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Purpose

This field trip guidebook presents a synthesis of the lower to middle Paleozoic stratigraphic architecture and paleogeographic scenarios for the sedimentary basins in southern Québec. The field trip will provide an opportunity to examine the Upper Ordovician Utica Shale and Lorraine Group flysch that were deposited in the Taconian foreland basin of southern Quebec. Cores presenting some aspects of the lateral variability of the internal facies architecture of the Utica will be examined during the first day whereas visits to key outcrops located in the Québec City area are planned during the second day to look at the overall Upper Ordovician stratigraphic architecture and primary facies distribution.

Regional Setting

Rocks ranging from the Neoproterozoic to the end-Mesozoic are found onshore eastern Canada (Fig. 1). Major deformation events documented in the Appalachians and are related to the accretion of volcanic arcs, oceanic crust, microcontinents and continents to the progressively more and more composite margin of Laurentia (van Staal et al., 1998; van Staal, 2005).

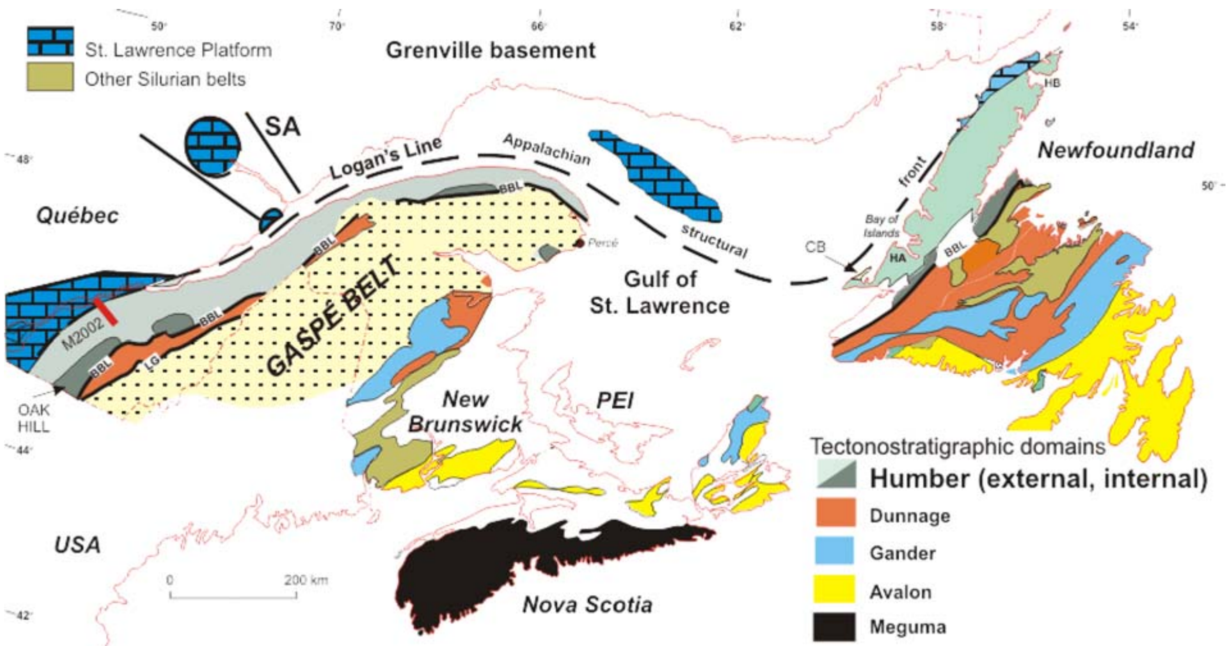

Figure 1. Early Paleozoic tectonostratigraphic domains and the Silurian-Devonian basin (Gaspé Belt) of the Canadian Appalachians. The Taconian belts are bordered to the northwest by the St. Lawrence Platform and the Grenville orogen of the Laurentia craton and are locally overlain by successor basin deposits. BBL: Baie Verte Brompton Line, LG: La Guadeloupe fault, SA: Saguenay Graben, Modified from Williams (1995) and Lavoie (2008).

In this overview, we only consider the time interval ranging from the Cambrian to the Late Ordovician. In southern Québec, this time interval covers the rift, passive margin and syn-orogenic (Taconian) episodes. An irregular-shaped continental margin with recesses and salients (Fig. 2) characterized the paleo-continental margin of Laurentia (Thomas, 1977, 1991). The shape of the margin played a significant role in the evolution of the cratonic St. Lawrence platform in eastern Canada (Stenzel et al., 1990; Lavoie 1994; Sharma et al., 2003).

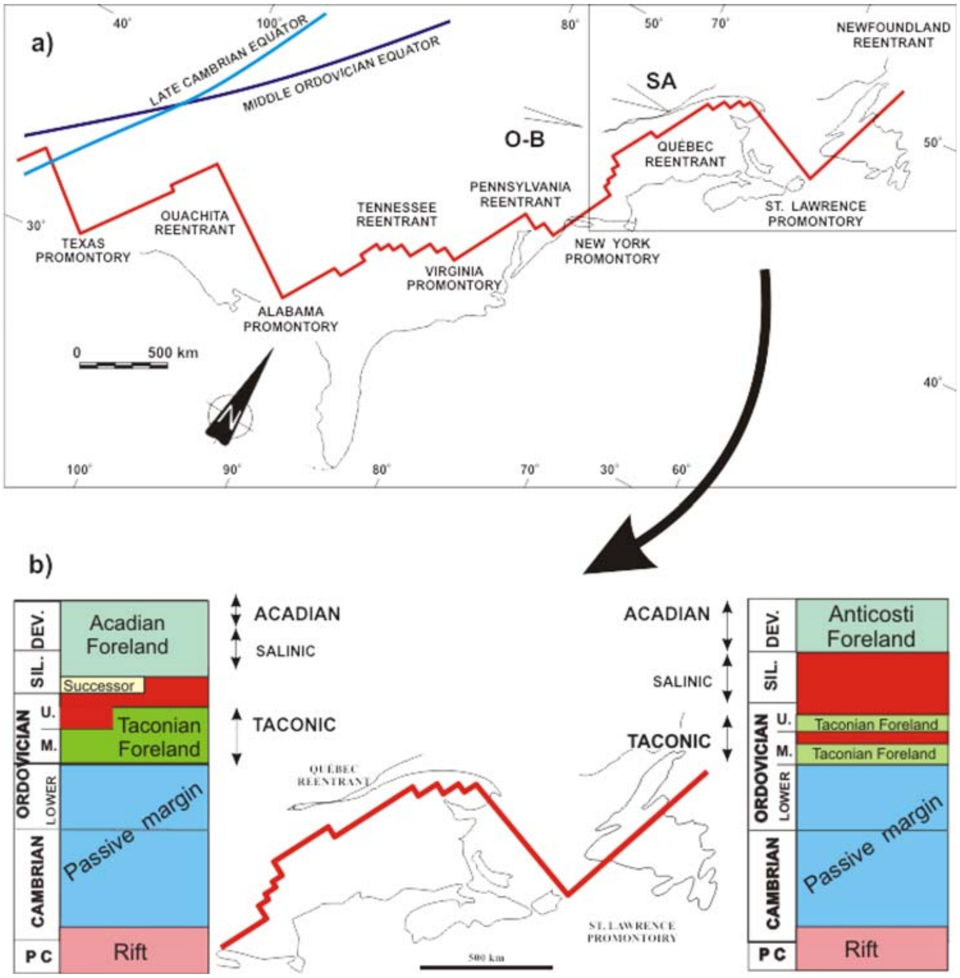

Figure 2. a) The Lower Paleozoic continental margin of Laurentia with the distribution of reentrants and promontories. O-B: Ottawa Bonnechère Graben, SA: Saguenay Graben. Modified from Thomas (1977, 1991) and Lavoie (2008). b) General tectonostratigraphic event zonation of the Québec Reentrant and St. Lawrence Promontory together with the most significant tectonic events.

The St. Lawrence platform is classically defined as the autochtonous sedimentary cover of the north-American craton. The St. Lawrence Platform (*sensu* Sanford, 1993) has been divided in western (Michigan and Alleghany basins), central (Ottawa Embayment and southern Quebec) and eastern (Anticosti and western Newfoundland) segments.

The St. Lawrence Platform is limited to the west by the Neoproterozoic metamorphic – intrusive units of the Grenvillian Orogen (Davidson, 1996; Rivers, 1997); the contact being either faulted or an unconformity (Fig. 3). On its eastern and southeastern side, the St. Lawrence Platform is in tectonic contact (Logan's Line or Fault in Quebec) with Cambrian-Ordovician of the Appalachian Humber Zone (Fig. 3) (Williams, 1976). In the Humber Zone, stacks of tectonic slices of Neoproterozoic basement and Lower Cambrian to Upper Ordovician rocks of Laurentia continental affinity (St. Lawrence Platform and coeval slope and rise sediments) are deformed and trusted over the St. Lawrence cratonic platform in a thin- to thick-skinned tectonic scenario (St-Julien and Hubert, 1975; Williams, 1978; van Staal et al., 1998; Waldron et al., 1998, 2003;

Stockmal et al., 1998, 2004; Glasmacher et al., 2003; Pincivy et al., 2003).

In Canada, detailed information on the rift, passive margin and foreland basin evolution of the shallow marine lower Paleozoic continental margin platform is available for western Newfoundland (James et al., 1989) and Anticosti (Desrochers, 1988; Long, 2007) and their coeval slope successions are well-studied (James and Stevens, 1986; James et al., 1989; Lebel and Kirkwood, 1998; Waldron and Palmer, 2000; Burden et al., 2001; Palmer et al., 2001; Waldron et al., 2003; Lavoie et al., 2003). Similarly, the information on the evolution of the Ontario segment of the platform can be found in Sanford (1993) and recently updated with subsurface information (Armstrong and Carter, 2006).

In southern Québec, slices of the St. Lawrence Platform units form a spatially restricted frontal Taconian deformation zone known as the "parautochthonous" or imbricated fault domain (St-Julien and Hubert, 1975; Comeau et al., 2004; Fig. 3). Outside of this domain, platform rocks were considered as marginally involved in tectonic stacking. Reprocessing and reinterpretation of seismic data indicate however that the St. Lawrence Platform records significant Taconian (?) compressive deformation and is affected by triangle zones and blind thrusts (Castonguay et al., 2003; 2006). The relative timing of deformation on the continental margin in the Québec Reentrant has been traditionally inferred from biostratigraphic age (St-Julien and Hubert, 1975). Recent $^{40}Ar/^{39}Ar$ and K/Ar metamorphic ages confirm the "classic" Middle to Late Ordovician Taconian age (Castonguay et al., 1997; Glasmacher et al., 2003; Pincivy et al., 2003) for the early deformation event on the continental slope margin successions.

