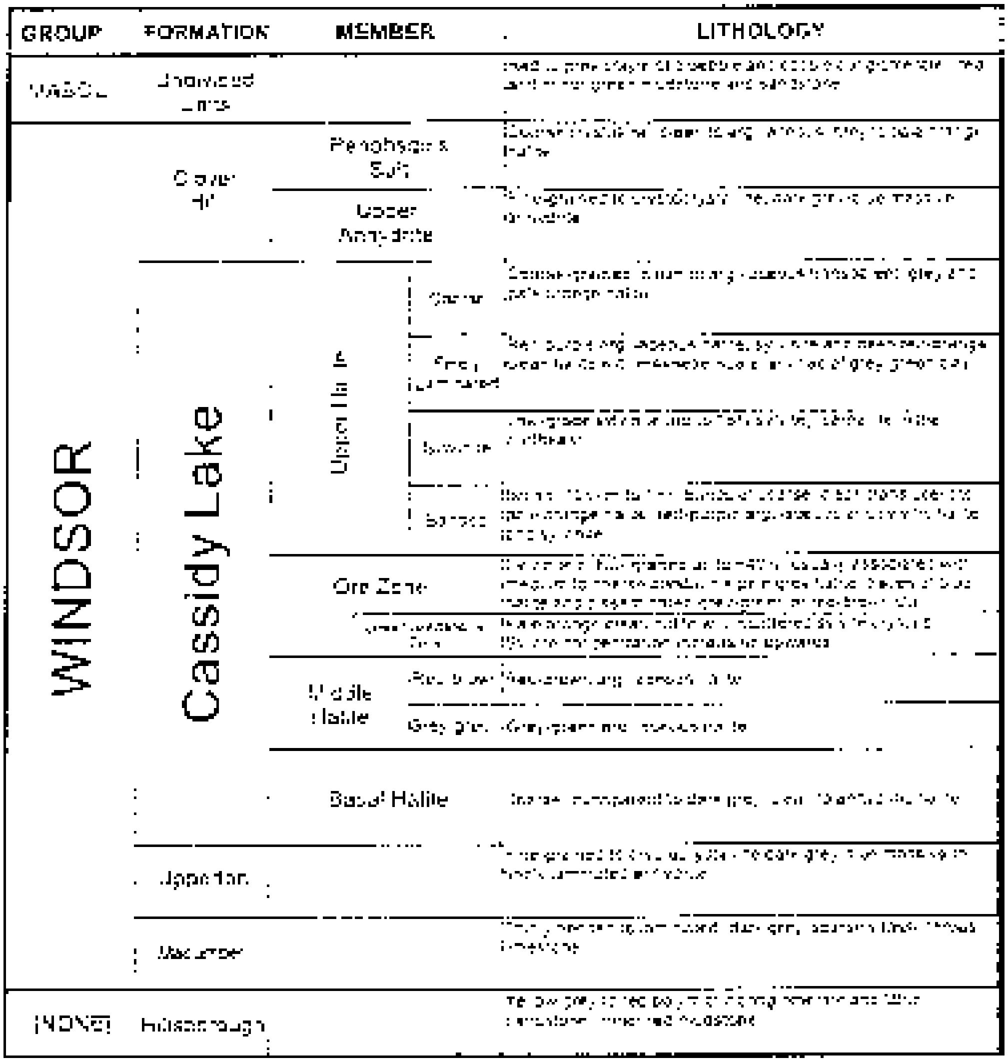
In south-central New Brunswick, Windsor Group evaporites host four known, economically important potash deposits. The Penobsquis deposit, which has been mined for over 30 years, is mined for potash and rock salt for and is, since 1993, being operated by the world’s largest potash producer, Potash Corporation of Saskatchewan Inc. (more commonly referred to as PotashCorp or PCS) (Fig. 46). PotashCorp operates six other potash facilities in Canada, all of are situated in the western province of Saskatchewan. This New Brunswick potash mine is the only potash mine on the east coast of North America.

Other potash deposits known in this part of New Brunswick are found near Cassidy Lake, Millstream; and very near PCS's existing Penobsquis mine and processing facility. The Cassidy Lake deposit was mined by the Potacan Mining Company until it flooded in 1997. At Millstream, the deposit, still undeveloped, was explored by BP Resources Canada Limited in the mid 1980s. The recently discovered Picadilly deposit is presently under construction by PCS.

Figure 46. The Penobsquis potash mine and processing facility of Potash Corporation of Saskatchewan Inc. (New Brunswick Division) near Sussex, Kings County, in south-central New Brunswick (photo used with permission, Roulston 2007).

The Penobsquis, Cassidy Lake, and Picadilly potash deposits occur in the, roughly 3600 km^2, Moncton Subbasin extending from Saint John, northeast to Moncton (Fig. 1, 2). It is regionally defined by Early Paleozoic and Neoproterozoic rocks to the north, south, and west, and contains thick sequences of the Windsor Group. These deposits occur in two distinct intrabasinal, fault-bound troughs in the southwestern half of the subbasin near Sussex, one referred to here as the Penobsquis-Plumweseep evaporite structure and the other called the Clover Hill-Salt Springs evaporite structure.

The Penobsquis-Plumweseep evaporite structure sometimes referred to as the Penobsquis "salt" ridge (St. Peter 2006), extends from Sussex over a northeast strike distance of approximately 40 km. The subsurface geology of this potash-bearing Windsor evaporite has been described in several papers. Wilson and White (2006) provide a convenient summary. In general, the Penobsquis salt ridge comprises a salt-cored anticline up to several hundred metres thick. The upper part of the structure contains a zone of potash ore (sylvinite) of variable structural complexity, thickness, and grade. The evaporites in the Penobsquis deposit are assigned to the Cassidy Lake and Clover Hill formations (Fig. 47). The mine workings have exposed the Lower Gradational and Sylvinite beds as well as parts of the Basal Halite, Middle Halite, and Upper Halite members (Fig. 11). Clover Hill strata are not exposed in the mine.



