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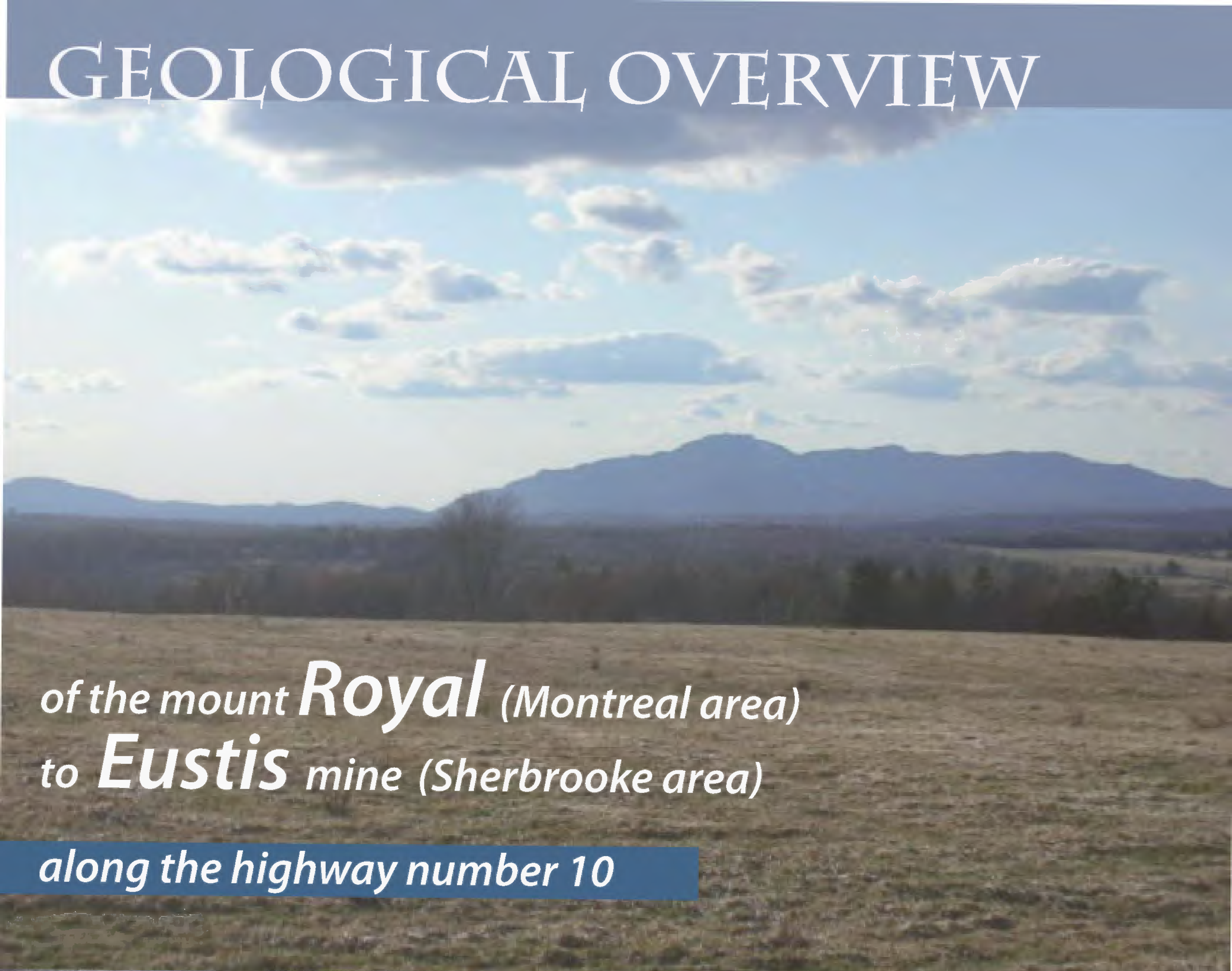
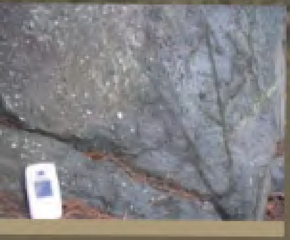
GEOLOGICAL OVERVIEW OF THE MOUNT ROYAL (MONTREAL AREA) TO EUSTIS MINE (SHERBROOKE AREA) ALONG THE HIGHWAY NUMBER 10

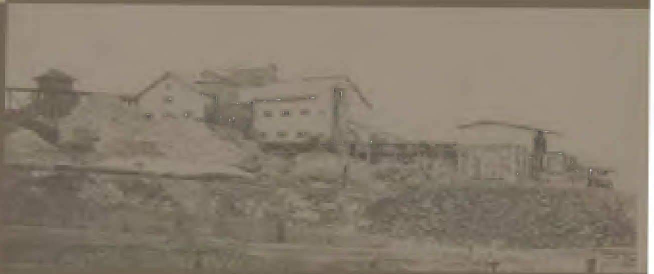


GEOLOGICAL OVERVIEW

of the mount Royal (Montreal area) to Eustis mine (Sherbrooke area)

along the highway number 10





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Ressources naturelles et Faune
Québec

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Ministère des
Ressources naturelles
et de la Faune
Québec Direction Générale de Géologie Québec

Geological overview of the Mount Royal (Montreal area) to Eustis mine (Sherbrooke area) along the highway number 10

Geological field trip

September 18, 2010

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Introduction

The goal of this field trip is to observe and understand the geology along a section of Highway 10 between the city of Montreal and the copper mines in the Estrie-Beauce region. We will observe Ordovician limestones exposed in the Montreal region, the Quaternary sedimentary cover in the St. Lawrence Valley, and finally the Dunnage internal nappe in the oceanic domain of the Estrie-Beauce region. This nappe is overthrust by the Québec Appalachians. The thrusting marked the closure of the Iapetus Ocean during the Acadian orogeny and the emplacement of island arcs that led to the formation of the ore deposits typical of the Estrie-Beauce region. (Fig. 1)

The field trip consists of six geological stops along Highway 10. We will begin our trip at the foot of Mount Royal where we can observe various geological domains and the contrast between Cretaceous igneous bodies and Middle Ordovician limestones. We will then move eastward to observe the sedimentary cover of the St. Lawrence Valley. We will cross over the Brompton–Baie Verte Line (BBL), which, according to some authors, marks the suture between the Humber and Dunnage zones (the external and internal nappes, respectively). Other authors believe the line represents a major normal fault in the Québec Appalachians. We will examine the internal nappe domains starting with the Tibbit Hill Formation of the Cambrian Oak Hill Group, and cross over the BBL to observe dismembered serpentinites, followed by the ordovician Magog Group which is contemporaneous to the limestones of the St. Lawrence Lowlands. Next on the agenda is a guided tour of an old copper mine that is typical of Estrie-Beauce mines at the beginning of the last century. We will end the trip by examining the Guadeloupe Fault, which marks the western limit of the Dunnage Zone.

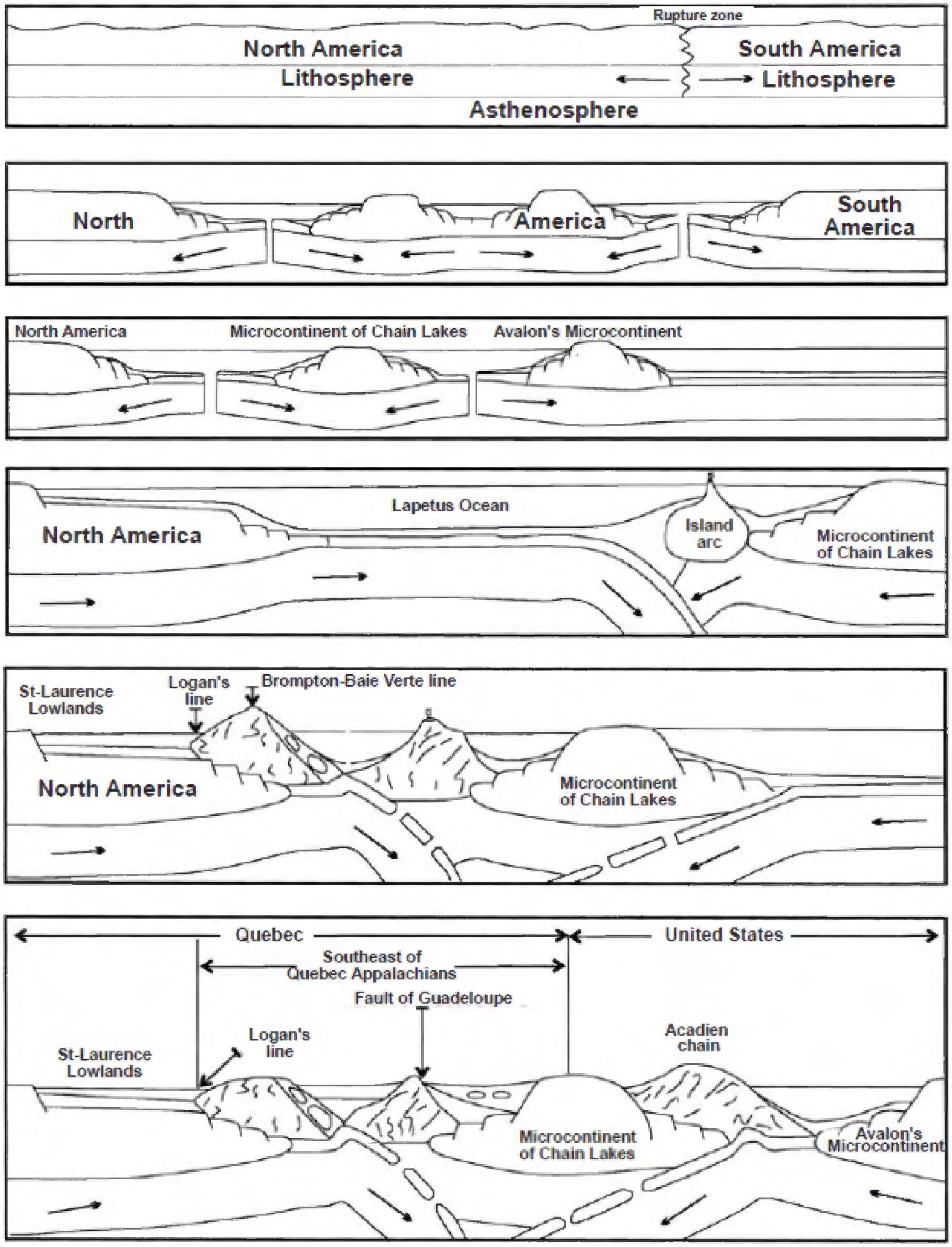


Figure 1. Construction of the Appalachians in southeastern Québec. (After Perras, L-P. and Marquis, R., 1998)