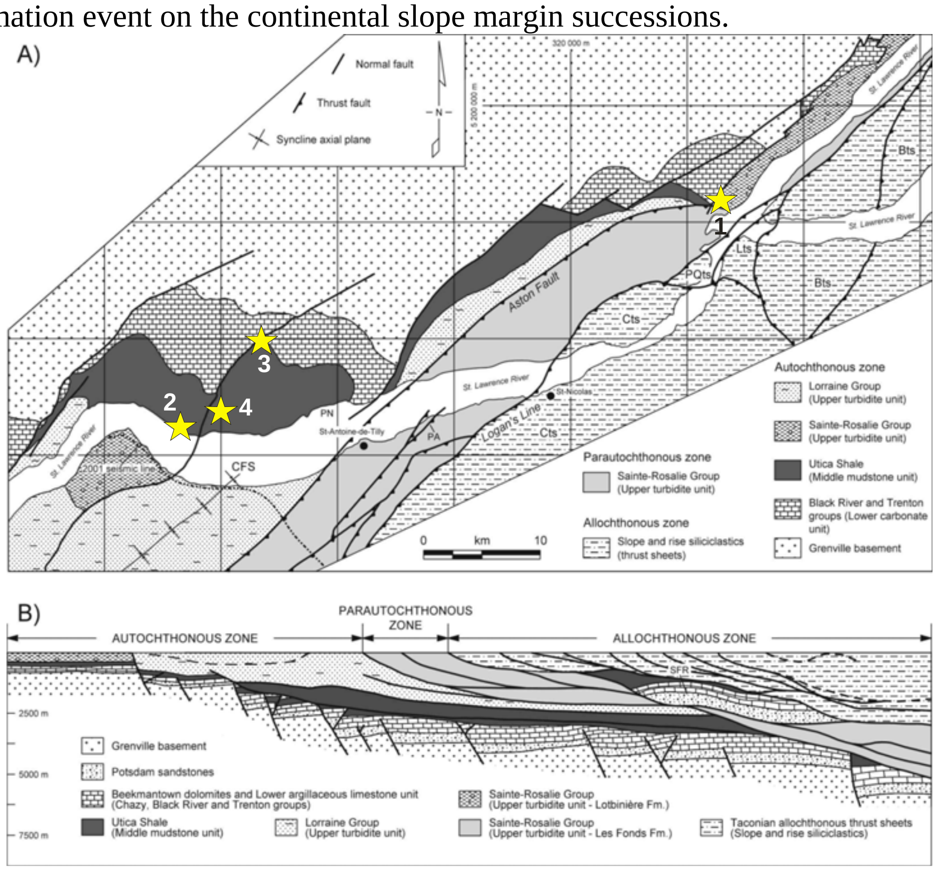

Figure 3. A) Geology of the Appalachian front in the Québec City area modified from Globensky (1987) and adapted from Castonguay et al. (2006). Stars locate field sections visited during the trip, 1: Montmorency falls, 2: Cap Santé, 3:

Jacques-Cartier River at Pont Rouge and 4: Jacques-Cartier River at Donnaconna. B) Cross section along 2001 seismic line adapted from St-Julien et al. (1983) and Castonguay et al. (2006). Location of the 2001 seismic line on figures 2a and 4. Abbreviations: Bts, Bacchus thrust sheet; CFS, Chambly-Fortierville Syncline; Cts, Chaudière thrust sheet; Lts, Lévis thrust sheet; PA, Pointe Aubin; PN, Plage Neuville; PQts, Promontoire de Québec thrust sheet; SFR, St-Flavien reservoir.

The shallow marine continental platform – A summary

In southern Quebec, the St. Lawrence platform corresponds to a siliciclastic and carbonate platform having a maximum thickness of 1200 metres, overlain by approximately 1800 metres of foreland deposits (Figs. 3 to 5) (Sanford, 1993; Lavoie, 1994).

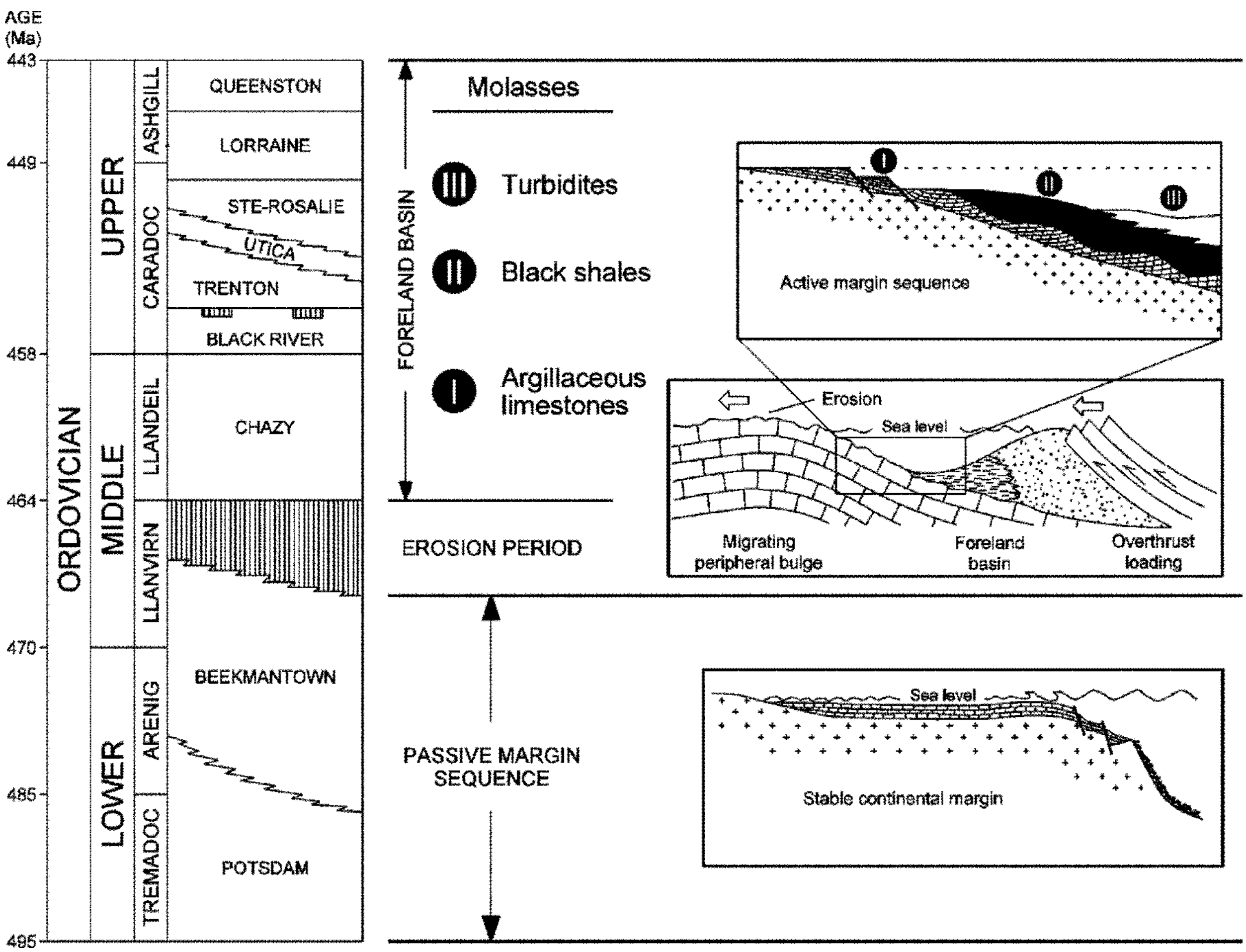

Figure 4. Stratigraphic framework for the Ordovician succession of the St. Lawrence Platform (modified from Lavoie, 1994 and Comeau et al., 2004). Vertical line pattern indicates non-deposition and erosion period.

The onset of marine conditions (rift and early drift episodes)

In the northern Appalachians, the breakup of a supercontinent around the Neoproterozoic-Cambrian boundary is recorded by predominantly mafic volcanic rocks and dykes and felsic to mafic intrusions. Occurrences of rift-related magmatic rocks have been documented from Labrador to Virginia for a distance of ~2500 km. Within the Grenville province of Québec, synrift magmatic products include a mafic dyke swarm, a group of alkaliccarbonatitic complexes and the Sept-Îles layered intrusion. Occurrences found in the Québec Appalachians correspond to variably altered, metamorphosed and deformed lava flows and dikes in dominantly clastic immature sedimentary rocks and as clasts of various size in polymictic conglomerates and olistostromes. The age of magmatic rocks ranges from 615 Ma to 550 Ma, but the volumetrically most important magmatic suites clustered around 558 +/- 7 Ma, a time interval which probably correspond to the most widespread igneous event.

The shallow marine record of the rift episode is meagre in southern Québec. In the St. Lawrence Platform, the base of the platform succession consists of the Cambrian Potsdam Group which unconformably overlies the Precambrian basement. The lower formation of the Postdam Group (Covey Hill Formation) has been equivocally assigned an Early Cambrian age (Sanford, 1993) without supporting faunal element. At the eastern end of the Humber external domain (Fig. 1), tectonic stacks of the shallow marine Oak Hill Group (Charbonneau, 1980) overlie rift volcanics of the Tibbit Hill Formation (Kumarapeli et al., 1989). In the Oak Hill Group, the Cheshire (quartz arenite) and Dunham (dolostone/limestone) formations have yielded Early Cambrian faunal elements (Clark, 1936; Clark and McGerrigle, 1944).

The Potsdam Group is dominated by fluvial to shallow marine interbeds of locally conglomeratic arkose and subarkose in its lower part (Covey Hill Formation, Fig. 5). A thin (~ 5 m), fossiliferous, dolomitic sandstone unit locally lies at the top of the Covey Hill Formation in SW Québec (Rivière Aux Outardes Member, Salad Hersi and Lavoie, 2000a). Recent discovery of medusa in that upper Covey Hill unit has been publicised and support an Upper Cambrian age of the Covey Hill (Lacelle et al., 2008).

The upper part of the group is represented by shallow marine strata of the Cairnside Formation. The latter consists of a lower unit of light gray to creamy white quartz arenite, and an upper unit of quartz arenite similar to that of the lower unit but with subordinate dolomitic sandstone interbeds (Clark, 1972; Globensky, 1987; Salad Hersi and Lavoie, 2000b). Where the dolomitic sandstone interbeds are missing, the upper unit is not distinguishable from the lower unit. In SE Ontario, the Cairnside-equivalent Nepean Formation has a terrestrially accumulated quartz arenite in its lower part (Wolf and Dalrymple, 1984, 1985).

The trailing (passive) margin

In the Québec Reentrant, the oldest known passive margin shallow marine platform unit is the upper Middle Cambrian Corner-of-the-Beach Formation in the Percé area (Fig. 1; Kindle, 1942; Lavoie, 2001). In southern Québec, the shallow marine carbonate platform of the Strites Pond Formation (Salad Hersi and Lavoie, 2001a; Salad Hersi et al., 2002b; Salad Hersi et al., 2007) in the Philipsburg Thrust Slice of the Humber zone yielded Upper Cambrian (lower Skullrockian) conodont fauna. For both formations, facies indicate platform margin (Lavoie, 2001; Salad Hersi and Lavoie, 2001a; Salad Hersi et al., 2002a; Salad Hersi et al., 2007).

The shallow marine record of the Sauk II and III sub-sequences is best expressed in the Lower Ordovician extensive carbonates of the Beekmantown Group and units in the Philipsburg Thrust Slice (PTS) of southern Québec (Globensky, 1987; Bernstein, 1992; Salad Hersi et al., 2002a, 2003, 2007) as well as of the Romaine Formation on Mingan Islands (Desrochers, 1988) and in the sub-surface of Anticosti Island (Brennan-Alpert, 2001; Lavoie et al., 2005). All these Lower Ordovician units are truncated by an unconformity, which is widely recognized in many parts of North America (See below; Sloss, 1963; Mussman and Read, 1986; Knight et al., 1991;

Salad Hersi et al., 2007).

Detailed lithostratigraphy of the Beekmantown Group of southwestern Quebec has refined the field application of the previously proposed tripartite division of the group (i.e., Theresa, Beauharnois and Carillon formations). The group is a peritidal-dominated succession that accumulated on the Laurentian passive margin from Early to early Middle Ordovician (Salad Hersi et al., 2003); the Beekmantown is partially time-correlative with the Wallace Creek to Naylor Ledge strata of the School House Hill Group of the PTS, southern Quebec (Salad Hersi et al., 2002b, 2003, 2007). The platform evolved as a distally steepened ramp during deposition of the Theresa Formation and the lower member (Ogdensburg) of the Beauharnois Formation (early to middle Ibexian). By late Ibexian, the platform developed a pronounced margin where thrombolites flourished under high-energy conditions and consequently, a broad lagoon formed on the lee side of the platform margin, where low energy conditions prevailed and accumulation of burrow-mottled dolostones of the Huntingdon Member, upper Beauharnois Formation took place. The lagoon became more restricted during the latest stages of the basin fill (Whiterockian), and high intertidal to supratidal sediments of the Carillon Formation where deposited.