GROUP	FORMATION	MEMBER		LITHOLOGY
MABOU	Unnamed Units			[illegible]
WINDSOR	Clover Hill	Penobsquis Salt		[illegible]
		Upper Anhydrite		[illegible]
	Cassidy Lake	Upper Halite	Clear	[illegible]
			Finely laminated	[illegible]
			Sylvinite	[illegible]
			Banded	[illegible]
		Ore Zone		[illegible]
		Lower Gradational Zone		[illegible]
		Middle Halite	Red-brown	[illegible]
			Grey-green	[illegible]
		Basal Halite		[illegible]
	Upperton			[illegible]
	Macumber			[illegible]
(NONE)	Hillsborough			[illegible]

Figure 47. Stratigraphy of the Windsor Group with special reference to members of the Cassidy Lake and Clover Hill formations, in the western half of the Moncton Subbasin near Sussex, Kings County, south-central New Brunswick [note: KCl = sylvite] (after Wilson et al. 2006).

The Basal Halite Member is mainly comprised of clear, medium- to coarse-grained halite, with an average grade of close to 99 % NaCl. It also contains minor anhydrite occurring in zones composed of alternating anhydrite and clear halite laminae. These zones can be traced extensively underground, a feature typical of deep water evaporites.

Near the contact with the overlying Middle Halite Member, the anhydrite beds, in contrast to those lower in the section, display irregular upper surfaces with elongated "grass-like" subvertical crystals, up to 5 mm high. These are pseudomorphs of gypsum.

The Middle Halite Member, up to 60 m thick, consists of a series of alternating clean and red brown to grey green argillaceous (containing up to 10% illitic and chloritic clay) halite. These cyclic repetitions of clean and dirty halite were probably the result of seasonal climatic changes.

The Potash Member or Ore Zone consists of a lower zone (up to 20 m thick) of medium-grained, light brown to orange halite, with scattered clusters and stringers of fine- to medium-grained, red-rimmed, and clear to white sylvite grading upward into a higher zone with sylvite concentrations near 40% KCl. This zone, often referred to as the main sylvinite bed, consists of thin beds (0.5 to 10 cm) of clean and argillaceous sylvinite with minor (<1%) disseminated grey green and red brown clay. Typically, the clear to red, fine-grained sylvite occurs in a matrix of fine- to coarse-grained, light brown to pale grey halite (Fig. 11). Its mineralogical homogeneity, over a thickness of 30 m in places, is indicative a static depositional environment not subject to wide variations in salinity.

The Upper Halite Member contrasts markedly with the lower part of the evaporite sequence and marks a distinct change in brine concentration and depositional environment. This "recessive salt" results from several small-scale cycles, each less than 10 m thick. These include banded, coarse-grained, clear to orange to red brown halite with minor sylvinitc halite + low-grade sylvinite (<15% KCl) and minor carnallite + red brown argillaceous halite with minor sylvinite and borate mineralization, orange to clear halite with thin laminae of grey green clay + coarse-grained, grey to orange argillaceous to clean halite. A diverse and widespread borate mineral assemblage found in upper part of this member has been interpreted by Roulston and Waugh (1981) as the result of syn-depositional volcanism that modified the geochemistry of the brine through the addition of boron to the system. The evaporite textures and lithologies in the upper part of the Upper Halite Member suggest of the last stages of an evaporite cycle synonymous with swallowing waters in the remnants of a former deep basin.

The Penobsquis potash deposit - bit of history

Following its discovery by a government sponsored drilling program in 1971, exploration and development rights to the Penobsquis-Plumweseep evaporite structure were awarded in 1973, through a competitive bidding process, to the Potash Company of America (PCA) a division of US based, Ideal Basic Industries. Over the next three years, 34 holes were drilled over 4.5 km^2 at a cost near $20,000,000. This initial exploration program resulted in the signing of a mining lease agreement, covering 191 km^2, with the New Brunswick Government in 1977. PCA invested $106,000,000 on the way to establishing New Brunswick’s first potash mining and milling facility on a site 6 km west of Sussex. A facility with an annual productive capacity of 635,000 t of potash product was envisaged. About 500 people were involved during the construction phase with the potential for 250 permanent employees pending the outcome of shaft sinking and subsequent underground development. In 1980, following satisfactory results, PCA officials announced the company would advance the project to commercial production. It would proceed immediately with the construction of a second production shaft along with a potash ore refinery and related surface infrastructure at a cost of $135,000,000 with production scheduled for 1983. After only two years of production, PCA sold the facility to Rio Algom. Subsequently, in 1993, the mine was purchased by the Potash Corporation of Saskatchewan Inc. and now operates under the name of PCS Potash (New Brunswick Division), abbreviated herein as PCS(NB). Since production began in 1983, over 47,000,000 t of potash ore and over 13,000,000 t of salt have been mined from the Penobsquis-Plumweseep deposit.

The potash ore zone, situated between 400 and 760 m below surface, varies in thickness from 7 to 61 m and has an average insitu grade of 25.84 % K_20 (Hogan 2006). PCS(NB) is a conventional mining operation and estimates its potash ore reserve on the basis of exploration drill hole data, seismic data, definition drilling underground and actual mining results. Recoverable reserves of 71,000,000 t with an average grade of 25.6 % K_2O are reported and considered sufficient to support production at current rates for 30 years (PCS 2007b).