Itinerary and stops

Figure 2a. Geological road map of the Montreal-Sherbrooke region showing stop locations. (Modified from the 1991 geotourism map for southern Québec: *Carte géotouristique 1991*)

Stop 1: Mount Royal: ordovician limestone and cretaceous intrusion landscape

(Based on notes Martin Roy and Pierre Bédard)

Mount Royal forms the dominant topographic relief in Montreal. It is a more or less circular hill 232 metres high. Five different geologic domains are visible from Mount Royal: the plain of the St. Lawrence Lowlands, the Monteregian Hills to the east, the Laurentian plateau to the north, the Appalachian Mountains to the southeast, and the mountainous massifs of the Adirondacks (Fig. 3).

The geological origin of Mount Royal is closely related to the origin of the other Monteregian Hills. These nine rocky massifs display many differences from a geochemical point of view, but their genesis is related to the same process of formation (Roy, M., 2008).

The core of Mount Royal is made of melanocratic and leucocratic gabbros, diorites, and nepheline monzonites (Gélinas, 1970). Mount Royal is Cretaceous with an age of 124 ±1Ma (138 ±6 Ma on gabbro and 117 ±3 Ma on diorite). Rising magma penetrated the Precambrian basement and St. Lawrence sedimentary sequence, assisted by the presence of zones of weakness in the St. Lawrence graben. Two thousand metres (2,000 m) of sedimentary cover were still present at the time of the intrusion's emplacement. A depositional hiatus lasted for 100 Ma and subsequent erosion exposed the intrusives as positive topographic relief. The cyclical passage of glaciers during the last two million years most certainly contributed to sculpting the landscape into its present form (Berré, F. and Lépine, J-F., 2000).

All three main families of rocks are present at Mount Royal: igneous, sedimentary and metamorphic. At the foot of the hill, we find the limestones beds of the Trenton Group. These grey stratified limestones were the product of a shallow marine episode in the Iapetus Ocean that lasted from Middle Ordovician and Devonian time. Contact metamorphic rocks are present around the periphery of Mount Royal, where the Trenton limestone has been transformed into marble, and the shale of the Utica Formation (Middle Ordovician age) into hornfels (Fig. 4). The rise of magma through the crust also deformed and fractured the sedimentary rocks. A multitude of vertical and horizontal fractures have been observed around the stock.

Two theories have been put forward to explain the Monteregian Hills. Some authors relate the formation of the monteregian magma with the opening of the Saint. Lawrence graben, which began during Jurassic time about 160 Ma. The tectonic forces (mainly tensional) that led to the formation of the ocean created a series of fractures along which the magma migrated. Dating studies on rocks from the Monteregian Hills indicate they were emplaced shortly after this period, between 140 and 99 Ma.

The other proposed mechanism of formation is based on the alignment of the E-W Monteregian Hill axis with the White Mountains of New Hampshire, which are composed of rocks of the same nature and are also Cretaceous in age. Moreover, a string of small undersea volcanoes off the New England coast (the Kelvin Mountains) also lie within the same axis. Some authors have suggested that these series of plutonic intrusions reflect the passage of the continent over a hot spot.

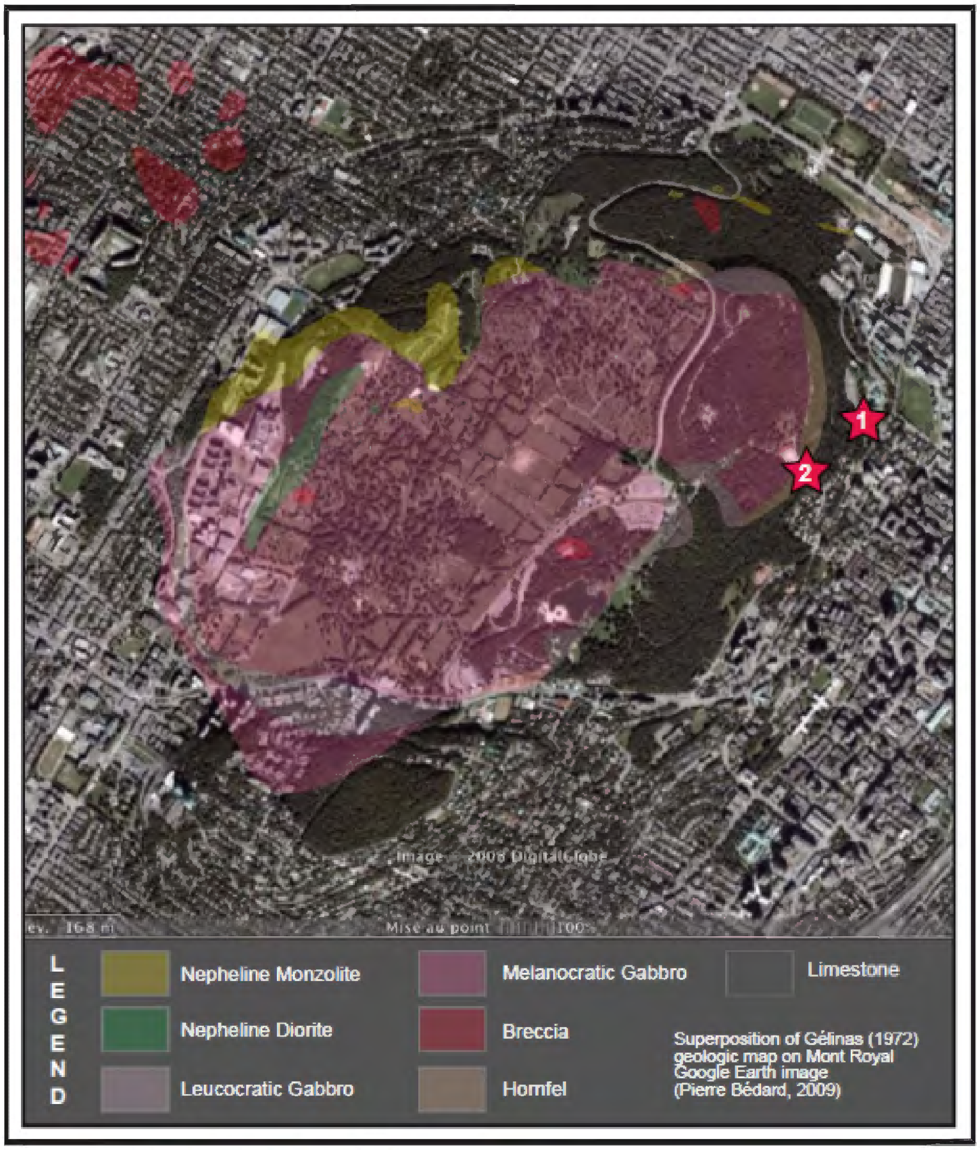


Photo 1. Le rocher calcaire situé à côté du monument Mc Tavish est partiellement métamorphisé, ce qui a probablement causé la disparition des plans de faiblesse liés aux lits de shale. Un réseau de fractures verticales isolent des monolithes spectaculaires.

Photo 2. Vue de l'est depuis le mont Royal vers les collines montérégiennes.

Figure 3. Photographs of mount Royal and the surrounding geologic domains. (Courtesy of Dr. Pierre Bédard, all rights reserved, 1998-2009)