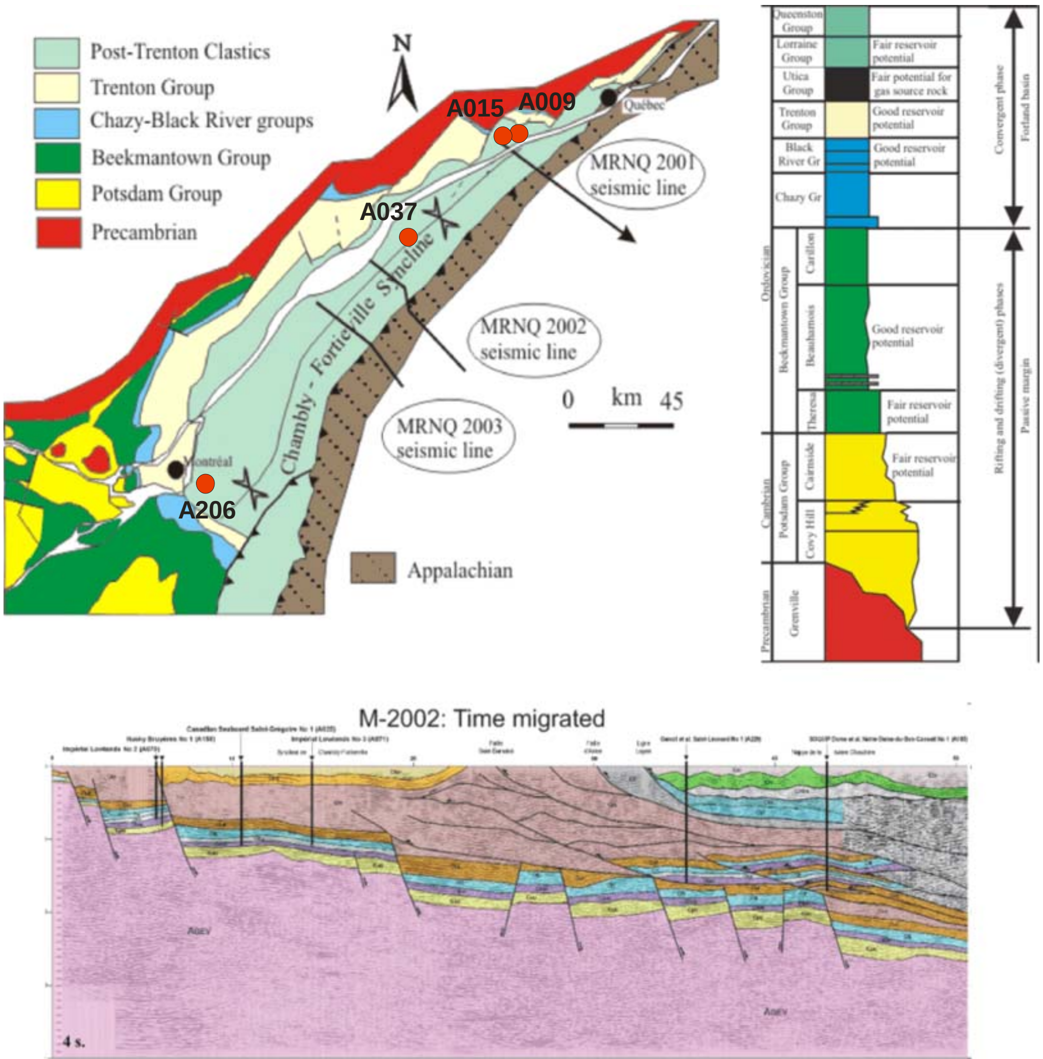

Figure 5. Simplified geological map of the St. Lawrence Platform in southern Quebec at the group level and position of the four cores (numbered red dots) examined during the visit. Modified from Globensky (1987). The stratigraphic column presents the current framework for the platform. Comments on reservoir and source rock potential are discussed further in text. The seismic line MRNQ-2002 is located on the geological map. The reprocessed and reinterpreted data indicate significant deformation (including triangle zone) well within the previously assumed non-tectonized St. Lawrence Platform. From Castonguay et al. (2006).

The Taconian foreland basin

The building of the marine trailing (passive) margin successions along the eastern seaboard of Laurentia was stopped by emergence and sub-aerial exposure of the platform in earliest Middle Ordovician. The resulting unconformity is known as the St. George (Newfoundland; Knight et al., 1991), the Romaine (Anticosti; Desrochers, 1988), the Beekmantown (southern Québec; Dykstra and Longman, 1995; Salad Hersi et al., 2003), the Naylor Ledge (southeastern Québec; Knight et al., 1991; Salad Hersi et al., 2007), and the Knox (east U.S.A.; Read, 1989) unconformity. This unconformity coincides with the limit between Sloss' (1963) Sauk and Tippecanoe sequences and marks the inception of the foreland basin at

Laurentia continental margin (Fig. 3). The evolution of the foreland basin became strongly diachronic along the continental margin, which suggests that the reentrant-promontory morphology played a key role in the shaping of the margin of Laurentia at that time (Stenzel et al., 1990; Lavoie, 1994).

The inception of the Taconian Orogeny, involving collision of the eastern continental margin of North America with a volcanic arc situated above a SE-dipping subduction zone, caused the initial collapse, subsidence and transgression of the Middle Ordovician carbonate platform throughout the length of the Appalachian Orogen (Hiscott et al., 1986). At the cratonic margin of the foreland, which was located near the paleoequator, the carbonate platform succession was covered by a deepening-upward sequence of argillaceous limestone and black organic-rich mudstone, followed by shallowing-upward flysch (Beaulieu et al., 1980; Hiscott et al., 1986; Dykstra and Longman, 1995; Comeau et al., 2004).

In Québec, the Taconian foreland basin can be viewed as a classical, under filled peripheral foreland basin and, following Sinclair's (1997) nomenclature, can be divided into three diachronous lithostratigraphic units: I-a lower argillaceous limestone dominated unit, II-a middle mudstone dominated unit and III-an upper turbidite dominated unit (Fig. 4).

Lower argillaceous limestone dominated unit

The sequence of foreland basin argillaceous carbonates comprises the Chazy, Black River and Trenton groups (I of Fig. 4). Salad Hersi and Dix (1997), Lavoie (1994, 1995) and Dix (2003) recognize eustatic marine regressions between the Chazy and the Black River groups and between the Black River and the Trenton groups and the development of local unconformities atop tectonic paleotopographic highs in the Taconian foreland basin. Regional facies distribution and thickness variations within the Trenton Group have been attributed to syn-sedimentary normal block faulting (Lavoie, 1994, 1995). The top of the Trenton Group consists of muddy limestone beds with abundant interbeds of shales.

The Middle Ordovician Chazy and Black River groups in southern Quebec are relatively thin units that are dominated by muddy carbonates characterized by a foramol-like faunal assemblage dominated by corals, stromatoporoids and green algae (Guilbeault and Mamet, 1976; Lavoie, 1995; Salad Hersi, 1997; Salad Hersi and Lavoie, 2001b). Both units consist of depositional facies indicative of shallow, low-energy tropical marine conditions. The overlying upper Middle to lower Upper Ordovician Trenton Group is primarily a deep marine fine-grained unit, however, the base of the group (the Deschambault Formation) is a coarse-grained, shallow marine and high-energy calcarenite unit that is phosphate-rich and characteristically displays a bryomol-like fauna dominated by bryozoans, crinoids and a total lack of green algae (Guilbeault and Mamet, 1976; Lavoie, 1995; Lavoie and Asselin, 1998). Similar transition from warm-water like to cool-water like in the early Late Ordovician is recorded along the entire segment of the eastern Laurentia margin that was located south of the 10-15°S of paleolatitude (Pope and Read, 1997; Pope and Harris, 2004).

Middle mudstone dominated unit

The middle mudstone unit (II of Fig. 4) consists of the deep water siliciclastic sediments and hemipelagic mud of the Utica Shale. They were deposited over the carbonate units due to rapid subsidence of the foreland basin (Globensky, 1987). Black shale is characteristic of early flysch-phase fill along the distal flank of the Middle to Late Ordovician Taconian peripheral foreland basin (Bradley and Kidd, 1991). The Utica Shale is a diachronous unit which is older when located closest to the Appalachian front, as in the Québec City vicinity (*Corynoides americanus-Orthogratus ruedemanni* to the *Climacograptus spiniferus* Zones) and younger to the southwest on the Laurentian platform, as in the Montreal region (*Climacograptus pygmaeus* Zone). Diachronous east to west progression of subsidence was coincident with the progressive westward change from carbonate-dominated to siliciclastic sedimentation within the foreland basin, also documented elsewhere in the Appalachian orogen (Ettensohn, 1991; Lehmann et al., 1995; Sharma et al., 2003). In the Québec City area, the Utica Shale is only 30 m thick and yields graptolites spanning the *O. ruedemanni* to the *C. spiniferus* zones (Globensky, 1987). This unit is distinguished from younger facies that contain more abundant clastic beds suggesting that it was laid down prior to overthrusting of the thrust sheets onto the continental margin.

Upper turdidite unit

The upper turbidite unit (III of Fig. 4) consists of synorogenic sediments accumulated during the Caradocian to early Ashgillian stages of the Late Ordovician during and after the overthrusting of the external thrust sheets. The siliciclastic source was located to the south-east and debris were derived from the thrust sheets (Globensky, 1987), representing a major reversal in the direction of sediment supply from the Laurentian shelf to more outboard elements of the tectonic wedge (Hiscott, 1995). The sandstones that accumulate at the toe of, and on top of the thrust wedge are highly immature and rich in lithic fragments with rarer volcanic detritus derived from erosion of the thrust wedge (Beaulieu et al., 1980; Schwab, 1986). Thrust-faulted highs generated during deposition of the middle unit lead to pounding of turbidite flows of the upper unit, generating thick sandstone beds overlain by thick mudstone drapes (Pickering and Hiscott, 1985).

The upper turbidite unit is dominated by thick successions of alternating sandstone and mudstone of the Sainte-Rosalie and Lorraine groups. The Lotbinière Formation belongs to the Sainte-Rosalie Group and the Nicolet River Formation to the Lorraine Group. The Sainte-Rosalie Group conformably overlies the Utica Shale at the Montmorency fall section. Elsewhere in the St-Lawrence Lowland this flysch sequence is broken into a series of imbricated slices and bounded by two major thrust faults: the Aston fault and the Logan fault in a northeast-southwest ribbon between Quebec City and the American border on the southeast limb of the Chambly-Fortierville syncline. The Sainte-Rosalie Group is well exposed on the south shore of the St-Lawrence River between Saint-Nicolas and Saint-Antoine-de-Tilly along a 15 km section (Beaulieu et al., 1980). Total thickness of the Sainte-Rosalie is difficult to estimate because of faults and 1000 m seems to be educated minimum estimate according to Comeau et al. (2004). The flysch of the Sainte-Rosalie consist mainly of medium- to very fine-grained lithic sandstone, mudstone, siltstone, fossiliferous limestone intervals and rare conglomerates. The sandstones display all the characteristics of a turbidite with graded beds, cross-laminations, flute casts and scour marks. The detrital fraction of the sandstones is composed of 71% quartz, 9% feldspath and 19% rock fragments consisting mostly of bituminous shale, argillaceous siltstone, quartzo-felsdpathic sandstone, various limestones, fossil fragments and 1% accessory minerals including chromite (Beaulieu et al., 1980).

The Lorraine Group is the thickest and the most widespread unit of the St. Lawrence

Platform. Globensky et al. (1993) estimate a thickness of 3800 m for the entire group. The Lorraine Group conformably overlies the Utica Shale on the northwest limb of the syncline. At Pointe-au-Platon, the Lorraine also overlies conformably the Sainte-Rosalie (Globensky, 1987) but the two groups are mainly in faulted contact along the Aston fault. The most complete exposures of the Lorraine Group are along the Nicolet River where Clark et al. (1979) measured a thickness of 825 m. The Lorraine Group consist of interbedded calcareous shales and fine grain turbidite sandstones with thin layers of limestone or calcareous sandstone occurring at intervals of about 3 meters. The shales are soft, bluish-black, fissile, and weather rapidly into roughly lenticular fragments approximately 1,0 cm in diameter. The fine grain sandstone layers are thinly bedded and exhibit cross-laminations. Since the Sainte-Rosalie and Lorraine both overly the Utica Shale they may be correlative regarding the diachronism of the Utica.