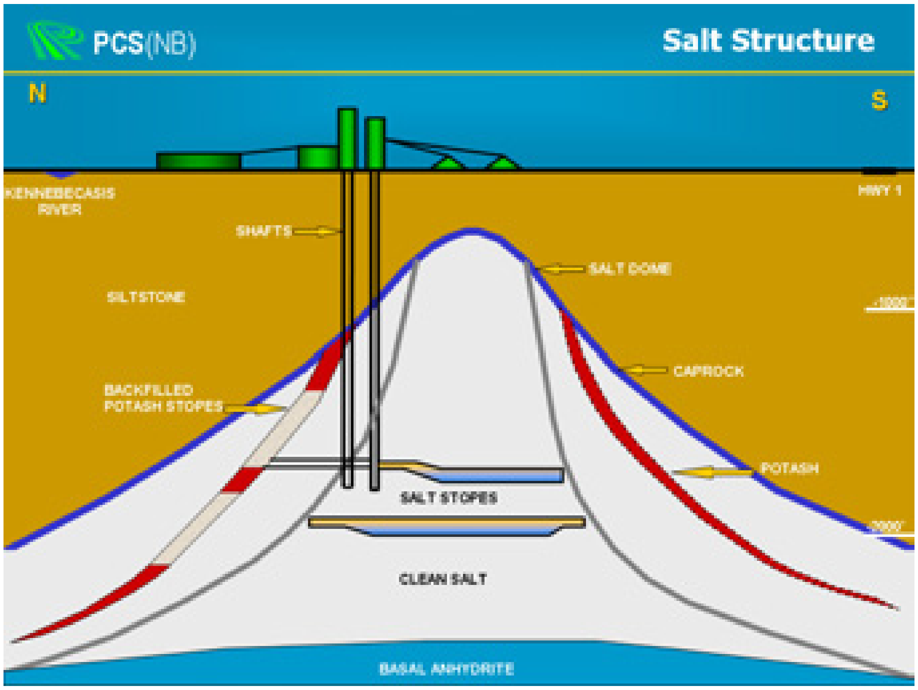
Potash production at PCS(NB) accounts for near 6% of parent PCS Inc’s total annual capacity of 10,700,000 t. Over the last decade, annual production of potash and salt at the New Brunswick operation has averaged 731,000 t while salt production has ranged between 590,000 and 600,000 t. The mine and mill facility generally maintains a work force of approximately 325 employees.

PCS(NB) Inc. - mining, processing, and waste management practices

Mining procedures adopted at PCS(NB) are described as conventional cut and fill stopes in potash zone and room and pillar in salt areas, with zero discharge (Fig. 48). This approach reflects the geological complexities of the deposit and the practice of disposing waste rock (tailings) from the potash milling process to the underground where it is used as backfill. The practice serves two functions: 1) it increases mine stability and 2) it allows for tailings storage in an underground setting instead of huge waste piles on surface.

The generally steeply dipping nature of the potash ore zone together with its variable strike and thickness dictate a flexible mining method to expedite efficient recovery of the resource. The potash and salt deposits are reached through two 5 m diameter, 600 m, vertical shafts; one serving the ore hoisting requirements from the mining operations and the other for moving personnel, equipment and supplies, tailings to the mine, and excess brine generated from tailings dewatering and a controlled water inflow (Hogan 2006).

During mining operations, potash is recovered using an overhand cut and fill method (Fig. 48). The potash ore body is mined longitudinally from elongated rooms (stopes) following the trend of the ore body at various levels with continuous mining machines (Fig. 49). A typical potash stope can approach a strike length of 900 m. Tailings from the on-surface milling process are utilized to backfill mined-out areas thereby establishing a substrate for the excavation machinery, which makes a return cut in the opposite direction once it reaches the end of the stope. As the track mounted machine inches forward along the working face, its boom mounted, rotating cutting head can be raised, lowered, and moved from side to side to create cavern-like stopes up to 7 m high and varying from 25 to 60 m wide. Broken potash ore from the cut face is simultaneously gathered by mechanical arms onto a network of conveyors and transported to the production shaft where it is hoisted to the surface in self-dumping buckets (skips) with 20 to 25 t capacities. A typical mining machine is capable of excavating up to 6,900 t of ore