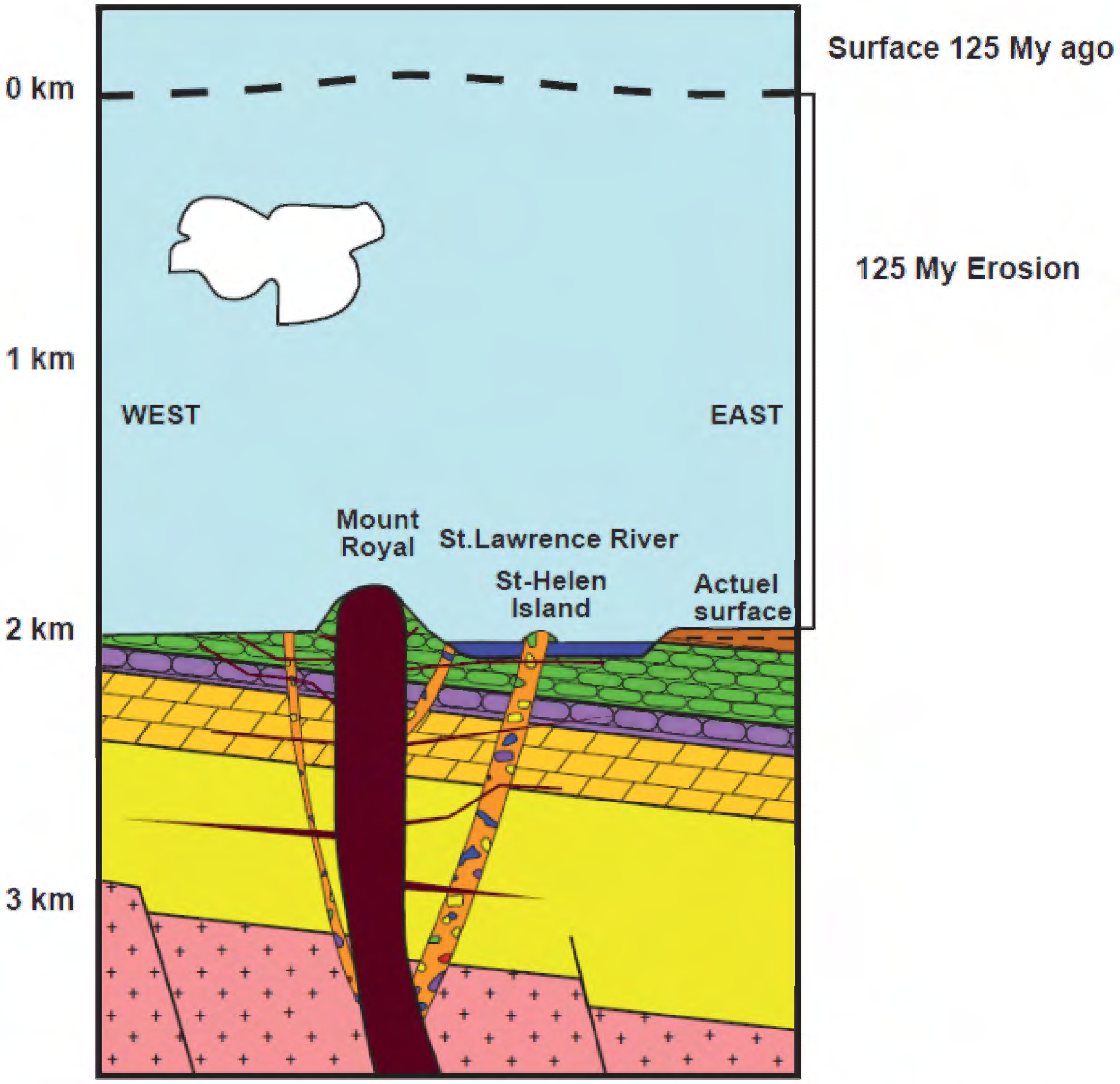


Figure 4. Geological cross section of mount Royal. (Courtesy of Dr. Pierre Bédard, all rights reserved, 1998-2009)

Stop 2: The St. Lawrence Valley

- ***Saint-Césaire, exit 48 on Highway 10***

In the Montreal region, the St. Lawrence Platform consists of rocks formed between ~500 and 400 Ma (Cambrian to Ordovician) in the warm and shallow Iapetus Ocean that bordered much of the Canadian Shield. Over time, the accumulation of numerous sediment layers solidified the material and formed large horizontal beds of relatively undeformed rocks. In the St. Lawrence Valley, this sequence of sedimentary rocks can be up to 2,000 metres thick. (Fig. 5. Clark, T.H., 1972)

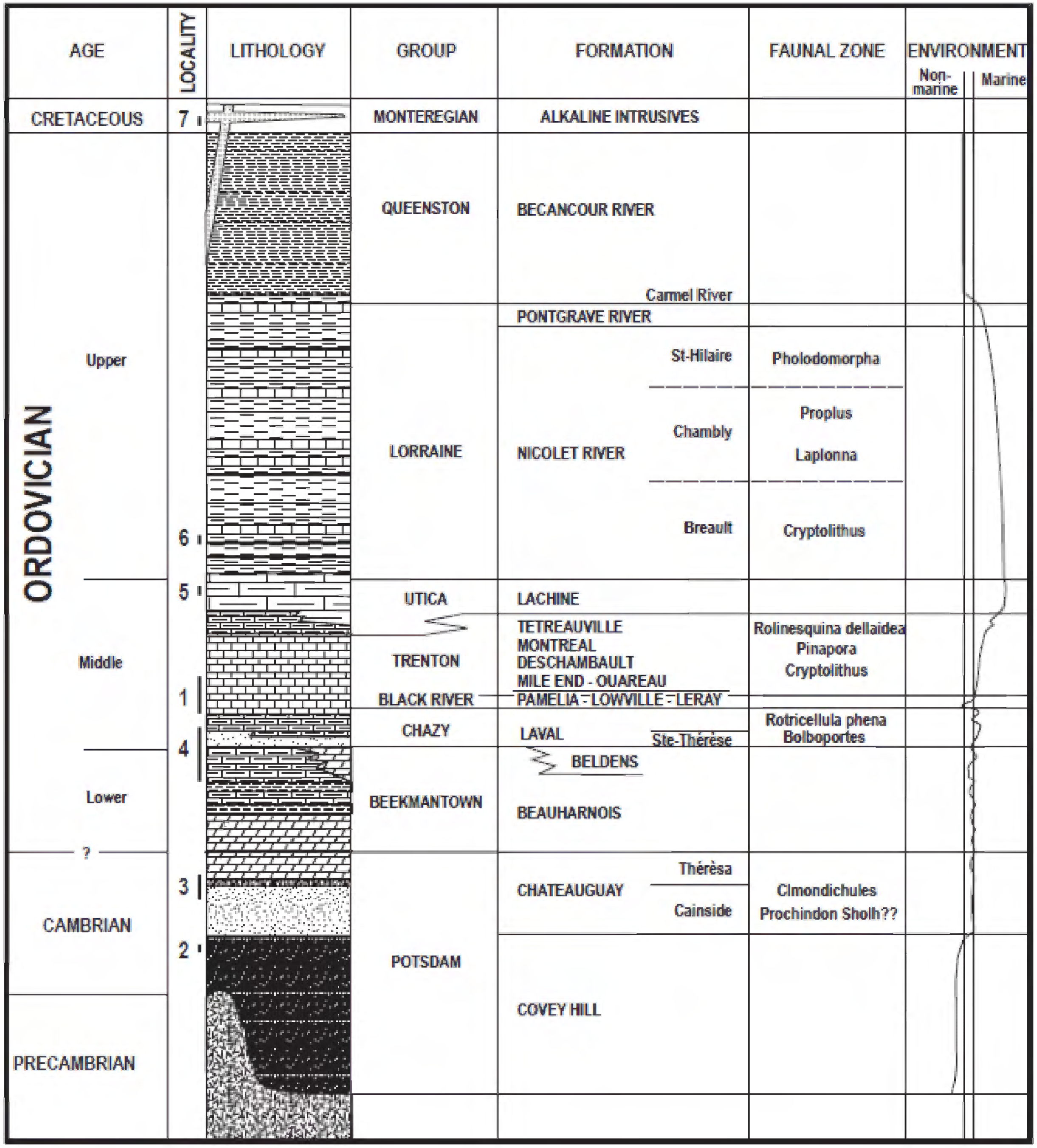


Figure 5. Stratigraphic column for the sedimentary cover in the Saint Lawrence Valley. (After Clark. T.H., 1972)

Regional stratigraphic context

Significant advances have been made over the last few decades in developing a chronostratigraphic framework for the Saint-Lawrence Lowlands and Appalachians. Many authors have contributed to its construction (Karrow, 1957; Gadd, 1971; McDonald and Shilts, 1971; Lamothe, 1985; Parent, 1987, etc.).

Figure 6 illustrates the generally accepted stratigraphic setting for the Saint-Lawrence Lowlands.

The age of the oldest glacial unit documented in the region, the Bécancour Till, has been interpreted as early wisconsin based on the absence of an interglacial sequence defined by oxygen isotope stratigraphy (Lasalle, 1982). This unit is bounded by glaciolacustrine rhythmites: Cap Lévrard Varves at the base and Pierreville Varves at the top (Fig. 7). The assemblage was overlain by fluvial and lacustrine sediments (Pierreville Sediments) during oxygen isotopic stage 3, which is middle wisconsinan in age. In addition to the sediments briefly described above, this sequence also includes peat horizons for which dating studies indicated an age between 66 and 74 ka (Dreimanis, 1960; Stuiver, 1978).

The return to glacial conditions is marked by another varve sequence (the Déschaillons Varves) found in direct contact with organic sands that can be correlated with the St-Pierre sequence. The varves are evidence of a water blockage caused by the advancing ice sheet. This last advance was also responsible for the deposition of the uppermost till in the region, the Gentilly Till.