Post-Ordovician rocks

Besides a small Lower Devonian carbonate breccia in the Montréal area (Clark, 1972), there is no preserved, physical record of post-latest Ordovician sedimentation on the St. Lawrence Platform. However, based on thermal maturation data (Bertrand, 1991), the top of the platform succession was buried to a depth of roughly 4-5 km, it is unknown if the burial is entirely tectonic (beneath Taconian thrust slices) or result from combined Taconian tectonic and later sedimentary (Silurian-Devonian) burial.

Petroleum geology – Conventional systems

Exploration history

The Lower Paleozoic St. Lawrence carbonate platform was initially tested for hydrocarbons in the late 50’s-70’s. Gas shows were reported in most of the wells in both passive margin (Beekmantown Group) and foreland basin (Trenton Group) carbonates. However, these first exploration efforts failed to encounter economic accumulations. Organic matter studies resulted in detailed maturity map of the St. Lawrence Platform and in the recognition of source rock potential of the Utica Shale (Bertrand, 1991; Bertrand and Lavoie, 2006). In the 1990’s, a new round of exploration targeted the deep autochthon below the Taconian Nappes again without significant success. All these previous exploration campaigns tested faulted structural highs and unconformity-bounded Lower Ordovician units. Current exploration activities focus on hydrothermal dolostones (Lower and Middle Ordovician) (Lavoie et al., 2005; Thériault and Laliberté, 2007; Lavoie and Chi, in press). In the early 2000’s, various gas discoveries have been reported, although without volume and potential production values; in the Beekmantown and Trenton groups. The first significant exploration success occurred in early 2007, when Talisman Energy reported from their second exploration well, significant natural gas flows up to 9 MMcf/d from hydrothermally-dolomitized intervals of the Trenton-Black River.

Source Rocks

Over the years, little oil has been recovered. A 46.9ºAPI oil has been reported in a hole north of Montréal. Detailed organic matter petrography and Rock Eval analysis have shown that the Upper Ordovician Utica Shales has a potential for gas (Bertrand, 1991). The formation contains Type II kerogen and a small amount of Type I. The Total Organic Carbon (TOC) values range from 1.0 to 3.0wt% and Hydrogen Index (HI) up to 294. The Utica Shale is a facies, but younger equivalent of the Middle Ordovician Black Cove Formation in Newfoundland; the Utica is facies and grossly time equivalent with the Upper Ordovician Macasty Formation (TOC: up to 5% and HI up to 260) on Anticosti Island and the Upper Ordovician Pointe Bleue Formation (TOC: up to 15.5% and HI up to 633) in the Lac Saint-Jean outlier. Other potential source rocks with lower potential include the upper part of the Trenton Group and shales of the base of the Lorraine Group.

Maturation and generation

Maturation increases southerly in the St. Lawrence Platform and three maturation domains are proposed. The Quebec City area is the least mature sector (Bertrand, 1991). The Utica Shale is in the upper part of the condensate zone in the northernmost sector of the St. Lawrence Platform. Elsewhere, the Utica Shale is within the condensate to dry gas zones. A significant maturation jump is noted at the Appalachian structural front. Studies of wells show that maturation positively correlates with depth and results from burial of the succession and precedes the formation of the Chambly-Fortierville syncline. Geochemical data indicate that Utica Shale has generated its entire hydrocarbon.

Migration and accumulation

From geochemical and maturation data, most of the hydrocarbons from the Utica Shale started to be generated at the onset of the Late Ordovician Taconian Orogeny (Bertrand et al., 2003). The presence of thermogenic gas in the Pointe-du-Lac Quaternary reservoir indicates that the Utica Shale still has locally some potential to generate gas (Saint-Antoine and Héroux, 1993). Recent gas shows in the St. Lawrence Platform (Dundee, Bécancour, Batiscan, Gentilly) argue for an up-dip (southeast to northwest) and vertical (along some of the extensional faults) migration of hydrocarbons of the Upper Ordovician Utica Shale towards Lower and Middle Ordovician carbonate reservoirs. Detailed petrographic study of the Beekmantown dolostones indicates a liquid hydrocarbon migration event after chemical compaction and a later phase of gas migration (Chi et al., 2000). There is no absolute age data on hydrocarbon migrations.

Reservoir facies

A first target consists of shallow water, intertidal to shallow subtidal facies of the Lower Ordovician (upper Tremadocian-Arenigian) Beekmantown Group (Chi et al., 2000; Bertrand et al., 2003). Depositional facies include peritidal dolostones and marine limestones. Facies are arranged in m-thick shallowing-upward cycles. The upper beds are locally karsted as result of sub-aerial exposure at the Sauk-Tippecanoe sequence boundary. Porous potential reservoir units only formed where dissolution and secondary dolomitization / brecciation occurred. The late secondary dolomitization is of hydrothermal origin. Pore coating bitumen and methane inclusions in late quartz cement indicates 2 pulses of hydrocarbon migration.

A second target is the Upper Ordovician (lower Caradocian) Trenton and Black River groups (Thériault and Laliberté, 2007). The favourable facies are shallow subtidal clean bioclastic and oolitic limestones (e.g., Deschambault Formation of the Trenton Group and Leray, Lowville and Pamelia formations of the Black River Group). Potential reservoir development is associated with hydrothermal dissolution and dolomitization. Proximity to extensional faults is a prerequisite for development of secondary porosity. A gas discovery in the Trenton-Black River groups has recently been publicized by Questerre Energy / Talisman.

Secondary targets consist of the Cambrian and Middle Ordovician basal sandstone units that overly the Precambrian and Sauk-Tippecanoe unconformities, respectively. These nearshore sands are locally porous and gas shows are reported. Finally, most of the wells that intercepted the Upper Ordovician flysch sandstones on the southern flank of the Chambly-Fortierville syncline have generated various amounts of gas.

Porosity and Permeability

Dolostones of the Beekmantown Group contain vuggy, moldic, intercrystalline and fracture porosities. Multiple events of dolomitization are known (early, late burial and hydrothermal; Chi et al., 2000). Measured porosities in the Beekmantown is highly variable and can even reach 17% in the deeply, allochthon buried successions. The limestones of the Trenton Group are locally fractured, although current interest lies in the potential presence of hydrothermal dolostones in that unit. No porosity/permeability values for the Trenton and basal sandstones are available. Recent tests report gas flows up to 9 MMcf/d.

Traps and seals

The St. Lawrence Platform strata form a broad monocline with no fold closure. In the target zone (Lower to Middle Ordovician succession), extensional faults are the most likely seals for reservoirs. The top of the Beekmantown Group is marked by the Sauk-Tippecanoe sequences boundary that, if not breached by faults, could have acted as a seal. The Utica Shale could have not only provided hydrocarbons but also likely sealed off the underlying Trenton Group. Diagenetic seals produced by lateral transition from porous hydrothermal dolostones to tight carbonates are expected in the Beekmantown and Trenton groups. Finally, compressional structural elements such as triangle zone and duplexes are locally documented along the SE limb of the Chambly-Fortierville syncline (Castonguay et al., 2006).

Exploration plays

The actual play concept for exploration in the St. Lawrence platform is derived from the model of fault-controlled hydrothermal dolomitization that has proven highly successful in coeval rocks in eastern USA (e.g., Albion-Scipio in Michigan Basin; Fingers Lake area in Appalachian Basin of New York) (Smith 2006). Detailed petrographic and geochemical studies in the Beekmantown Group have revealed the presence of late saddle dolomite in both field and well samples. Reprocessed seismic profiles have documented the presence of still untested fault-bounded platform sags. Movement along these faults is assumed to have taken place during the early Taconian foreland basin development (e.g., Chazy to Trenton) as suggested by thickness increases on the downthrown block. The recent significant discovery that has been announced indicates that the Upper Ordovician hydrothermal dolomite play extends from New York and

Ontario into southern Quebec.

Secondary types of conventional play consist of the Cambrian to Middle Ordovician porous sandstone units that are structurally put in favourable contact with the Upper Ordovician Utica Shale. Finally, compressive structures involving deep marine impure Upper Ordovician flysch sands at the Appalachian structural front correspond to another type of play.

Petroleum Geology – Shale gas: Utica/Lorraine (Upper Ordovician)

Geological framework and definition of unit limits

The Utica Shales

In the surface and subsurface along the St. Lawrence River and southward into the U.S., black shales of Edenian age succeed the Trenton limestones and comprise the Utica Group, a rich hydrocarbon source rock, approximately equivalent to the slightly younger Eastview, Billings, Collingwood and Blue Mountain formations of Ontario (Poole et al., 1970; Belt et al., 1979; Sanford, 1993; Dykstra and Longman, 1995: Armstrong and Carter, 2006). These black shales include the dark brown and black, laminated and non-bioturbated, calcareous, graptolitic shales which lie disconformably on Trenton limestones to the north (Clark, 1972; Sanford, 1993). The entire Utica Group may reach 300 m in thickness (Aguilera, 1978) and represents the thickest and most widespread of the Lower Paleozoic black shale source rock intervals (Ryder et al., 1998). In New York, where these Ordovician black shales were first formally recognized (Ruedemann, 1912), the initial biostratigraphic-oriented framework was replaced by a lithostratigraphic framework (Bair and Brett, 2002) that takes into account the lateral and vertical variability (in facies and age) of the shale-dominated succession. In southern Quebec, the transition between the Trenton and the Utica is either gradual (e.g. Quebec City area) or abrupt and disconformable (e.g. Montréal area) (Riva, 1969). The limit between the two units corresponds to the interval where shale dominates the section.

The Lorraine Flysch

The Utica rocks are overlain by up to 800 m of grey to dark grey calcareous, bioturbated shale, with upward increase of siltstone and very fine grained sandstone interbeds of Upper Ordovician flysch, the formal designation of which varies across southern Quebec (the Lotbinière Formation of the Ste-Rosalie Group and the Nicolet River Formation of the Lorraine Group); those units are approximately equivalent to the Carlsbad and Georgian Bay formations of Ontario (Clark, 1972; Sanford, 1993).

The Lorraine Group gradually overlies both the Utica (NW segment of the St. Lawrence Platform) and the Ste-Rosalie (SE segment of the St. Lawrence Platform) (Globensky, 1987; Comeau et al., 2004). The limit between the Utica and the Lorraine is put at the first sandstone bed in an otherwise fine-grained (mudstone and siltstone) dominated succession. Therefore, such transition is definitively not easily recognized everywhere as the distal flysch of the Lorraine Group are not always marked by significant sandstone beds.

The Lorraine Group is conformably overlain by Queenston Group redbeds (Belt et al., 1979), a late to post-Taconian-related sedimentary units of latest Ordovician age.

Regional considerations

Recurrent tectonism (Taconian, Acadian, and Alleghenian) likely created a pervasive fracture network in these rocks which allowed partial upward migration of generated gas through this leaky seal into overlying Lower Silurian sandstone reservoirs in Ontario and New York (Ryder et al., 1998).

Gas generated from the Upper Ordovician shales is also recognized in the Pointe-du-Lac and St. Flavien reservoirs of Quaternary and Ordovician ages, respectively (Saint-Antoine and Héroux, 1993; Bertrand et al., 2003). Abundant seeps (>1900 pockmarks) on the St. Lawrence estuary seafloor are the product of major gas venting from reservoirs in the St. Lawrence platform (Pinet et al., 2008 and Lavoie work in progress).