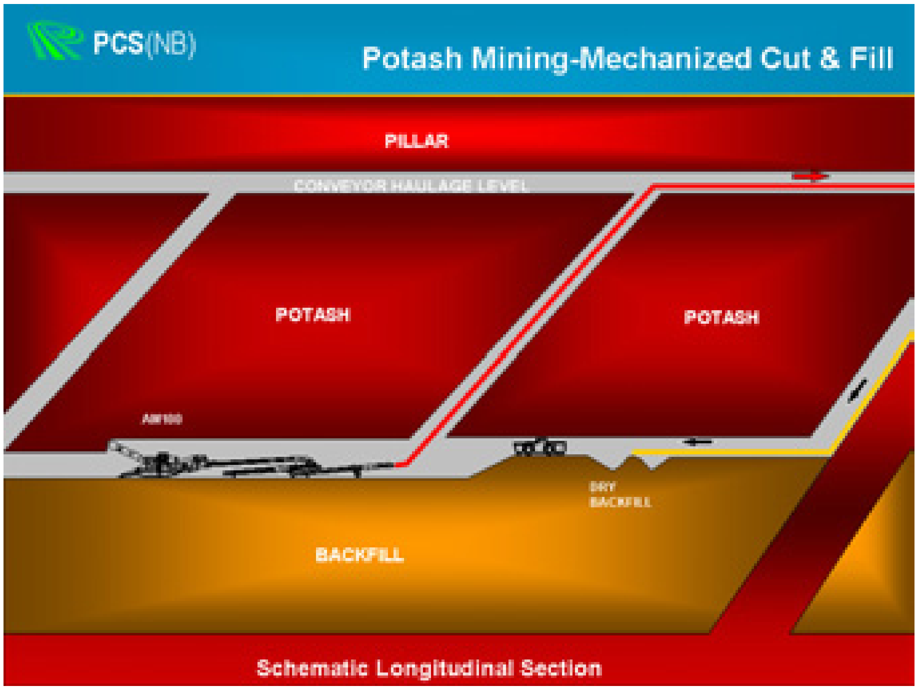


Figure 48. General illustration of the Penobsquis potash/salt structure and mining method at Potash Corporation of Saskatchewan (New Brunswick Division) Inc. near Sussex, Kings County, south-central New Brunswick (photos used with permission, Roulston 2007). Cut and fill mining supports a unique, integrated, closed-loop approach to potash ore extraction and underground disposal of process tailings. PCS(NB) is the only potash operation in the world that returns all its process tailings underground.

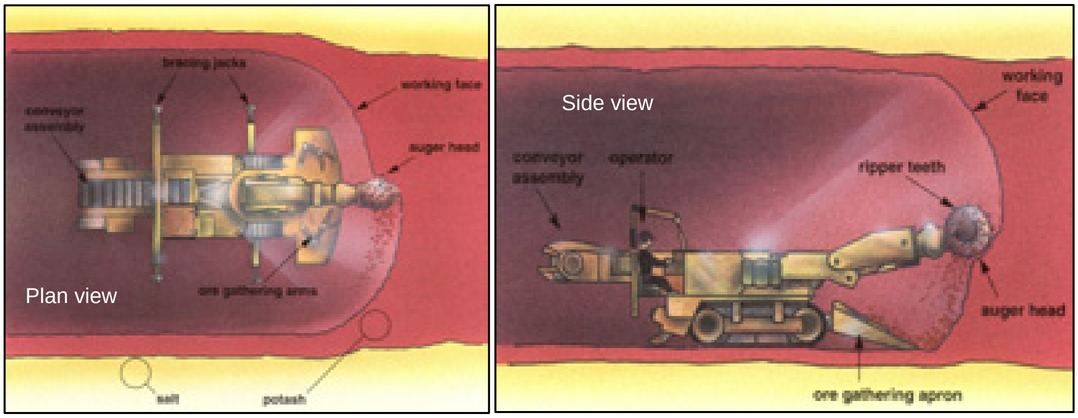


Figure 49. A typical mining machine used at PCS(NB) near Sussex, Kings County, south-central New Brunswick. This type of cutting machinery is very effective in excavating several thousand tonnes of potash ore daily.

daily. PCS(NB) utilizes several Voest Alpine AM100 Mining Machines and a PCA Mining Machine for potash stoping and related development work (Hogan 2006).

As part of its integrated mining plan, salt is also mined at PCS(NB) and is an important part of the operations waste management strategy (Roulston 1995). Most of the mined salt is crushed and screened and marketed as road de-icing material. The mine's current salt production capacity is established at 800,000 t/y; however, actual production seldom exceeds 600,000 t/y. Salt stopes are usually mined in pairs, transverse to the dip of the potash ore body, by way of a room and pillar mining method. Stopes vary in length from 300 to 460 m, and are approximately 20 m wide and 20 m high with 50 m pillars left between (Hogan 2006). Mined salt is crushed and sized underground. Marketable product is hoisted to surface and undersized material is conveyed to a potash production stope to be used as backfill.

Approximately two tonnes of potash ore are mined for every tonne of potash product (Roulston 1995). In an operation with an annual product production capacity of 785,000 t, there is the potential to create 1,570,000 t of waste material. The potash refining process and salt and potash mining operations generate three main waste streams: salt, slime, and brine, which must be managed in an environmentally acceptable manner. Since New Brunswick's maritime climate does not permit for such materials to be stored on surface, fine salt tailings from the refining process and rock salt crushing and screening operation are sent directly to active potash mining stopes and used as backfill. Insolubles (slimes) and excess brine generated are piped as slurry to one of several basin shaped stopes created during the mining of salt. After the insolubles in the slurry settle out the clarified brine is withdrawn to an adjacent stope and subsequently pumped back to surface. This brine serves as feedstock for an evaporation process, where the contained potash is recovered, compacted, and crushed for product. The fine salt generated during the process is added to the solid tailings stream for mine backfill.

Excess brine from the refining process is not the only excess brine mine officials are managing. Brine generated by an inflow into the underground workings since 1998 is kept under control by way of underground drilling and grouting operations. In 2007, increasing inflow rates prompted the implementation of an enhanced drill/grout program from surface into a fracture zone encountered above the salt structure at 389 m. Late that fall, it was reported that inflow had stabilized. Brine from the inflow is collected and pumped to surface. Over 300 tanker truck loads of brine leave the mine site daily for the 38 km haul to PCS's Cassidy Lake Division where it is carried through a 35 km pipeline for disposal in the Bay of Fundy. Brine is also transported 70 km to the potash terminal in Saint John for disposal in the Bay when required. Company officials report (PCS 2007a) that mitigation costs associated with the inflow impact production and operational costs at the existing mine and are a long term concern.