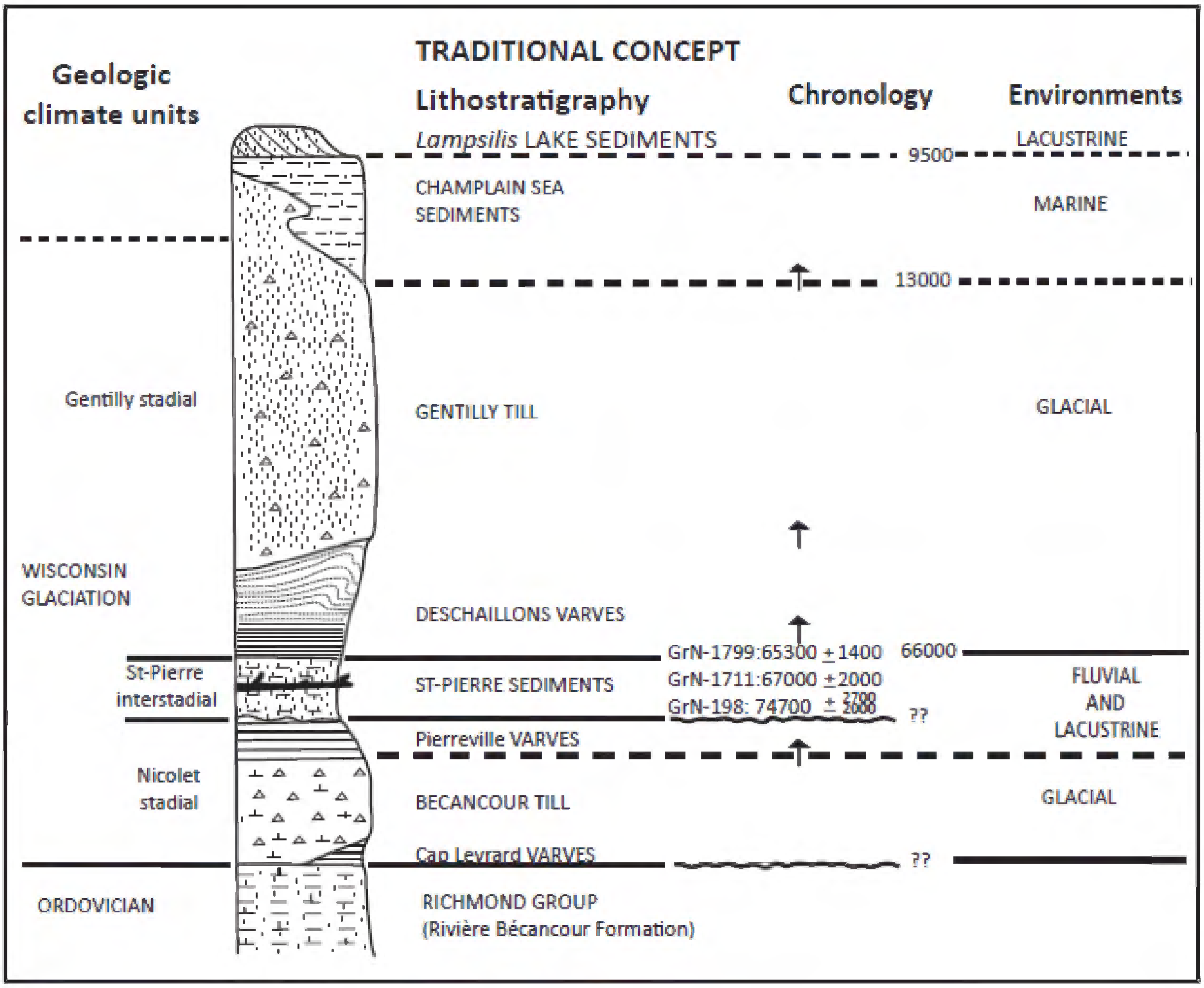


Figure 6. Chronostratigraphic framework for the Saint Lawrence Lowlands. (After Gadd, 1971 and Karrow, 1957)

During the subsequent glacial retreat, an arm of the Atlantic Ocean invaded the isostatic depression left by the melting ice sheet (around 12 ka). The Champlain Sea filled the topographic depressions with clay, silt and sandy littoral deposits, levelling off the northern part of the region. This oceanic arm gradually became cut off from the Atlantic, and the residual waterbody became increasingly briny. The appearance of a freshwater mussel community (Lampsilis) marked the end of the Champlain Sea and the beginning of Lampsilis Lake. Lac St-Pierre is all that remains of this waterbody today.

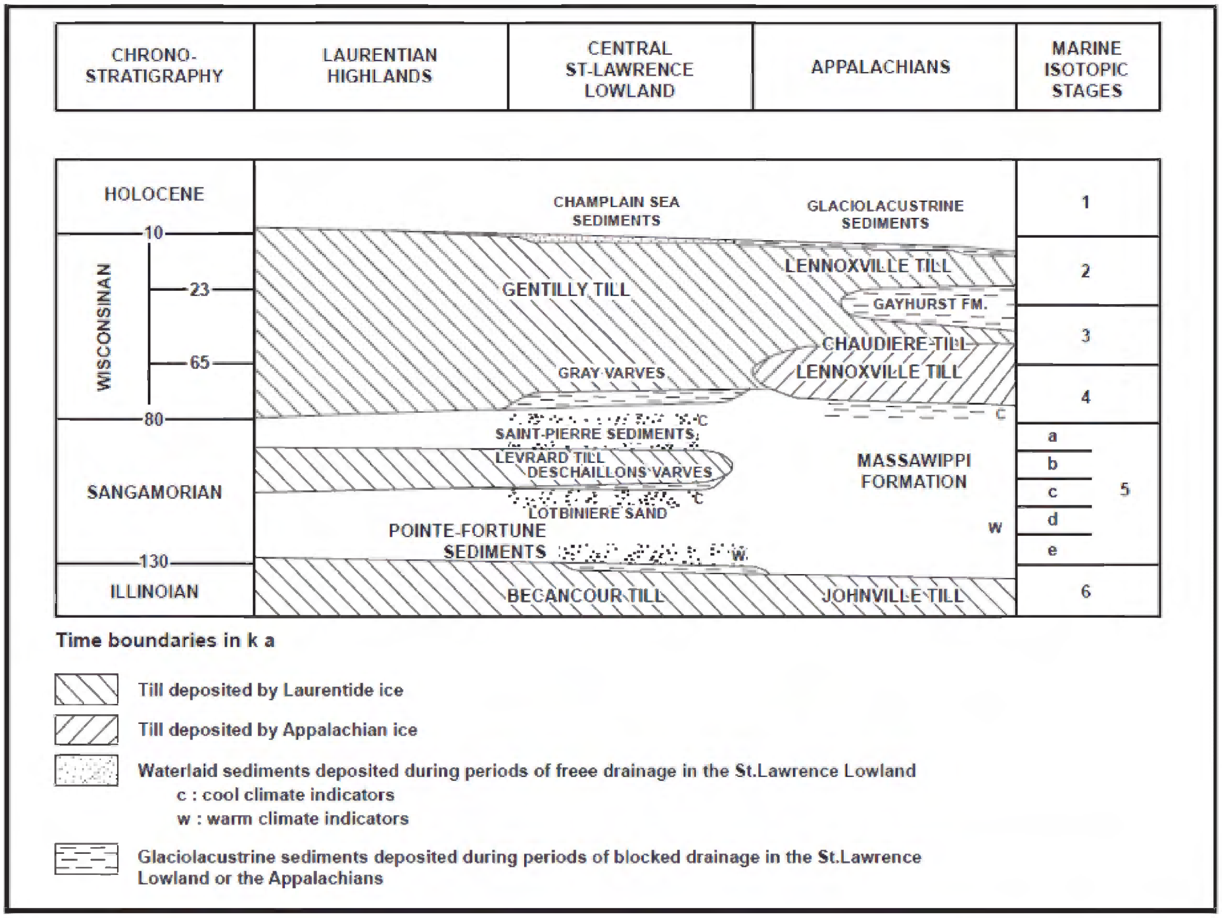


Figure 7. Stratigraphic correlations between the St. Lawrence Lowlands and the Appalachian region. (After Parent, 1987)

St-Césaire (Des Coteau) sandpit stop:

This stop, near the town of St-Césaire, will provide us with an opportunity to examine several interesting features of the Quaternary geology in the Saint. Lawrence Lowlands. In addition to the site's geological interest, the stratigraphic succession sheds light on important aspects of Quaternary geology–groundwater interactions.

The St-Césaire sandpit (now known as the Des Coteaux sandpit, owned by Mr André Viens) is located about two kilometres southwest of the town bearing the same name, on Chemin St-François (Fig. 8). It has been excavated for more than forty years.

Although there is not an abundance of stratigraphic diversity to be seen at this site, the sandpit is nevertheless noteworthy for its visible sequences, its sedimentary architecture, and the fossil content of its Champlain clays.

Figure 8. Localisation of « du Coteau » sandpit. (From Google Earth)

LaSalle (1982) worked in this region, particularly at the St-Césaire sandpit. The following figure illustrates the interpretation for the deposits observed at St-Césaire and in the stratigraphic profiles at St-Jacques-le-Mineur (Prichonnet, 1984) situated about 50 km to the south-west.

Due to intense excavation in the sandpit over the past thirty years, the sections examined by LaSalle (1982) no longer exist (Fig. 9). LaSalle reported on drilling data that revealed the presence of till at depth under the deformed (faults, load casts, etc.) sands and gravels. The assemblage was overlain by a second glacial unit known as the St-Jacques Till in reference to the till mapped at St-Jacques-le-Mineur by Prichonnet (1984).