Geochemical and reflectance data

Limited technical data exist for the Utica shales in the St. Lawrence Platform of southern Quebec. The publicly available data for the Utica shales suggest that TOC contents increases from 1.0 in the south to 3.0% in the north and west (Fig. 6), and that vitrinite reflectance ranges from 1.0% in the north (immediately overlying the Canadian Shield) to 4.0% in the south adjacent to the Taconian overthrust Belt (Bertrand, 1991; Fig. 7). The GSC Rock-Eval Database includes 295 samples of Utica with the following characteristics: TOC up to 2.70%, averaging 0.8%; T_{max} up to 505, averaging 407; S_1 up to 6.58, averaging 1.40; S_2 up to 4.34, averaging 0.39; S_3 up to 2.13, averaging 0.71; HI up to 294, averaging 31, OI up to 132, averaging 64 (Obermajer et al., in preparation Fig. 8). Similarly, the GSC Rock-Eval Database includes 231 samples of Lorraine and correlatives units with the following characteristics: TOC up to 5.49%, averaging 0.5%; T_{max} up to 491, averaging 411; S_1 up to 9.93, averaging 1.57; S_2 up to 41.14, averaging 3.41; S_3 up to 2.39, averaging 0.47; HI up to 818, averaging 30, OI up to 337, averaging 54 (Obermajer et al., in preparation).

A significant new geochemical and mineralogic database on the Utica/Lorraine (and correlative units) in southern Quebec will be available before end-2008 (Thériault, in press). The database will include close to 1500 Rock Eval data (new and old information) as well as close to 350 new XRD results.

In a recent study, Karlen (2007) preliminary reported on 300 new samples of core and well-cuttings from both the Utica and Lorraine. Results suggest a type III kerogen, TOC of up to 2.0% and Ro/Rhstd values over 1.6. Isotherm analysis yielded values of up to 66 scf/ton for Lorraine and some Utica samples. Reported XRD analyses of the Lorraine Formation suggest lower quartz and calcite and higher clay content compared to Barnett and Utica. The recent study of Karlen (2007) supports the potential of the Utica.

There are no published data on the fracture systems of these potential shale gas units, but faulting is common in the area.

Exploration history and potential

The Ordovician Utica shale gas potential in the St. Lawrence Platform of Quebec was first demonstrated at Villeroy, Quebec during the 1970's with maximum gas flows of 500 mcf/day on DST and IP's of over 4 mmcf/d at high pressure.

The potential for shale gas production from the Utica was significantly put at the forefront after a press release from Forest Oil in early April 2008. In the press release and accompanying material, the Utica recoverable potential on their 339 000 gross acres in southern

Quebec was estimated to be 4.1 Tcf (with a recovery efficiency of 20%). The rock properties were indicated to be relatively comparable with the Barnett (Utica vs *Barnett*: Clay (%) 15-26 vs *15-30*; TOC (%): 1-3.1 vs *3.5 – 5%*; Gas-filled porosity (%): 3.2-3.7 vs *3.0-4.8*; pressure gradient (psi/ft): .45-.6 vs *.46-.5*; and maturity (Ro): 1.3-2 vs *1-2.2*). The main difference, favourable for the Utica, is its shallower depth. Initial testing on 2007 vertical wells yielded rates up to 1mmcf/d with at least two producing horizons. Gas was documented to be 99-07% methane, with 1027-1136 BTU. Of course, the significant NYMEX premium for nearby gas is another critical economic element.

In May 2008, Talisman Energy released numbers from their initial technical works on the Utica and Lorraine. Both units are described as having significant OGIP (25-260 and 50-190 bcf/section; Utica and Lorraine respectively); significantly higher than their internal estimates for the Marcellus Shales. Talisman evaluates the OGIP in their acreage to be around 48 Tcfe.

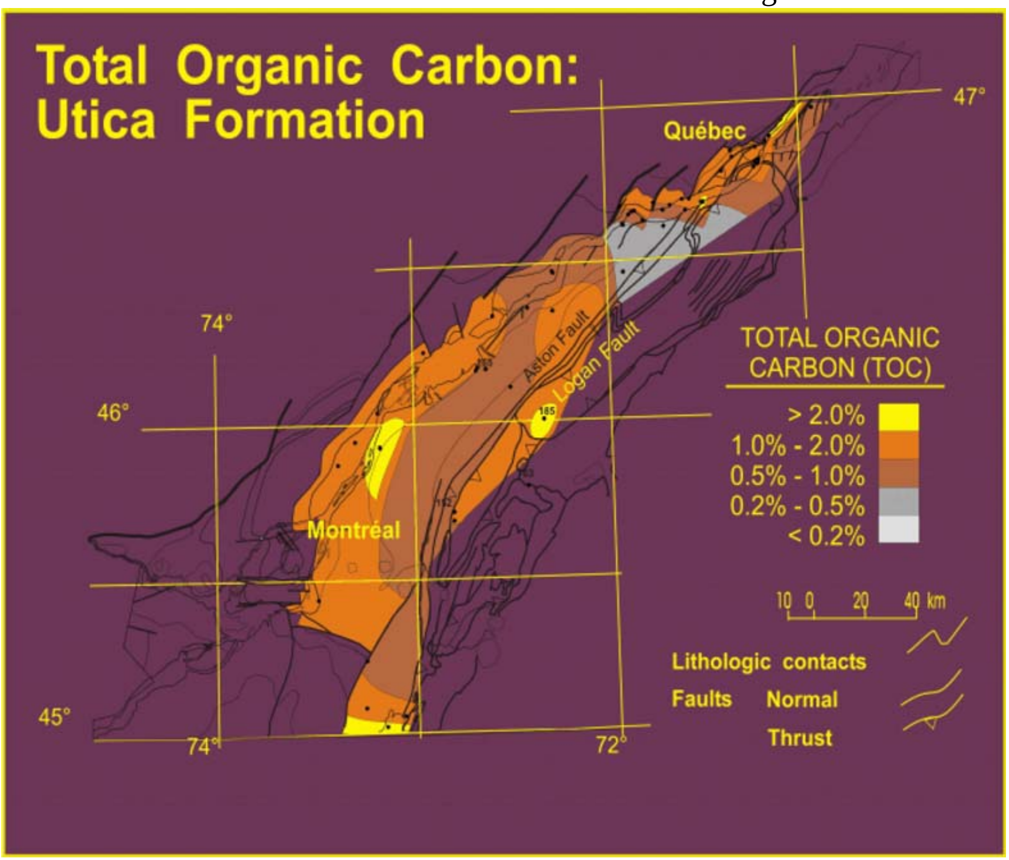

Figure 6. Distribution of TOC values for outcrops of the Utica Shale, St. Lawrence Platform of southern Quebec. Modified from Bertrand (1991) and Bertrand and Lavoie (2006).

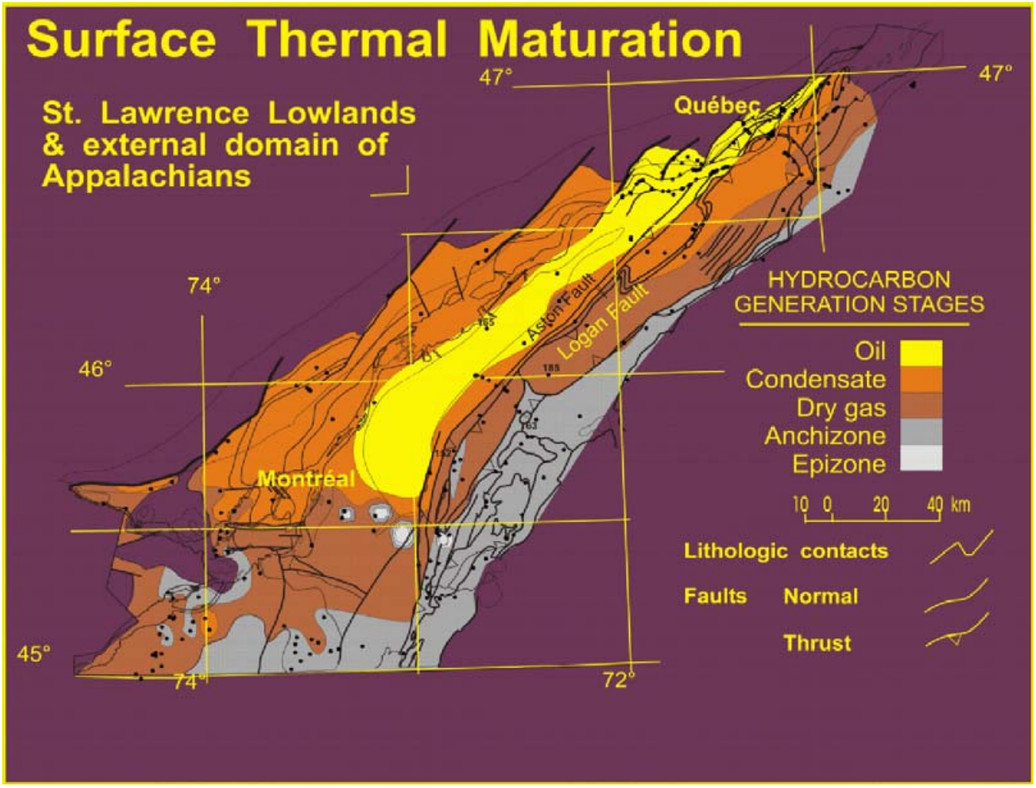

Figure 7. Thermal maturation of the Utica Shale based on outcrop samples, St. Lawrence Platform of southern Quebec. Modified from Bertrand (1991) and Bertrand and Lavoie (2006).

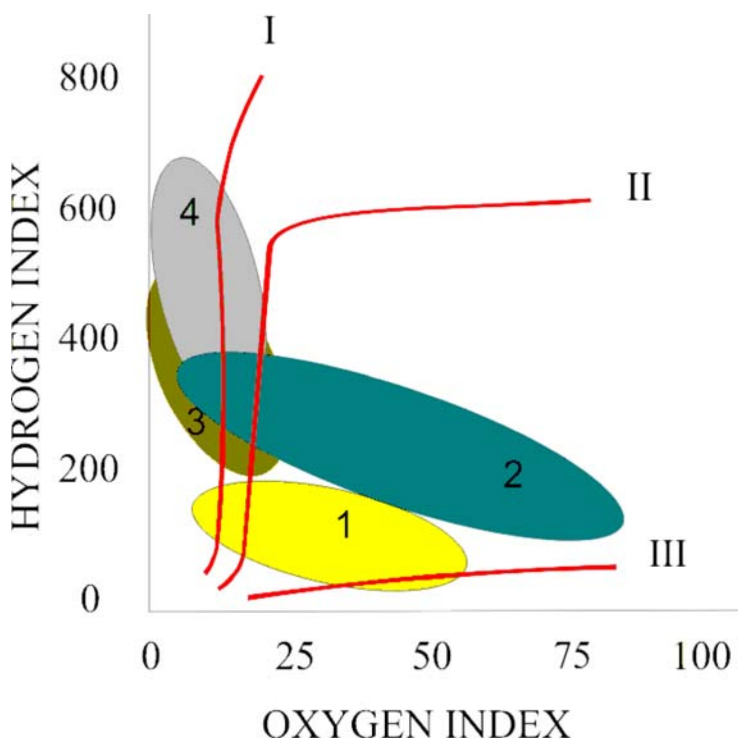

Figure 8. Summary of HI and OI for various Ordovician source rocks in Quebec. 1: Utica Shale from Bertrand

(1991), 2: Utica Shale (new data) in Obermajer et al. (in press), 3) Macasty Formation (Anticosti) from Bertrand (1987, 1991) and 4: Pointe Bleue Shale (Lac St. Jean) from Bertrand (1991).

Summary

The Utica-Lorraine succession includes a thick sequence with good source rocks (Type II/III organics), which range from thermally immature to overmature, with good potential for an Antrim-like (Style A of Hamblin, 2006) or for an Ohio/New Albany-like (Style B of Hamblin, 2006) plays. However, further study of the stratigraphy, sedimentology, geochemistry, maturity and mineralogy would lead to much better understanding of the shale gas potential. The detailed stratigraphy and sedimentology are not well known, fracture patterns are unknown and relatively few samples have been analysed. These strata form part of the vast Upper Ordovician shale-dominated succession of the Appalachian Basin, which may soon emerge as the next important shale gas province, and could provide a large but as yet unevaluated resource. Within the St. Lawrence Platform-Appalachian region, the Utica-Lorraine successions (and its correlatives) probably present some of the best prospects for shale gas potential.