The potash or sylvinite ore at PCS is a mixture of approximately 38% KCl as sylvite and 60% NaCl as halite, with an insoluble fraction, up to 2%, composed mainly of clay minerals and sulphate (Hogan 2006). Separation of the potash from the unwanted components requires a multi-stage refining process (Fig. 50). The first step (scalping) sizes and separates the oversized ore from the finer mined material. The oversized ore is crushed and mixed with salt brine to create a slurry. The slurry is further crushed and sized to liberate KCl particles then agitated and cycloned to remove clay and other deleterious particles, a process commonly referred to as desliming.

Following desliming, the potash-salt slurry is mixed with various chemicals to assist in further separation of the KCl, a process known as floatation. The treated slurry is placed in a series of floatation cells. When air is circulated through the slurry, particles of KCl attach to rising air bubbles forming a potash-rich froth on top that is subsequently skimmed off as concentrate. The concentrate is washed with a weak NaCl solution to dissolve any leftover salt, further improving the quality of the KCl product. Salt particles, which do not attach to the air bubbles, sink and are re-ground to further liberate any fine-grained potash that will be recovered in a final flotation process. The balance of waste materials, which includes salt tailings and clay slimes, are transported underground to active potash and salt stopes.

During the refining process, the solution of some potash and salt is inevitable and additional brine is produced. Stored temporally in other underground salt stopes, this fluid is eventually pumped back to surface and circulated through an evaporator. The brine, which is steam heated until it boils, is separated into three products: purified water, a NaCl precipitate that is added to the flotation process, and a KCl and NaCl saturated brine, often referred to as the mother liquor. This mother liquor is once again heated to a boil and circulated through a series of vessels called crystallizers, resulting in a high purity KCl product that is added to the flotation concentrate. The leftover brine is returned to the refining process. The combined potash concentrate is centrifuged to remove any excess brine and subsequently dried in rotary kilns fired by local sources of natural gas. Natural gas, which was discovered on the PCS(NB) mining lease in 2002 and brought in to production in 2003, has resulted in very significant energy saving and a subsequent reduction in greenhouse gas emissions from the former oil-fired dryers.

The dried KCl product is compacted, crushed, and sized to granular and standard products. Almost all of the potash produced is loaded onto railcars for the journey 78 km to the ocean load out terminal at the Port of Saint John. Product to be railcar-loaded, a minimum of 60% K_2O (95.0% KCl), is quality tested before departure to the Port facility. De-icing and chemical rock salt is also shipped by vessel from the Port facility or by rail and truck from the mine site in Penobsquis.

The Saint John potash terminal, operated by Furncan Marine Limited, consists of two covered storage sheds each with a maximum capacity 250,000 t for each of two potash products (granular and standard grade). Since 2000, annual shipments have generally exceeded 890,600 t annually with granular product accounting for over half of the total shipments. In 2007, 74 vessels called on the Saint John terminal for potash shipments with 51% headed for Brazil and the remainder to United States (5%), Mexico (5%), the Caribbean (20%), and several other South American countries (19%) (Roulston 2007).

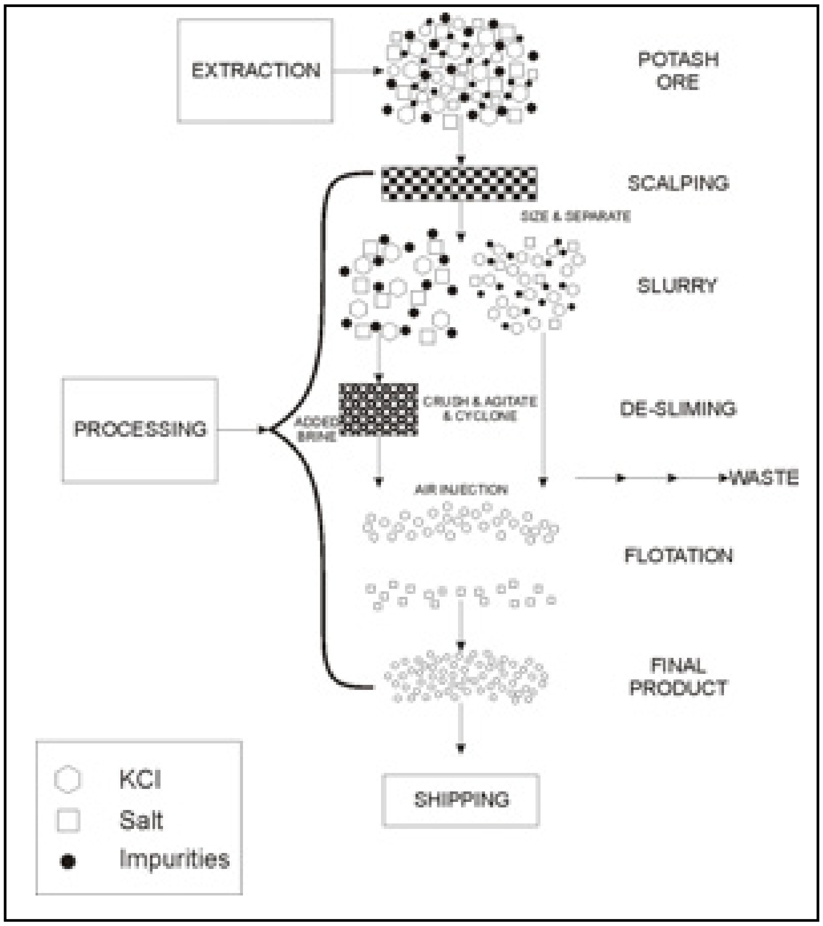


Figure 50. Typical potash refining process: from potash ore (KCl + NaCl + Insols.) to muriate of potash (KCl); 60% K_2O) product.