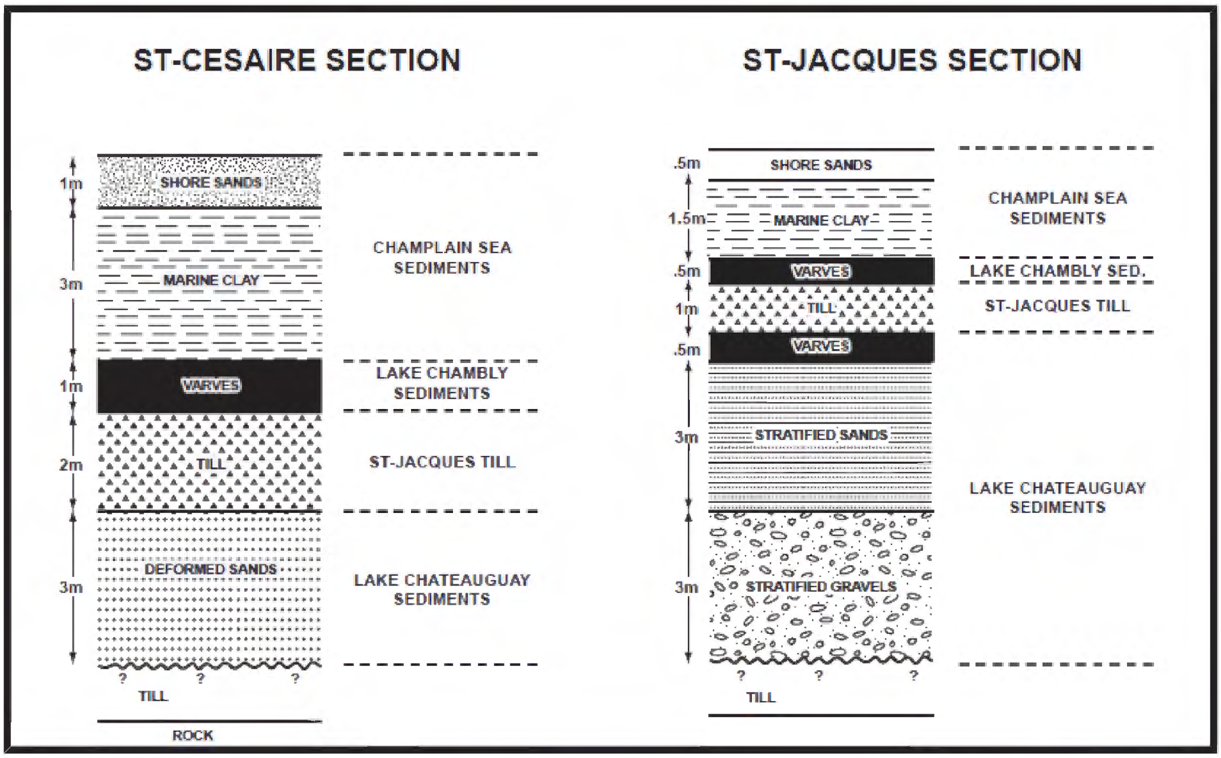


Figure 9. Stratigraphic interpretation of the St-Césaire sandpit and St-Jacques-le-Mineur. (From LaSalle, 1982)

Stop 2.1

This part of the sandpit provides a wonderful window into the fluvioglacial assemblage (Fig. 10). From the floor of the sandpit, we can see a major esker-type ice-contact sequence about 10 metres thick. The sequence displays many grain size changes and current structures (ripples, crossbeds, etc.). The conical and elongated structure and the sediment's size variations suggest that this sequence should represent an esker. The predominance of the sand fraction and the mainly horizontal sand bedding could also indicate a subglacial outwash. Figure 5 shows a genetic model of an esker and the associated subglacial outwash.

Many ripple marks are present in the sequence. Overall, the paleocurrent measurements indicate that ice flow was to the south-southeast (~158°). In addition, several normal faults are visible in the core of the structure, attesting to the effects of glacio-tectonic deformation (caused by the melting of buried ice blocks) or the release of stresses following the glacier's retreat.

At the summit, the esker is draped by finer sediments signalling the retreat of the ice margin. These fine sediments locally display deformation caused by gravity flows on the slopes of the esker or the emplacement of the overlying glacial unit. At the upper contact of the unit is a compact diamictic sequence measuring several metres thick on the slopes of the fluvioglacial butte and less than a metre near the top. It is surprising to come across this stratigraphic assemblage because it would seem unlikely that a loose body of sediments like an esker could resist glacial erosion. The proximity and position of Mount Rougemont must have certainly played a role in protecting the sequence.

LaSalle (1982) correlated this sequence to the St-Jacques Till. No mention was made about the underlying fluvioglacial unit, and the sands and gravel visible at the time were interpreted as Lake Chateauguay glaciolacustrine deposits.

This stratigraphic framework appears to be a recurrent feature of the region. Sections examined elsewhere in the contiguous basins of the Yamaska and Richelieu rivers display essentially the same stratigraphic succession. In addition, geophysical profiles constructed using vibrating trucks also seem to indicate the presence of a buried esker or at least fluvioglacial sequences under the surface clays and till. Other than its scientific interest, this setting also represents excellent potential in terms of groundwater resources.

Stop 2.2:

This second stop near the entrance displays distal sandy outwash and massive rhythmic silts in contact with the uppermost till. Paleocurrent measurements taken in the sands at the base of the section still indicate a flow direction to the south-southeast (~162°).

Although no contact has ever been clearly observed between the till and the uppermost marine clays, this succession is nonetheless assumed.

Finally, a small pocket of marine sediments was preserved nearby. About two metres of fossiliferous clays are visible, overlain by littoral sands. We can observe a fossil assemblage of *Macoma Balthica, Mytilus Edulis, Hiatella Arctica* and *Thethya Logani.*

The figure 11 presents the results of the paleoecologic analysis for this marine sequence.

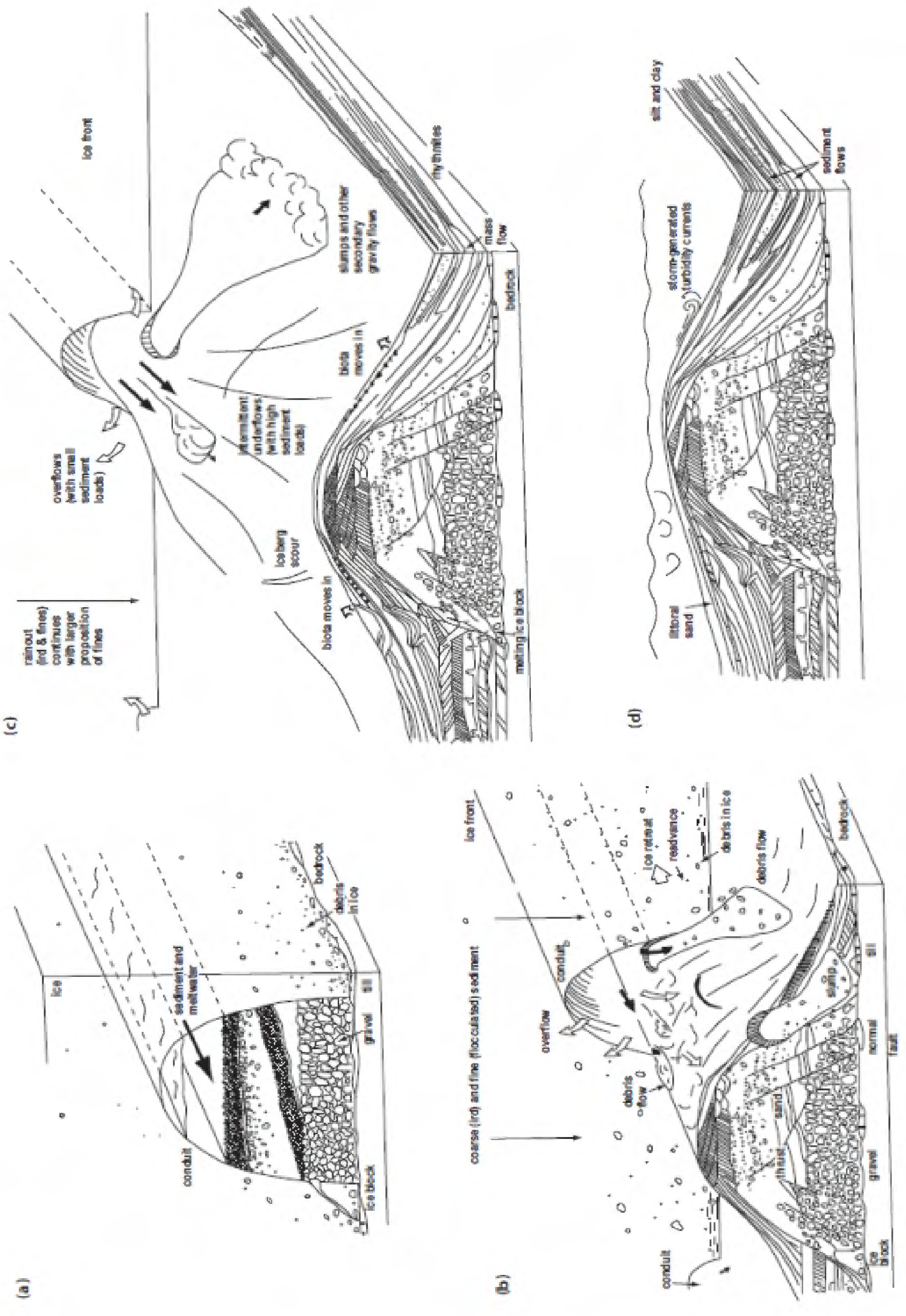
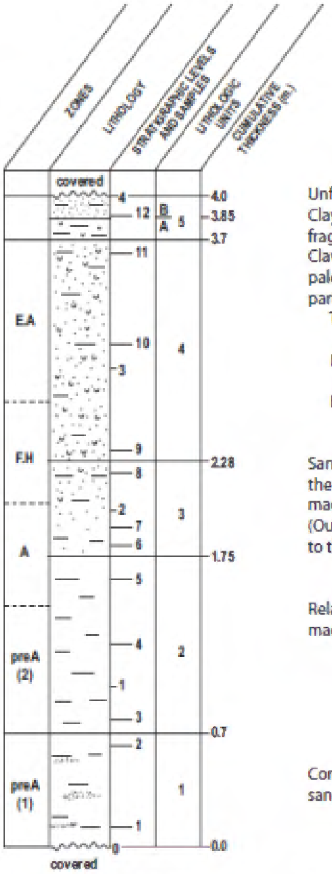


Figure 10: Model showing the formation of an esker and associated subaqueous fluvioglacial outwash. A) Infilling of the sub-glacial tunnel by rising melt waters. B) Ice margin retreat, stress release and debuttressing leading to the formation of normal faults and mudflows. C) Draping of the fluvioglacial assemblage by fine sediments due to the increasing distance to the ice margin. D) Reworking by water and turbidity currents. (Benn and Evans, 1998)