In the adjacent U.S., the Utica shales have Type II and III organic matter and TOC contents ranging 0-4.3%, averaging 1.8%; thermal maturities are in the oil window, with geochemical characteristics similar to the Collingwood shale of Ontario (Ryder et al., 1998). The Utica can be subdivided from top to base, into the upper and lower members of the Indian Castle Formation, the Dolgeville and the Flat Creek formations (Baird and Brett, 2002). These various units can also be recognized on the basis of their TOC content; the Flat Creek Formation is characterized by TOC values that range from 1.5%- 3.0%, the ribbon limestone-dominated Dolgeville Formation offers TOC values between 1% -1.5 %, and the TOC content of members of the Indian Castle Formation is usually less than 1.0%. (Nyahay, 2008). Some of the current work in Quebec aims at the potential recognition of these internal units within the Utica. On their characteristics, the Utica Shale has been compared with the Cretaceous Lewis Shale of the San Juan Basin, New Mexico (Karlen, 2007). The shale gas potential of the Utica Shale (and younger Devonian shales) in New York is also currently being aggressively evaluated by the industry and government organizations (Martin et al., 2004).

Utica cores

Four cores of the Utica will be examined; these cores were selected on the presence of described contacts with the overlying Taconian flysch (Lorraine and / or Lotbinière formations) and with the underlying Trenton Group. The aerial distribution of the cores (see Fig. 4) also offers a preliminary albeit fragmentary image of facies and thickness variations within the St. Lawrence Platform, from northeast to the southwest. A brief summary of these cores is presented below together with the results of recent Rock Eval analyses on punctual samples taken from these cores.

Core A 009, Bald Mountain, Cap Santé #1 (Annex 1)
N 46^{o} 40' 42.1"
W71^{o} 47' 61.4"

This well was drilled in 1957, and reached a total depth of 954 feet (291 m). The interval assigned to the Utica ranges from 57' (17 m) to 330' (100 m) (273' or 83 m) (Annex 1).

The core shows a nice transition zone with the Trenton Group characterized by a rapid decrease of fine-grained limestone layers in an increasingly shaly succession (Fig. 9). The Utica is typified by number of metric cycles with a shaly bottom and an upper limestone-shale interval. Burrowing is abundant; a thin (2 cm) bentonite layer is present at 172' (52.3 m).

Figure 9. Limestone rich interval (pale shaded interval in the core) that marks the transition with the Trenton Group

Six samples were collected from this core and analyzed

Sample	Depth	S1	S2	PI	S3	Tmax	Tpeak	S3CO	PC(%)	TOC	RC%	HI	OI
2007-26	328.5	0,23	0,99	0,19	0,30	440	479	0,19	0,12	0,46	0,34	215	65
2007-27	313.5	0,52	2,19	0,19	0,33	443	482	0,05	0,24	0,89	0,65	246	37
2007-28	304.5	0,48	1,83	0,21	0,32	442	481	0,07	0,21	0,68	0,47	269	47
2007-29	259.5	0,44	2,16	0,17	0,30	443	482	0,11	0,24	0,93	0,69	232	32
2007-30	147.25	0,56	2,68	0,17	0,32	444	483	0,15	0,29	1,21	0,92	221	26
2007-31	97.5	0,58	2,29	0,20	0,34	443	482	0,11	0,26	1,05	0,79	218	32

Core A015, Bald Mountain, Portneuf #1 (Annex 2)
N 46° 40' 59.1"
W71° 55' 17.4"

This well was drilled in 1957, and reached a total depth of 1387 feet (422 m). The interval assigned to the Utica ranges from 392' (119 m) to 698' (212 m) (306' or 93 m) (Annex 2).

The well was drilled at short distance from the Cap Santé #1 and like the previous one, it is characterized by a nicely developed transition zone with the underlying Trenton carbonates. The Utica is here again typified by the presence of discrete fine-grained limestone interbeds. Five samples were collected for Rock Eval analyses.

Sample	Depth	S1	S2	PI	S3	Tmax	Tpeak	S3CO	PC(%)	TOC	RC%	HI	OI
2007-35	677.5	0,61	2,23	0,22	0,37	442	481	0,03	0,25	1,06	0,81	210	35
2007-36	663.5	1,24	4,09	0,23	0,33	446	485	0,07	0,46	1,94	1,48	211	17
2007-37	594.5	0,97	2,75	0,26	0,33	444	483	0,09	0,33	1,24	0,91	222	27
2007-38	489.75	0,76	2,51	0,23	0,41	442	481	0,04	0,29	0,98	0,69	256	42
2007-39	383.75	0,17	0,90	0,16	0,27	440	479	0,04	0,10	0,56	0,46	161	48

Core A037, Nicolet #1 (Annex 3)
N 46° 14' 39.3"
W72° 32' 57.4"

This well was drilled in 1956, and reached a total depth of 2875 feet (874 m). The interval assigned to the Utica ranges from 2400' (730 m) to 2875' (874 m) (475' or 144 m) (Annex 3).

The well was drilled on the south shore of the St. Lawrence River, the succession encountered in the well was deposited further from the assumed paleoshoreline compared to the previous two wells. The succession is almost entirely devoid of limestone beds, a situation that could be related to its more distal paleosetting. Three samples were collected for Rock Eval analyses. It can be seen that the TOC are significantly lower compared to the previous wells.

Sample	Depth	S1	S2	PI	S3	Tmax	Tpeak	S3CO	PC(%)	TOC	RC%	HI	OI
2007-32	2795	0,10	0,23	0,30	0,22	446	485	0,05	0,04	0,33	0,29	70	67
2007-33	2676.3	0,07	0,20	0,27	0,17	454	493	0,01	0,03	0,28	0,25	71	61
2007-34	2419	0,07	0,25	0,23	0,23	450	489	0,06	0,04	0,33	0,29	76	70

Core A206, SNC Soligaz, Montréal Est #3 (Annex 4)
N 45° 36' 54.4"
W73° 30' 32.8"

This well was drilled in 1986, and reached a total depth of 184 metres. The interval assigned to the Utica ranges from 14 to 24m (10m) (Annex 4).

This well is located near the southwestern end of the St. Lawrence Platform in an area documented to have experience deeper burial and higher thermal conditions (Bertrand, 1991). The base of the core is marked by a sandy calcarenite bed; overall the Utica is significantly darker compared to the previous wells and given its thinner assigned interval, it could possibly be interpreted as a condensed section. Three samples were collected for Rock Eval analyses.

Sample	Depth	S1	S2	PI	S3	Tmax	Tpeak	S3CO	PC(%)	TOC	RC%	HI	OI
2007-40	23.9	0,34	0,18	0,65	0,30	301	340	0,02	0,06	1,34	1,28	13	22
2007-41	19.3	0,36	0,31	0,54	0,24	483	522	0,02	0,07	1,86	1,79	17	13
2007-42	17	0,20	0,33	0,38	0,23	505	544	0,06	0,05	1,66	1,61	20	14

Utica outcrops

<u>Montmorency Falls (Section 1, Fig. 2)</u>

19T 0336511
5195244
N 46^o 53' 26.1"
W71^o 08' 46.1"

This locality is the most famous geological site near Quebec City where all three major geological domains of southern Quebec (e.g., the Precambrian basement and the Lower Paleozoic St. Lawrence Platform and the Appalachians; Fig. 10) can be visually appreciated from one of the many view points above the falls.

Figure 10. A panoramic view of the Montmorency fall section, looking northeastward. 1: Precambrian gneiss marking the position of the Montmorency normal fault. 2: flat-lying Upper Ordovician carbonates of the Trenton Group on the upthrown block. 3: Top of the Upper Ordovician Utica Shale on the downthrown block. 4: Upper Ordovician Lotbinière Formation, the dashed line is the units contact. 5: far view, Cambrian-Lower Ordovician units on the Ile d'Orléans which belongs to the Humber zone Appalachians. Logan's line (the white dashed line at the margin of the island) is the limit between the St. Lawrence Platform and Appalachian allochtons

This stop is located at the Montmorency fall, a major topographic feature that results from syn- to post-Taconian (post-Utica) extensional movement of the Montmorency fault. The upthrown block of the fault consists of Grenville Precambrian gneisses unconformably overlain by Middle?-Upper Ordovician platform sediments whereas the tilted downthrown block is overlain by Upper Ordovician platform and deep marine sediments.

From the parking lot, cross the walking bridge over the falls and right after the bridge, turn left and follow the path in the park along the Montmorency river (Fig. 11). The section starts at the southern end of the Grenville exposures (Section 1 on Fig. 11). The basement consists of felsic gneiss with strong E-W mineral lineations. The Precambrian surface is very irregular and the base of the overlapping sedimentary succession is represented by a 50 cm-thick unit of buff weathering arkosic sandstone characterized by low angle cross laminations (Fig. 12a). This sandstone is glauconite-rich and its exact age is unknown. This sandstone is overlain by a 60 cm-thick fossiliferous calcirudite with sparry calcite cement. Fossils are dominated by centimetre-sized well rounded to heavily broken *Solenopora* red algae and crinoids. The calcirudite is devoid of sedimentary structures although poor preservation of allochems suggests an agitated

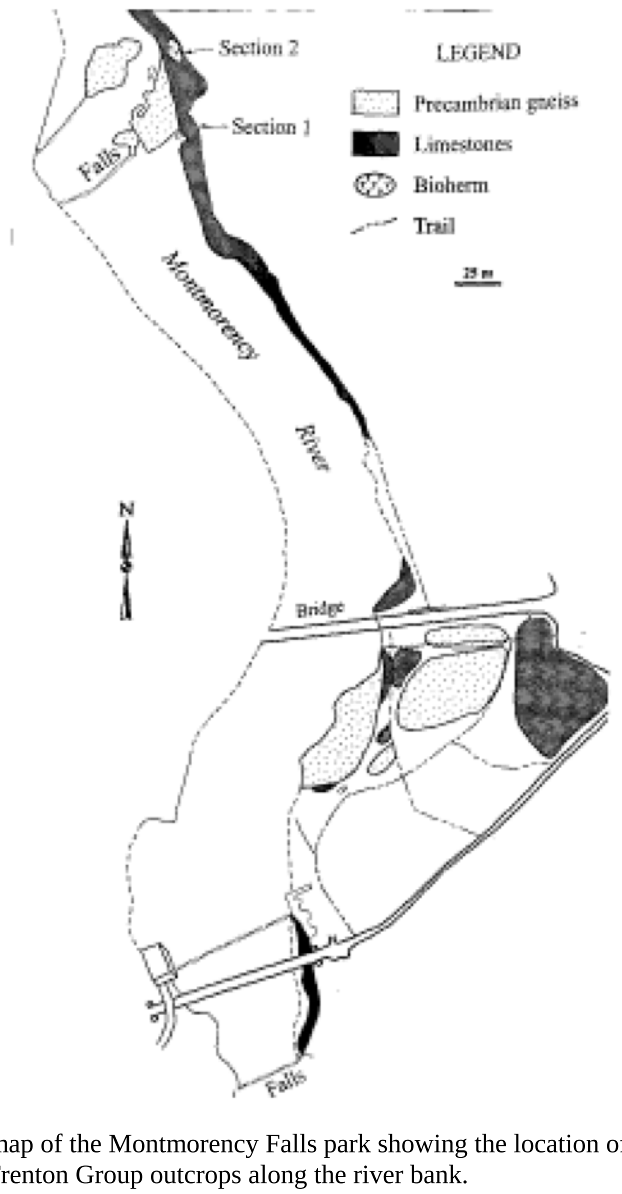

Figure 11. Detailed location map of the Montmorency Falls park showing the location of the trail adjacent to the river and the location of the Trenton Group outcrops along the river bank.

marine environment. The calcirudite bed wedges out against the Precambrian basement and note, on the gneiss outcrop, the presence of abundant potholes and fractures filled with the calcirudite facies (Fig. 12b). Diagenetic analyses of the calcite cement indicate a complex history of marine – meteoric – marine and burial events (Ndzangou, 1997). This bed is included in the Pont-Rouge Formation. The calcirudite bed is overlain by the Deschambault Formation that consists of a 3 metre-thick coarsening-upward succession with initial (approx. 40 cm) wavy-bedded wackestone calcilutite with thin shale partings. This first unit still wedges out on the Grenville gneiss. This first unit is overlain by a 2 metre-thick interval of thin wackestone-packstone calcarenite having abundant thin partings. This second unit transgresses over the Precambrian knoll. The uppermost unit at that locality is a 60 cm-thick interval of thickly-bedded grainstone calcarenite – calcirudite. The last three units are characterized by abundant crinoids, brachiopods, molluscs and bryozoans with the latter forming *in situ* growth thickets. The overall amount of lime mud significantly decreases upward.