PCS(NB) Inc. - Picadilly deposit

In 2007, PCS(NB) announced construction plans for a new, 2,000,000 t/y mine and expanded milling operation for a potash deposit discovered on its mining lease, less than a kilometre south of its present mining operation. Following its initial discovery, during an exploration drilling program for natural gas in 2002, the deposit has been defined by 10 potash exploration drill holes, three natural gas wells and a 45 km^2, 3-D seismic survey. Compared to the steeply dipping nature of the Penobsquis deposit, the newly discovered resource, referred to as the Picadilly deposit, is relatively flat, consisting of two potash zones each varying in thickness up to approximately 18 m. Exploration has delineated insitu measured and indicated resources of 389,000,000 mt with an average grade of

23.5% K_2O (Roulston 2007). At a 50 % extraction rate and annual KCl production of 2,000,000 t, the new mine is reported to have a projected life of 32 years.

The new Picadilly mine, situated adjacent existing operations, will be able to utilize some of the infrastructure already in place. This will assist in expediting the construction phase and should also result in cost savings of half a billion dollars. This is significant considering cost projections for a new 2,000,000 t/y green-fields potash operation built in Saskatchewan would be in the order of $2.2 billion dollars (PCS 2007a). PCS is pursuing an ambitious construction schedule for the Picadilly mine project, expecting completion to the predevelopment stage by 2012 at an estimated cost of $1.7 billion (PCS 2007c). This expenditure will be complimented by $1.2 million enhancement to the existing processing facility. A three-year, ramp-up period is expected to follow (Roulston, 2007), with full production realized by 2015. During the construction phase, it is expected that 2,500 person years of employment will be generated, with the addition of 140 new, full-time positions to the operations present labour requirements of 326 people. Plans are to keep the existing mine and mill fully operational throughout the new mine’s construction and development phases. Once fully developed however, underground operations will cease due to concerns over an inflow situation the company has been dealing with for several years.

To return to Fredericton from Stop 2.3, turn right as you exit PCS(NB), proceed to Highway 1, turn right, and follow signage to Fredericton via Highways 10 and 2. Driving time will be approximately 1½ hours.

BIBLIOGRAPHY

Anderle, J.P., Crosby, K.S., and Waugh, D.C.E. 1979. Potash at Salt Springs, New Brunswick. Economic Geology, **74**, p. 389-396.

Arseneault, S.P., Scrodeder, J., Bérubé, D., and Falbert, R. 1997. The caves of southeastern New Brunswick (revised and supplemented). New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 97-7, p. 18-23.

Atlantic Geoscience Society 2001. The Last Billion Years. Nimbus Publishing Ltd., Halifax, Nova Scotia, p. 102-108.

Barnett, D.E. 1984. Potash production in New Brunswick. Fertilizer International, No. 186, p. 38-43.

Chandra, J.J., Chandra, S., Wallace, J., Williams, D., and Webb, T. 1982. Gravity survey of New Brunswick. New Brunswick Department of Natural Resources, Mineral Resources Division, Open File Report 82-11, 70 p.

Gussow, W.C. 1953. Carboniferous stratigraphy and structural geology of New Brunswick, Canada. Bulletin of the American Association of Petroleum Geologists, **37**, No. 7, p. 1713-1816.

Hamilton, J.B. 1961. Salt in New Brunswick. New Brunswick Department of Lands and Mines, Mines Branch, Mineral Resource Report No. 1, 73 p.

Hamilton, J.B. and Barnett, D.E. 1970. Gypsum in New Brunswick. New Brunswick Department of Natural Resources, Mineral Resources Branch, Report of Investigation 10, p. 36-43.

Hogan, M.H. 2006. PCS Potash (New Brunswick Division), Fact Sheet 2006, 12 p.

Hopewell Rocks, 2008. http://www.thehopewellrocks.ca/English/index.htm (accessed March 2009).

Howie, R.D. 1988. Upper Paleozoic evaporites in Atlantic Canada. Geologic Survey of Canada Bulletin, **380**, 20 p.

Kingston, P.W. and Dickie, D.E. 1979. Geology of New Brunswick potash deposits. Canadian Institute of Mining and Metallurgy Bulletin, **72**, No. 802, p. 134-141.

Krukowski, S.T. 2007. “Lime kilns at Wapanucka, [Oklahoma], ca. 1909.” Encyclopedia of Oklahoma History and Culture, http://digital.library.okstate.edu/encyclopedia/entries/L/LI004.html (accessed March 2009).

McCutcheon, S.R. 1981. Stratigraphy and paleogeography of the Windsor Group in southern New Brunswick. Unpublished M.Sc. thesis, Acadia University, Wolfville, Nova Scotia, 206 p. New Brunswick Department of Natural Resources, Mineral Resources Division, Geological Surveys Branch, Open File Report 81-31, 210 p.

McCutcheon, S.R. 1983. Potash in the central New Brunswick Platform. Canadian Institute of Mining and Metallurgy Bulletin, **76**, No. 857, p. 70-76.

McCutcheon, S.R., McLeod, M.J., Webb, T.C., Roulston, B.V., and Waugh, D.C.E. 1980. Stratigraphy and paleoenvironment of the Windsor Group in New Brunswick. Geological Association of Canada/Mineralogical Association of Canada, Halifax, Nova Scotia, Field Trip Guidebook, No. 5, 39 p.