DESCRIPTION		PALEOECOLOGIC DESCRIPTION (Zoning of Guilbaut, 1980) based on foraminifer and osttracod fauna.
Unfossiliferous clavey sand Clay with few indeterminate macrofossils fragments Clavely sand packed with disarticulated palecypod valves. The sediments is at least partly shell-supported. Macrofossils: Top: Macoma balthica, Mytilus edulis scattered Hiatella arctica Middle: Hiatella arctica, scattered Mytilus edulis Base: Hiatella arctica, Mya truncata	EA	Paleosalinity variable but probably not more than 10% at the top of the unit. Water depth very shallow, possibly no more than a few meters but as the material appers reworked, the actual depth might have been greater. There is evidence for a water temperature increase in this zone compared to the underlying zones, but this might be only a consequence of reduced depth.
Sandy clay to clavey sand, more sandy in the upper part. Few small indeterminate macrofossils. Scattered large foraminifers (Ouinqueloculina seminulum) are visible to the naked eye.	EH	Paleosalinity highly variable with a maximum prbably lower than zone A. Water depth maximum 20 m. The abrupt lithological change in the middle of the zone correlates with a faunal change suggesting a decrease in the water depth. This can be explained if the shell bed is assumed to be formed of material washed down from shallower water by wave or tidal action.
Relatively soft clay. Few small indeterminate macrofossils in the upper part of the unit	A	Paleosalinity in the range of 25 to 30%. Water depth 20 to 30 m or more. This is the main deep water facies of the Champlain see with near to normal marine conditions.
	pre A (2)	Freshwater to ologohaline (maximum salinity 2 to 3%). water depth unknown.
Compact clay with irregular bands of fine sand.	pre A (1)	No reliable evidence available. Probably freshwater to oligohaline. water depth unknown.

Figure 11. Paleoecologic analysis of the Champlain Sea sediments in the sandpit, LaSalle (1982).

Stop 3: Cambrian transitional metabasalts of the Tibbit Hill Formation, Oak Hill Group

- ***exit 90 on Highway 10***

The Oak Hill Group is a fault-bounded lithostratigraphic sequence originally described in the Cowansville region on the northwest limb of the Mount Pinnacle anticline. It was subsequently recognized from the Vermont border to the village of Danville near Asbestos (Cooke, 1955; Osberg, 1965; Globensky, 1995). The original nomenclature underwent several changes over time (Table 1).

PERIOD	EPOCH	GROUP		FORMATIONS					
ORDOVICIAN	Middle			Clark 1936	Cooke 1952	Osberg 1965	Globensky 1978	Charbonneau 1980	Marquis 1989
	Early	OAK HILL	upper		Melbourne				Melbourne
CAMBRIAN	Early			Sweetsburg	Sweetsburg		Sweetsburg		
				Scottsmore	Dunmore	Sweetsburg	Scottsmore	Sweetsburg	Sweetsburg
				Oak Hill					
				Dunham			Dunham	Dunham	Dunham
						Gilman		Cheshire	Gilman sup.
				Gilman	Gilman	Bonsecours	Bonsecours	Frelighsburg	
				West Sutton	Stukely			West Sutton	Gilman inf.
			lower	White Brook				White Brook	White Brook
				Pinnacle	Pinnacle	Pinnacle	Pinnacle	Pinnacle	Pinnacle
				Call Mill	Call Mill		Call Mill	Call Mill	Call Mill
				Tibbit Hill	Tibbit Hill	Tibbit Hill	Tibbit Hill	Tibbit Hill	Tibbit Hill
					Racine				

Table 1. Stratigraphic correlation for the Oak Hill Group. (After Marquis, R . and Nowlan, G., 1991).

The Oak Hill Group rests on the Grenvillian basement, which subsided during the opening of the Iapetus Ocean. This basement rock crops out in Vermont along the southern extension of the anticline (Christman and Secor, 1961).

The units of the Oak Hill Group formed in an intracratonic rift environment that evolved into a continental platform. The transition corresponds to an early Cambrian marine transgression. This rift-drift transition has been dated between 550 and 570 Ma (Williams and Hiscott, 1987). It is defined by the change from volcano-clastic sedimentation of variable thickness and extent, to shallow marine sedimentation, first siliciclastic then carbonate, which uniformly extended over greater distances. The oldest rocks of the Oak Hill Group occur in Québec and were dated at 554Ma by U/Pb on zircon from a rhyolite of the Tibbit Hill Formation that was sampled in the Waterloo region (Kumarapeli *et al.*, 1989). The youngest marine sediments in the Oak Hill Group are represented by a graphitic black limestone intercalated with black phyllite, which is part of the Melbourne Formation. Mainly preserved in the centroclinal summit of the Mount Pinnacle anticline, this limestone contains rare fragments of conodonts from late Arenig to early Llanvirn time (Marquis and Nowlan, 1991). Two thin sandy dolomitic units with variable composition may mark unconformities within the Oak Hill Group.

The Tibbit Hill road cut outcrop along exit 90 of the Eastern Townships autoroute (Highway 10) (Fig. 12) displays the most common facies in this transitional volcanic formation metamorphosed to greenschist facies (Fig. 13). The Tibbit Hill Formation of the Oak Hill Group is represented by three lithologies: fine-grained schist containing chlorite, epidote, plagioclase and magnetite, intercalations of a bluish phyllite of sedimentary origin, and lava flows that mark the upper and lower limits of the formation (Fig. 14). Isotopic dates for these lava flows reveal that they were emplaced during the rifting phase of the Iapetus Ocean (Kumarapeli *et al.*, 1989). Amygdules in the flows (Fig. 15) serve as kinematic markers, indicating tectonic transport to the northwest (D1?). However, the regional S2 schistosity dips to the northwest, and this is taken as evidence of southward backthrusting during D2.

Figure 12 (left). Outcrop of the Tibbit Hill Formation. Road cut along Highway 10, exit 90.

Figure 13 (right). Tibbit Hill Formation. Greenschist facies. Chlorite-epidote schist.

Figure 14 (left). Contact between the schists and phyllite of the Tibbit Hill Formation.

Figure 15 (right). Amygdules filled by quartz and feldspar. Note the direction of the flow.

Stop 4: The Brompton–Baie Verte Line, a major suture in the Appalachians of southern Québec: Serpentinites exposed at the Orford rest stop

Williams (1979) divided the Cambro-Ordovician rocks into five tectono-stratigraphic zones: Humber, Dunnage, Gander, Avalon and Meguma. The Humber and Dunnage zones are remnants of the Laurentian margin and the adjacent oceanic domain, respectively. The Humber zone are considered part of Notre Dame subzone (Van Staal et al., 1998). The seismic reflection data show that this subzone is allochtonous and structurally underline by the Grenville margin.

The Dunnage Zone groups together the Cambro-Ordovician oceanic deposits, of which a large part is tectonically dismembered. The western limit of the Dunnage Zone is occupied by a corridor of intense deformation along which numerous slivers of ultramafic rocks crop out, representing dismembered oceanic crust. The largest slivers form the ophiolitic complexes of the Estrie-Beauce region, and their NE-SW alignment defines the Brompton–Baie Verte Line. The eastern limit of the Dunnage Zone corresponds to the Guadeloupe Fault (David, J. and Marquis, R., 1994).

According to Tremblay and Castonguay, (2002), the Brompton–Baie Verte Line is a major normal fault () in the Québec Appalachians marked by serpentinized ultramafic rocks. The fault exposes ophiolitic complexes and serpentinized ultramafic lenses that were emplaced during the upper Ordovician taconian orogeny. These complexes and lenses were subsequently affected by the middle Devonian Acadian orogeny.

The Estrie-Beauce ophiolites can be distinguished from most other complexes because they were formed in a subduction setting along a developing rift, and not along a mid-ocean ridge, which is usually the case. Ophiolites formed in subduction zones have the tendency to be boninitic in composition, rich in magnesium and poor in titanium. This particular characteristic may explain the ophiolites' great endowment in chromium-platinum and copper (Gauthier et al., 1989). Numerous mineralized showings, copper deposits and talc deposits are known in this segment of the Brompton–Baie Verte Line structural complex.

The serpentinites exposed at this outcrop (Fig. 16) form part of the Orford ophiolitic Complex (Figs. 17, 18 and 19) and the Brompton–Baie Verte Line (BBL) structural complex. The serpentinite is massive to crystalline, dark green, and may display a fibrous texture. It is essentially composed of antigorite, chlorite, talc, calcite and chrysotile, and displays anastomosing cleavage. These rocks were affected by the Middle Devonian Acadian deformation that is typical of the Dunnage Zone.

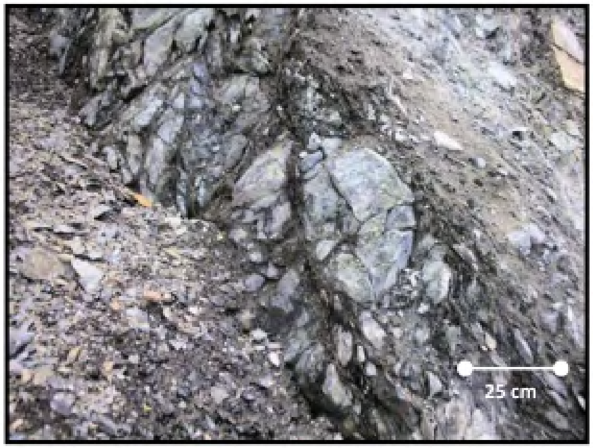


Figure 16 (left). Serpentinites at the base of the Orford Ophiolitic Complex

Figure 17 (right). Base of the Orford Ophiolitic Complex

Figure 18 (left). View of Mount Orford looking west

Figure 19 (right). View of Mount Orford looking east from rest stop 112

Stop 5: Black Ordovician mudslate of the Magog Group, contemporaneous with limestones of the St. Lawrence Lowlands

- ***Exist 115 on Highway 10***

The bedrock in the Sherbrooke region (Dunnage Zone, internal nappe) consists of three main units: the Ascot Complex (Lower to Middle Ordovician), the Magog Group (Middle to Upper Ordovician), and the Saint-Francis Group (Silurian to Devonian).