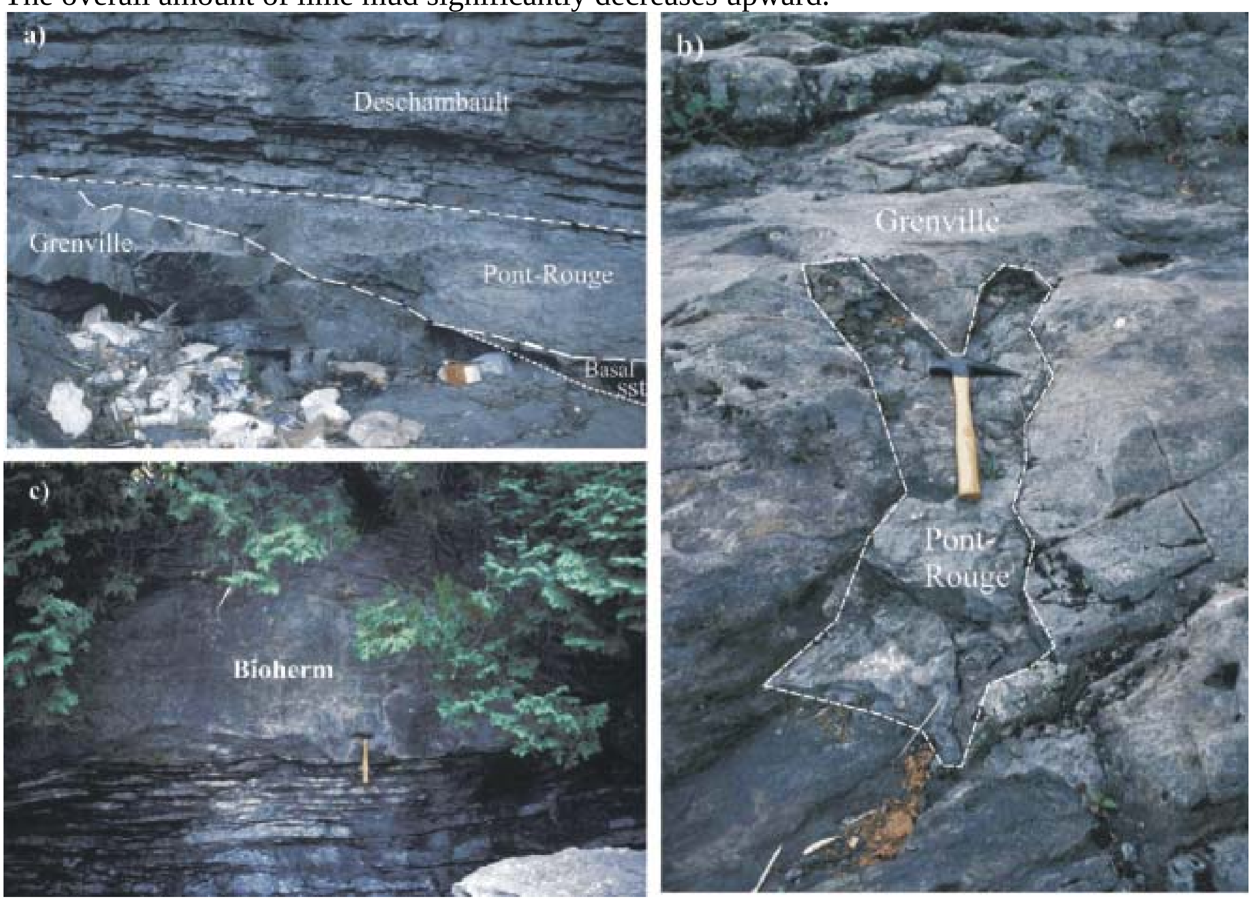

Figure 12: a) Onlapping succession of basal sandstone (sst), Solenopora-rich calcirudite (Pont Rouge Formation) and wavy bedded limestone interval (Deschambault Formation) over the Grenville basement. b) Pothole developed in grenville gneiss and filled by Solenopora calcirudite. c) Bryozoan bioherm surrounded by bryozoan and crinoid grainstone.

Higher beds can be observed at a very short distance to the north (approx. 20 m; Section 2 on Fig. 11). A thinner coarsening-upward succession overlies the irregular Precambrian basement, this succession is similar to the one previously described with the exception of a thinner middle calcarenite interval. Of interest is the presence of two mound-shaped bioherms that are seen in the small cliff along the river (Fig. 12c). Note the draping of adjacent beds (bryozoan-rich packstone calcarenite – calcirudite) which suggest some small synoptic relief on the seafloor. These mounds consist predominantly of lime mud with a relatively abundant (approx 35%) well-preserved bryozoan fauna. Accessory fauna is given by crinoids, molluscs and few brachiopods. Polished slabs of the unit reveal the presence of pelletoidal crusts (cryptomicrobial?) locally surrounding and connecting the bryozoans therefore providing a bind for the structure (Ndzangou, 1997)

Go back to the bridge over the falls and go to the opposite way to the northeast and get to the top of the cliff adjacent to the fall. Walk to the stairs that bring you down to the lower level at the toe of the fall. While descending, you will see grey and greenish siltstone and mudstone with fine sandstone laminae of the Upper Ordovician Lotbinière Formation (Belt and Bussières, 1981). This flysch unit belongs to the Sainte-Rosalie Group. Flysch sedimentation records the rapid foundering of the carbonate platform as the continental margin was collapsing as the result of westward migration of the Taconian allochthons, this deepening-upward trend occurred at a time of global glacio-eustatic sea level lowering.

At the base of the stairs, walk towards the fall (and be ready to get splashed), at a small observatory facility, to your right, you will see in a gully, the contact between the upper part of the platform succession (Neuville Formation, upper beds of the Trenton Group) and the overlying black shale of the Upper Ordovician Utica Group. Both the uppermost beds of the Trenton Group (lime mudstone calcilutite) and of the Utica (petroliferous mudstone) have high TOC content (between 1% and 3%, Bertrand, 1991) and can be considered as good hydrocarbon source rock, in particular for the black shale with high HI (150-250) and low OI (15-30).

The contact with the Lotbinière is at the first coarse-grained sandstone bed (Fig. 13a) of grey sandy siltstone with numerous 10-15 cm coarser beds with scoured bases and tool marks; the beds have sharp flat tops and internal horizontal and cross-laminations. The sandstone to siltstone ratio is roughly 1:10. The coarser-grained base of the Lotbinière overlain by tens of metres of grey sandy siltstone and rare 5-10 cm coarser fine to medium sandstone with sharp flat bases and rippled tops. Few fractures are visible and the unit shares similarities with the Georgian Bay Formation of Ontario. The base of the Lotbinière has locally some potential for shale gas generation (as documented in recently drilled wells farther to the south and as recently documented by Talisman Energy). Note that the facies observed here are quite different from those observed in coeval, Utica-overlying flysch elsewhere as the Montmorency section is characterized by a higher percentage of coarser-grained facies near the base of the formation. One sample has been collected for Rock Eval near the base of the formation

Sample	S1	S2	PI	S3	Tmax	Tpeak	S3CO	PC(%)	TOC	RC%	HI	OI
LKA-2007-23	0,22	0,87	0,20	0,38	449	488	0,03	0,11	0,61	0,50	143	62

From the base of the cliff, looking up, one can easily see bundles of thin sandstone beds forming top of coarsening-upward parasequences (Fig. 13b)

Figure 13. a) Close-up view of some of the coarse-grained sandstone that marks the base of the Lotbinière. b) Metre-thick coarsening and thickening upward cycles in the flysch succession.

Cap Santé (Section 2, Fig. 2)

19T 0286603
5172262
N 46° 40' 11.6"
W71° 47' 23.5"

This outcrop is located approximately 55 km SW of Quebec City along St Lawrence River. The section starts with a beach rocky outcrop on the western side of the wharf (Fig. 14a).The lowermost exposure is a 4 m thick succession of organic-rich, dark grey calcareous shale with thin 2-10 cm calcisiltite beds with sharp bases. On freshly broken surface, the rock has a strong petroliferous (condensate) smell. The siltstone to shale ratio is 1:10. The succession is characterized by abundant nautiloid shells and is rich in graptolites.

Fractures are well developed and dominant sets are: 155/345, 115/295, 125/305, 45/225, 35/215

A Rock Eval sample gave

Sample	S1	S2	PI	S3	Tmax	Tpeak	S3CO	PC(%)	TOC	RC%	HI	OI
LKA-2007-20	0,88	3,37	0,21	0,18	449	488	0,11	0,37	1,22	0,85	276	15

Walk to the east along the railroad tracks to a 10 m thick exposure (stratigraphically higher)

19T 0287102
5172173
N 46° 40' 09.2"
W71° 46' 59.8"

The succession is flat-lying and consists of dark grey to black shale with few thin 1-5 cm micrite beds with sharp bases, laterally continuous for at least 20 m (Fig. 14b). The succession seems slightly less organic-rich but is still slightly petroliferous. Farther along the railroad tracks, micrite beds up to 20 cm in thickness occur in bundles, no obvious fracture sets. Bioturbation is locally well developed and beds rich in graptolites and cephalopods are common. The lateral width of the outcrop is roughly one kilometer.

Two samples have been analyzed with Rock Eval, sample #5 is approximately 4 meters above sample# 20 and is 6 metres below sample #6.

Sample	S1	S2	PI	S3	Tmax	Tpeak	S3CO	PC(%)	TOC	RC%	HI	OI
LKA-2007-05	0,94	3,98	0,19	0,24	447	486	0,05	0,43	1,52	1,09	262	16
LKA-2007-06	0,51	2,93	0,15	0,51	445	484	0,19	0,31	1,52	1,21	193	34

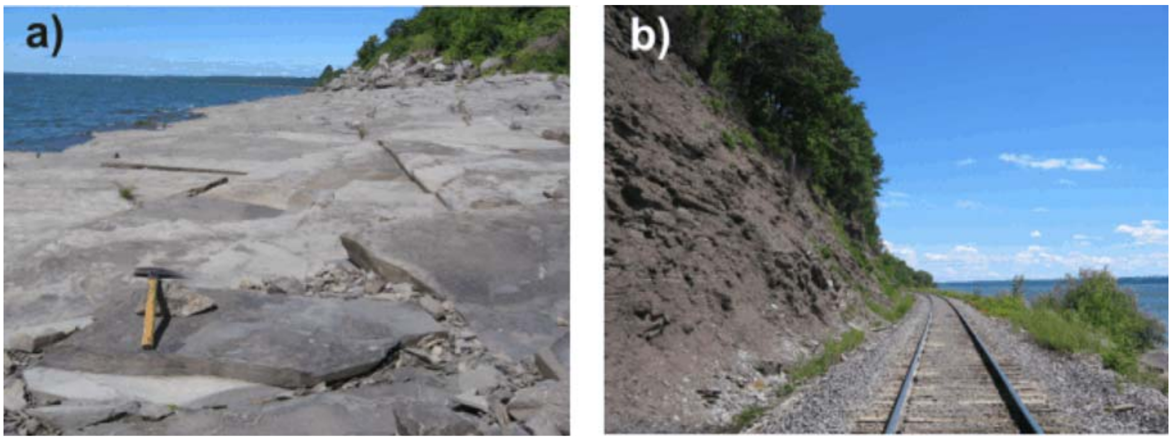

Figure 14. Cap Santé section. a) section along the shore and b) the adjacent rail road section. In b) the beds with positive relief are calcilutites.