McCutcheon, S.R., Roulston, B.V., and Webb, T.C. 1985. Stratigraphy and paleoenvironmental setting of the Windsor Group potash deposits, southeastern New Brunswick. *In* Fredericton 85, Field Excursions. R.K. Pickerill, C.K. Mawer, and L.R. Fyffe (editors). Geological Association of Canada, Mineralogical Association of Canada, Fredericton, N.B., Excursion 5, 32 p.

New Brunswick Department of Natural Resources and Energy 1993. Industrial Minerals – An important segment of New Brunswick’s mineral industry. Mineral Resources Division, Miscellaneous Report No. 10, p. 31-43.

New Brunswick Department of Natural Resources 2008. Bedrock Geology of New Brunswick, Minerals and Energy Division, Map NR-1(2008 Edition) (revised December 2008).

New Brunswick Department of Natural Resources 2009. New Brunswick Bedrock Lexicon Database. http://www1.gnb.ca/0078/GeoscienceDatabase/Lexicon/GeoSearch-e.asp.

Noble, J.P.A. and Webb, T.C. 1982. Lithofacies analysis on the Windsor limestones of the Havelock area, Kings County, New Brunswick. New Brunswick Department of Natural Resources, Mineral Resources Division, Open File Report 82-6, 30 p.

Playford, P.E. and Cockbain, A.E. 1976. Modern algal stromatolites at Hamelin Pool. *In* Stromatolites. M.R. Walter (editor), Elseveir, New York, N.Y., p. 389-412.

Potash Corporation of Saskatchewan Inc. (PCS) 2007a. Potash Corp announces new potash mine and mill expansion in New Brunswick. News Release, July 20, 2007, 2 p.

Potash Corporation of Saskatchewan Inc. (PCS) 2007b. Yesterday, today and tomorrow. Annual Report of Form 10-K for the year ended December 31, 2007. Part I, p. 4.

Potash Corporation of Saskatchewan Inc. (PCS) 2007c. Operations highlights. PotashCorp 2007 Online Annual Report. http://www.potashcorp.com/investor_relations/financial_performance/annual_results/annual_reports_archive/2007/html/our_story/operations (accessed August 2008).

Roulston, B.V. 1995. Canada’s zero effluent potash mine. *In* 29th Forum on the Geology of Industrial Minerals: Proceedings. *Edited by* M. Tabillo and D.L. Dupras. California Department of Conservation, Division of Mines and Geology Special Publication 110, p. 261-267.

Roulston, B.V. 2007. Picadilly potash project. A presentation at Exploration and Mining New Brunswick, 2007. New Brunswick Department of Natural Resources; Minerals, Policy and Planning Division, Fredericton, New Brunswick, November 4-7, 2007.

Roulston, B.V. and Waugh, D.C.E. 1981. A borate mineral assemblage from the Penobsquis and Salt Springs evaporite deposits of southern New Brunswick. Canadian Mineralogist, **19**, p. 291-301.

Roulston, B.V. and Waugh, D.C.E. 1985. Stratigraphic comparison of the Mississippian potash deposits in New Brunswick, Canada. *In* Sixth International Symposium on Salt – 1983. *Edited by* B.C. Schrieber and H.L. Harner. The Salt Institute, Alexandria, Virginia, 1, p.115-129.

Roulston, B.V., Webb, T.C., and Monahan, M.E. 1995. Stratigraphy and depositional synthesis of middle to late Visean evaporates in part of the Moncton Subbasin, New Brunswick, Canada. *In* Proceedings: 30th Forum on the Geology of Industrial Minerals(1994). *Edited by* S.A.A. Merlini, New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Miscellaneous Report 16, p. 171-179.

St. Peter, C. 1993. Maritimes Basin evolution: key geologic and seismic evidence from the Moncton Subbasin of New Brunswick. Atlantic Geology, **29**, p. 233-270.

St. Peter, C. 2003. Southeastern New Brunswick Maritimes Basin Field Trip (unpublished), New Brunswick Department of Natural Resources, 13 p.

St. Peter, C. 2006. Geological relationship between the Cocagne Subbasin and Indian Mountain Deformed Zone, Maritimes Basin, New Brunswick, Canada. *In* Geological Investigations in New Brunswick for 2005. *Edited by* G.L. Martin, New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Resource Report 2006-3, p. 103-183.

St. Peter, C., Barr, S.M., and White, C. 2005. Bedrock geology of the Petitcodiac area (NTS 21 H/14) Kings, Westmorland, and Queens counties New Brunswick. New Brunswick Department of Natural Resources, Minerals, Policy and Planning Division, Map Plate 2005-47.

St. Peter, C. and Johnson, S.C. 2008. Carboniferous geology of the Hillsborough area, Albert and Westmorland counties New Brunswick. New Brunswick Department of Natural Resources, Minerals, Policy and Planning Division, Map Plate 2008-23.

St. Peter, C. and Johnson, S.C. 2009. Stratigraphy and structural history of the Upper Paleozoic Maritimes Basin of southeastern New Brunswick, Canada. New Brunswick Department of Natural Resources, Minerals, Policy and Planning Division, Memoir 3, 348 p.

Smith, E.A. 2005. Bedrock geology of southwestern New Brunswick (NTS 21 G and part of 21 B). New Brunswick Department of Natural Resources, Minerals, Policy and Planning Division, Map Plate NR-5 (Second Edition).

Smith, E.A. 2006. Bedrock geology of southeastern New Brunswick (NTS 21 H). New Brunswick Department of Natural Resources, Minerals, Policy and Planning Division, Map Plate NR-6 (Second Edition).

Smith, E.A. (compliler) 2007. Bedrock geology of the Salisbury area, (NTS 21 I/03), Queens, Kings and Westmorland counties New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Map Plate 2005-47.