The Magog Group is oceanic in nature (Slivitzky, A. and St-Julien, P., 1985). Stratigraphically, it is divided into four formations. From base to summit: Frontière, Etchemin, Beauceville, and Saint-Victor.

- Frontière Formation: This formation only crops out in the northeastern Estrie-Beauce region. It consists of alternating green feldspathic sandstone and green mudslate. The sandstone beds range from 10 centimetres to 2 metres thick.

- Etchemin Formation: This formation consists of volcaniclastics and green mudslate. At its base, the mudslate is interbedded with purple mudslate. In the upper part, the mudslate is interbedded with green felsic volcaniclastics and some cherty siltstone horizons. It crops out only in the northeastern Estrie-Beauce region. The cherty siltstone was used by the first inhabitants of the area to make stone tools.

- Beauceville Formation: Exposures of this formation can be found throughout the Estrie-Beauce region and form a NE-SW band. The formation consists of graphitic schists interbedded with tuffaceous arenites, acid tuffs, and chert beds. An Ordovician age was assigned to the formation based on graptolite dating, which makes it contemporaneous with formations of the St. Lawrence Valley.

- Saint-Victor Formation: Exposures of this formation, which represents a graptolite zone (*Diplograptus Multidens*), are present throughout the Estrie-Beauce region. Outcrops reveal lithologies typical of sandy pelitic turbidites. The formation consists of a regular alternation of quartzo-feldspathic sandstone, siltstone, and blackish mudslate. The main sedimentary structures are normal graded bedding, ripples, and intraformational breccias. These turbidites are intercalated with felsic pyroclastics. The interstratification of detrital sedimentary rocks with rocks of volcanic origin suggests proximity to a volcanic edifice that was active during Middle Ordovician time.

The rocks of the Magog Group may represent the preserved portion of the fore-arc basin if the group's current position reflects its original position relative to the volcanic arc, supported by the southeast polarity of the subduction zone that was active during Middle Ordovician time (David, J. and Marquis, R., 1994).

The outcrop at this stop displays the hinge of an anticline overturned to the NW (Fig. 20). Faults genetically related to the folding event are also present. Quartz veins are abundant. Slickenlines between the beds are locally visible. The regional S1 cleavage is axial planar to the fold and oriented NE with a steep dip to the SE. Two other foliations are apparent: an S2 cleavage with a dip to the NW, which is only locally present, and an S3 crenulation cleavage with a dip to the NW, which is commonly observed. The latter is marked by fine crenulations that plunge to the NE (Marquis, R. and Tremblay, A., 1993).

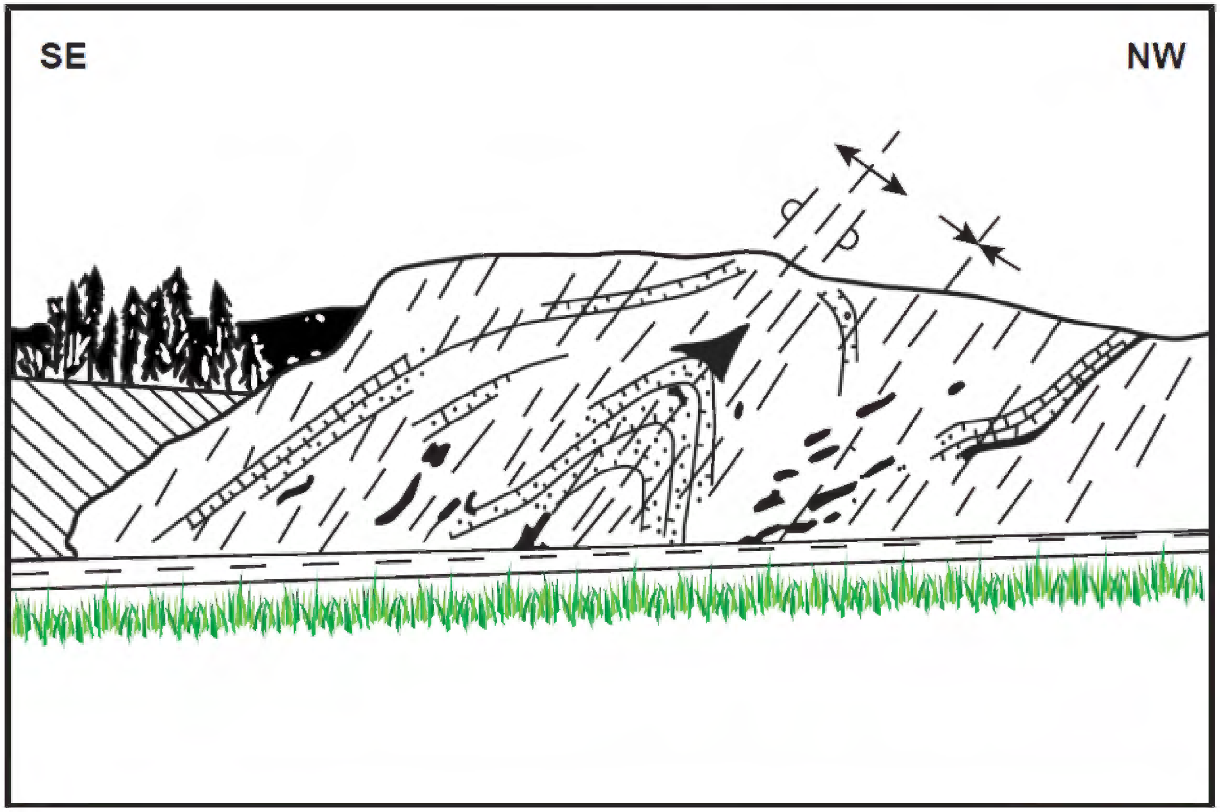


Figure 20. Sketch of the Magog Group turbidite outcrop showing the anticline overturned to the NW.

Stop 6: Visit of a 19th century mine in the Estrie region – the Eustis mine.

A little history…

The Eustis mine produced ore from the time it opened in 1965 until its closure in 1939. While in operation, an estimated 3 million tonnes of pyrite and chalcopyrite ore were extracted at a grade of 3% copper and 40% sulphur. The mine is 6 km from Sherbrooke and 1.3 km from the Massawippi River.

The copper mines of Ascot Township became very important during the American Civil War (1860-1865), which demanded a steady supply of copper for weapons manufacturing. In 1863, the Albert deposit was discovered by prospecting, and just over one year later, in 1865, the mine's lateral extension was discovered, which was named Lower Canada, then Crown.

In 1877, the American mining engineer W.E.C. Eustis purchased a nickel property in the Orford Township and a copper property in the Ascot Township. A young lawyer, R.M. Thomson, accompanied him at the time to examine the property claims. In 1878, they formed the "Orford Nickel and Copper Company". In 1886, W.E.C. Eustis dissociated himself from Thomson and the "Orford" company. He left with the Eustis mine as his parting share. In 1888, he formed the "Eustis Mining Co." Meanwhile, Thomson became involved in a project in northern Ontario with heaps of copper and nickel. The "Orford" company successfully developed a process to separate the copper and nickel and became, in 1912, the "International Nickel Company".

The end of the civil war led to the closure of most of the small copper operations in the Eastern Townships. The Albert–Eustis mines survived thanks to the quality of the deposits and the on-site production of chemical products derived from the extraction of copper. A large mining, metallurgical and chemical complex grew in Capelton.

In 1887, the owner of the Albert mine, G.H. Nichols & Company, built a chemical factory at Capelton that produced sulphuric acid, nitric acid, and gunpowder, all of which were products derived from the extraction of copper. (Figs. 21, 22 and 23)