Smith, E.A. 2008. Bedrock Geology of central New Brunswick (NTS 21 I and part of 11L). New Brunswick Department of Natural Resources, Minerals, Policy and Planning Division, Map Plate NR-10.

Smith, E.A. and Fyffe, L.R. 2006. Bedrock geology of central New Brunswick (NTS 21 J). New Brunswick Department of Natural Resources, Minerals, Policy and Planning Division, Map Plate NR-4 (Second Edition).

Trenhaile, A.S, Pepper, D.A., Trenhaile, R.W., and Dalimonte, M. 1997. Stacks and notches at Hopewell Rocks, New Brunswick, Canada. Earth Surface Processes and Landforms, **23**, p. 975-988.

van Stall, C.R. 2007. Pre-Carboniferous tectonic evolution and metallogeny of the Canadian Appalachains. In Mineral Deposits of Canada: A Synthesis of Major Deposit-types, District Metallogeny, the Evolution of Geological Provinces, and Exploration Methods. *Edited by* W.D. Goodfellow. Geological Association of Canada, Mineral Deposit Division, Special Publication No. 5, p. 793-789.

Waugh D.C.E. and Urqhart, B.R. 1983. The geology of the Denison-Potacan's New Brunswick potash deposit. *In* Sixth International Symposium on Salt – 1983. *Edited by* B.C. Schrieber and H.L. Harner. The Salt Institute, Alexandria, Virginia, 1, p. 85-98.

Webb, T.C. 1977. The geology of New Brunswick glauberite deposits. New Brunswick Department of Natural Resources, Mineral Resources Branch, Open File Report 77-15 (revised 1980), 29 p.

Webb, T.C. 1984. New Brunswick potash deposits. *In* Geology of Industrial Minerals in Canada. The Canadian Institute Mining and Metallurgy, Special Volume **29**, p. 41-47.

Webb, T.C. 1994. The Millstream potash prospect, Kings County, New Brunswick. New Brunswick Department of Natural Resources and Energy; Minerals and Energy Division, Reference 208, 24 p.

Webb T.C. 1997. Carboniferous limestones of New Brunswick: Geology and development potential. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 97-6, p. 35-41; p. 69-79.

Webb, T.C. 2001. Geology, development history and exploration alternatives for gypsum and anhydrite resources in the Wilson Brook-Demoiselle Creek area (part of NTS 21 H/15), southeastern New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 2001-4, 33 p.

Webb, T.C. 2002a. Geology and development of Albert County gypsum and anhydrite resources, southeastern New Brunswick. Unpublished field trip guide for the New Brunswick Prospectors and Developers Association Annual Field Trip, June 8, 2002, New Brunswick Department of Natural Resources and Energy; Minerals and Energy Division, 34 p.

Webb, T.C. 2002b. Geology, development history and exploration alternatives for gypsum and anhydrite resources near Hillsborough (part of NTS 21 H/15), Albert County, southeastern New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 2001-6, 47 p.

Webb, T.C. 2009. New Brunswick potash: A review of developments and potential exploration alternatives. New Brunswick Department of Natural Resources, Minerals, Policy and Planning Division, Information Circular 2008-4, (CD-Rom), 21p.

Webb, T.C. and Barnett, D.E. 1986. New Brunswick potash: Discovery to production. A paper presented at the CIM Fifth District Meeting, November 20-22, 1986, Halifax, Nova Scotia, New Brunswick Department of Natural Resources and Energy, Mineral Development Branch, Reference 128, 47 p.

Webb, T.C. and Roulston, B.V. 1994. Geology and development of New Brunswick's potash deposits. Nova Scotia Department of Natural Resources and New Brunswick Department of Natural Resources and Energy, 30th Forum on the Geology of Industrial Minerals, May 21-27, 1994, Fredericton, N.B. and Halifax, N.S., Field Trip No. 1, 33 p.

Webb, T.C. and Smith, E.A. 2009. Potash. New Brunswick Department of Natural Resources; Minerals, Policy and Planning Division, Mineral Commodity Profile No. 4, 8 p.

Webb, T.C. and Thibault, J. 1994. Geology and development of Lower Carboniferous limestone deposits in southeastern New Brunswick / Peat mining in New Brunswick. Nova Scotia Department of Natural Resources and New Brunswick Department of Natural Resources and Energy, 30th Forum on the Geology of Industrial Minerals, May 21-27, 1994, Fredericton, N.B. and Halifax, N.S., Field Trip No. 2, 57 p.

Wilson, P. 2003. Stratigraphy, evaporate structure and tectonic history in the McCully area, southern New Brunswick: Preliminary results. *In* Current Research 2002. *Edited by* B.M.W. Carroll, New Brunswick Department of Natural Resources, Minerals, Policy and Planning Division, Mineral Resource Report 2003-4, p.101-121.

Wilson, P. 2005. Stratigraphy, structural geology and tectonic history of the McCully area, Moncton Subbasin, southeastern New Brunswick. New Brunswick Department of Natural Resources; Minerals, Policy and Planning Division, Mineral Resource Report 2005-5 104 p.

Wilson, P. and White, J.C. 2006. Tectonic evolution of the Moncton Basin, New Brunswick, eastern Canada: new evidence from field and sub-surface data. Bulletin of Canadian Petroleum Geology, **54**, No. 4, p. 319-336.

Wilson, P., White, J.C., and Roulston, B.V. 2006. Structural Geology of the Penobsquis salt structure: late Bashkirian inversion in the Moncton Basin, eastern Canada, Canadian Journal of Earth Science, **43**, p. 405-419.

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