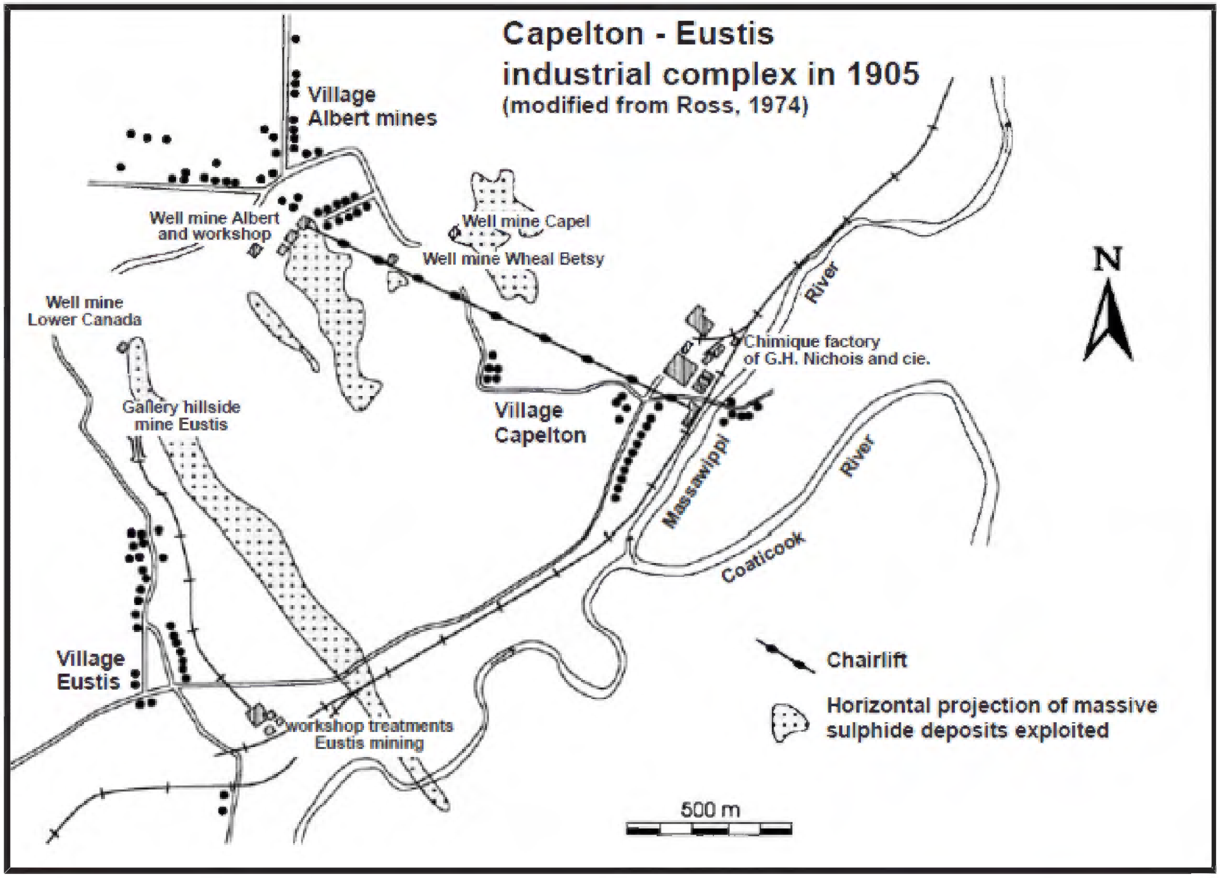


Figure 21. Map of the Capelton–Eustis industrial complex in 1905. (Modified from Ross, 1974).

Figure 22. Factory ruins.

Figure 23. Factory ruins.

The proximity of the railroad and river were considerable advantages for the mining companies. The open-air roasting process for the cupriferous pyrite was fairly straightforward. At the time, sulphuric acid from Capelton was the most concentrated in all of Canada (98%) and the factory one of the biggest in the world.

On more than one occasion, farmers in the area complained about the pollution generated by the facilities. The effect of the pollution on the local environment was already evident in 1876. We can imagine how strong the acid rain must have been, and how devastating its effect on harvests and animals, etc. (Fig. 24)

From the time it opened in 1865 until its closure in 1939, the Eustis mine produced 1,610,800 tonnes of ore at a grade of 2.7 % copper. In 1971, estimated reserves were 90,700 tonnes at 1% copper.

For more information please visit:
http://gsc.nrcan.gc.ca/mindep/synth_prov/appalachian/index_e.php

Mining

Two types of technology were used to extract the ore:

1. Pyrite roasting, which caused considerable air pollution and created local acid rain with disastrous effects on harvests and animals. On the other hand, only a small amount of solid residue was produced by this method, and this waste was easy to store and resistant to erosion. The solid residue was iron oxide, and this explains the red soil of Capelton.

2. Copper recovery was done by grinding the ore and using flotation cells and heavy liquids to separate the copper from the iron. The copious amounts of fine-grained barren waste were disposed of in a very acid form that quickly contaminated the nearby river. The impact of this waste on the countryside was very significant. Wind erosion has transported large amounts of the waste toward the river since the site was abandoned. The sediment is so acidic that it destroys the plants on which it lands.

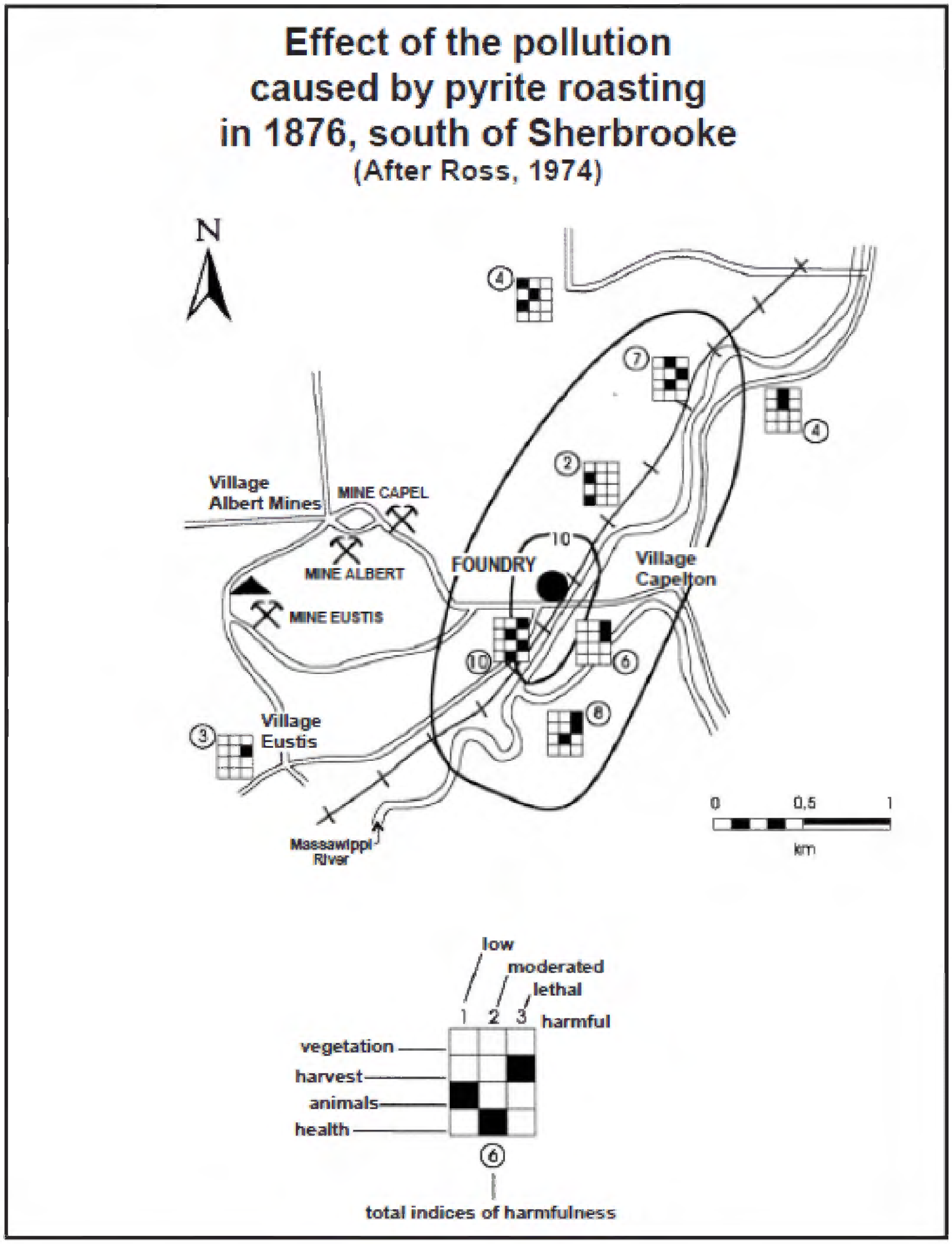


Figure 24. Effect of the pollution caused by pyrite roasting in 1876, south of Sherbrooke. (After Ross, 1974)

Mine rehabilitation

In 2006, the *Ministère de Ressources naturelles et de la Faune*, in collaboration with the *Fondation des lacs et des rivières du Canada* and the *Fondation des villages miniers de Capelton* prepared a rehabilitation plan for the Eustis site. The chosen method consisted of covering the mine tailings with materials that are impermeable to oxygen. The goal is to prevent oxidation, rain and melt water infiltration, and acid mine drainage (Figs. 25 and 26).

Figure 25 (left). Confinement and revegetation of the Eustis mine tailings

Figure 26 (right). Revegetated mine tailings at Eustis

Mine geology

The Eustis mine is a copper-rich massive sulphide body hosted in volcanic island arc rocks that were deformed and metamorphosed to greenschist facies. These rocks belong to the Ascot-Weedon belt, which lies east of the fore-arc basin (Magog Group). This belt encompasses relatively complete sections of strongly tectonized volcanic edifices (Gauthier et al., 1989). The Ascot–Weedon Formation is divided into two districts (Slivitzky, A. and St-Julien, P., 1987): Sherbrooke (Eustis mines) and Stratford-Weedon. These two districts are distinguished by the geometry of their volcanic edifices and by their levels of erosion. The Sherbrooke district appears to correspond to the proximal facies of composite volcanoes. The Ascot volcanic complex is interpreted as the remnants of an island arc related to the convergent phase of the Taconian orogeny during Middle Ordovician time. A study by David, J. and

Marquis, R. (1994) on inherited zircons indicated that this closure did not occur during middle Ordovician time; instead, the thrusting responsible for the imbrication in the Dunnage Zone must have occurred during a period lasting from lower Silurian time until the D3 deformation associated with the Acadian, not Taconian, phase. Mineralization is linked to the closure of the Iapetus Ocean and the formation of island arcs (Gauthier *et al*., 1989, page 229).

In the Eustis mine, the Guadeloupe tectonic corridor (Fig. 27) dislocates the Ascot-Weedon Formation. The fault is a ductile deformation corridor decametres wide that likely follows an anastomosing path along the northwest edge of the Gaspé-Connecticut Valley Synclinorium. It is interpreted as an Acadian thrust that transported the deformed, but little metamorphosed, Silurian and Devonian sedimentary sequences to the northwest (David, J. and Marquis, R., 1994).

Figure 27. Massawippi River and the sun setting over the Guadeloupe Fault.

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