<u>Jacques Cartier River at Pont Rouge (Section 3, Fig. 2)</u>

19T 0294054
5180316
N 46^o 44' 40.2"
W71^o 41' 46.0"

At this locality, while walking to access the Trenton-Utica contact, we will see some examples of dolomite-filled fractures and evidence for synsedimentary extensional collapse of the Trenton deep marine (below wave base) carbonate ramp. The small dolomite-filled fractures are interpreted to be a distal expression of a hydrothermal dolomitization system. The fractures occur in bioclastic limestone of the Caradocian (Upper Ordovician) Deschambault Formation (middle unit of the Trenton Group) (Fig. 15a). Associated with the coarse-grained dolomite infill, some bitumen-filled fractures and voids are abundant. Hydrothermal dolostones that host significant gas has been recently (early 2007) drilled by Talisman Inc. a few kilometers to the South (Gentilly #1)

Walk eastward and up-section through the deepening-upward Trenton Group (Caradocian Neuville Formation). On some outcrop beds, anomalous concentrations of oriented cephalopods that indicate east-west currents are visible (Fig. 15b). These are death assemblages that accumulated during a long period of minimal sedimentation. This bed indicates a sudden deepening event that resulted in the disruption of the carbonate production “factory”, the deepening event is of tectonic origin and similar bed-event are recognized at other stratigraphic intervals in the Upper Ordovician succession, and another one is visible at the field exposure of the Jacques-Cartier River Fault a few meters downstream. There, the accumulation of cephalopods is associated with the development of dolomitic and phosphatic submarine crusts or hardgrounds (Fig. 15c) which are also evidence for minimal sedimentation and prolonged seafloor exposure. At this point, the Jacques-Cartier River fault is nicely exposed with the last visible movement (Taconian Orogeny?) of the fault resulting in the juxtaposition of the Deschambault Formation (upthrown block) and of the upper part of the Neuville Formation (downthrown block); from regional consideration, the vertical throw is about 150 metres. However, the extensional movement that resulted in the stop of carbonate sedimentation and development of submarine hardgrounds and cephalopods concentration occurred before that last movement, likely in the early distal pulses of the Taconian Orogeny.

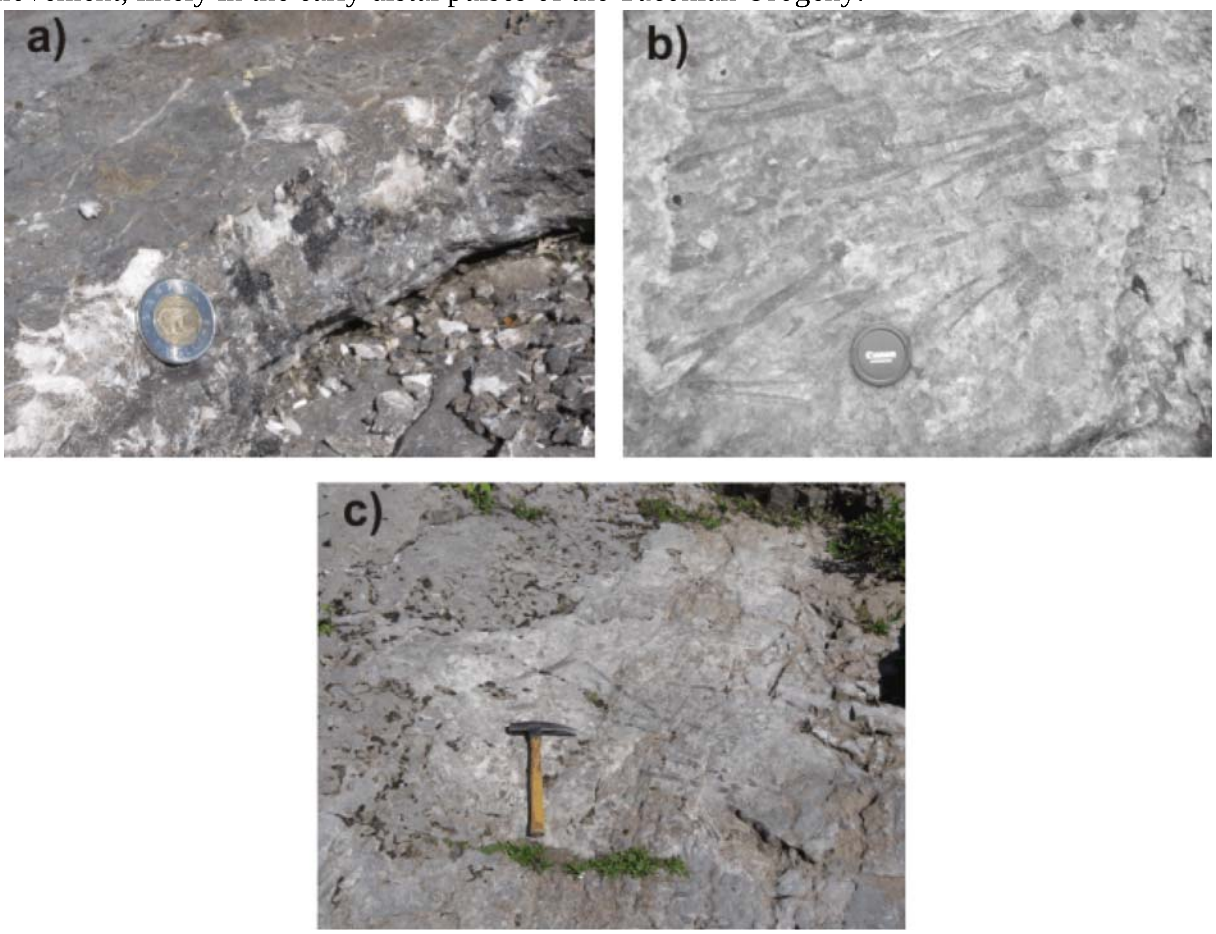

Figure 15. a) Fracture filled with dolomite and late pore-filling bitumen, Deschambault Formation. b) Oriented cephalopods on a bedding plane, Neuville Formation. c) Oriented cephalopods on a bedding plane characterized by abundant phosphate crust or hardgrounds.

Cross the Jacques-Cartier River Fault and walk westward into uppermost Trenton Group (e.g., the Grondines Member of the Neuville Formation) that consists of deepening-upward nodular micritic limestone with crinoids and few bioclastic beds; the succession is characterized by an upward-increase of shaley partings.

Transition between Trenton and Utica
19T 0294171

5179664
N 46° 44' 19.0"
W71° 41' 39.4"

The upper few metres of the Neuville Formation consist of thinly interbedded micritic limestone with dark grey laminated shale. The limestone to shale ratio is roughly 5:1. Limestone facies indicate a below storm wave base setting for accumulation. The uppermost thick limestone bed is considered as the top of the Trenton Group (Fig. 16a). It is a 50 cm thick, nodular grey micritic limestone that is sharply overlain by 10 m of dark grey laminated shale with thin 5-10 cm sharp-based limestone beds. The limestone to shale ratio is roughly 1:3 (Fig. 16b).
Many of the thin limestone beds within the shale are discontinuous and no obvious bioclastic bed is present; a situation similar to the Collingwood Formation of Ontario
Four samples have been collected in the transition interval for Rock Eval analysis

Sample	S1	S2	PI	S3	Tmax	Tpeak	S3CO	PC(%)	TOC	RC%	HI	OI
LKA-2007-16	0,19	1,52	0,11	0,75	444	483	0,13	0,17	0,96	0,79	158	78
LKA-2007-17	0,56	1,56	0,27	0,27	446	485	0,05	0,19	0,66	0,47	236	41
LKA-2007-18	0,15	0,82	0,16	0,37	440	479	0,03	0,09	0,41	0,32	200	90
LKA-2007-21	0,43	1,50	0,22	0,30	446	485	0,03	0,17	0,67	0,50	224	45

Figure 16. a) Last thick (50 cm) limestone bed at the top of the Trenton Group (Neuville Formation). b) Base of the Utica overlying the last thick limestone bed. Hammer (30 cm) for scale

<u>Jacques Cartier river near Donnaconna (Section 4, Fig. 2)</u>
19T 0289873
5174745
N 46° 41' 35.9"

W71° 44' 53.3"

At this locality, we will examine some cliff exposures of Utica, somewhere above the base that was examined at the previous stop but at a largely unknown stratigraphic location (Fig. 17a). This section is approximately 5 kilometres to the east of the Cap Santé section and both localities are on the opposite limbs of the Cap Santé Anticline with the east limb affected by the Jacques Cartier River fault.

At this section, near the very base of it, some thin bentonite layers are visible; these are testimony of felsic volcanic activity that took place in Upper Ordovician time when Taconian subduction and accretion took place at some distance of the continental margin.

The visible section is 10 metres thick and consists of horizontal strata that are of difficult vertical access but offer some well-exposed faces.

The accessible beds consist of thinly laminated grey to dark grey silty mudstone with some minor bioturbation. The succession is fairly uniform and no very black shale is present. Graptolites can be locally abundant graptolites on some bedding planes. Downstream to the south, thin 10-15 cm limestone beds interbedded with the mudstone in the upper 7 metres of outcrop are visible and are forming bundles (Fig. 17b).

Two prominent fracture sets have been identified: 25/205, 95/275

Two samples have been collected for Rock Eval, the #7 is from the base and #22 is stratigraphically 5 metres above the previous one.

Sample	S1	S2	PI	S3	Tmax	Tpeak	S3CO	PC(%)	TOC	RC%	HI	OI
LKA-2007-07	1,50	4,22	0,26	0,20	450	489	0,04	0,49	1,59	1,10	265	13
LKA-2007-22	0,81	3,14	0,20	0,54	447	486	0,06	0,35	1,44	1,09	218	38

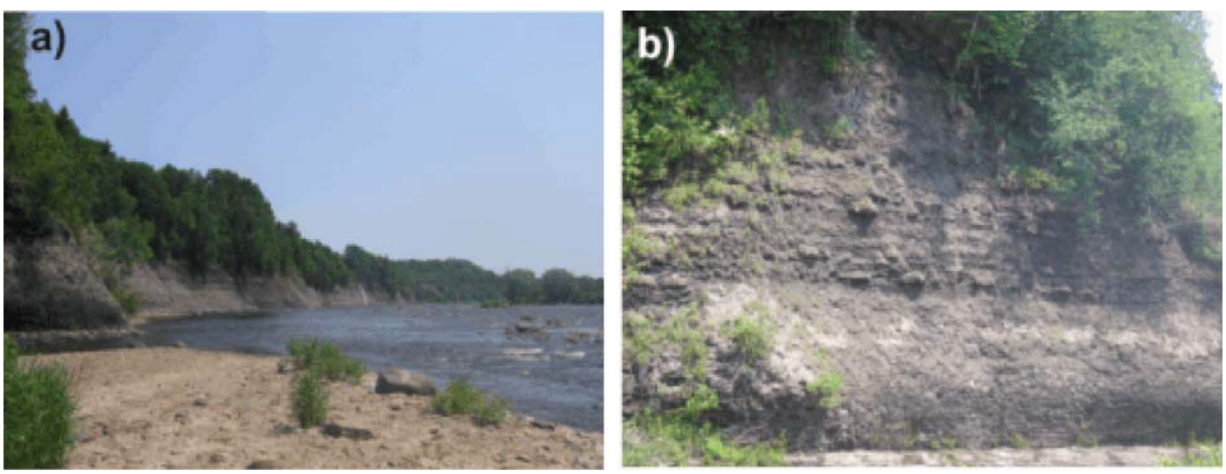

Figure 17: Utica Shale on the Jacques Cartier river near Donnaconna. a) general view of the kilometer-long section of flat-lying limy mudstone and calcilutite. b) Close-up view of a 5 metre-thick interval dominated by finely laminated to massive fine-grained limestone (calcilutite).

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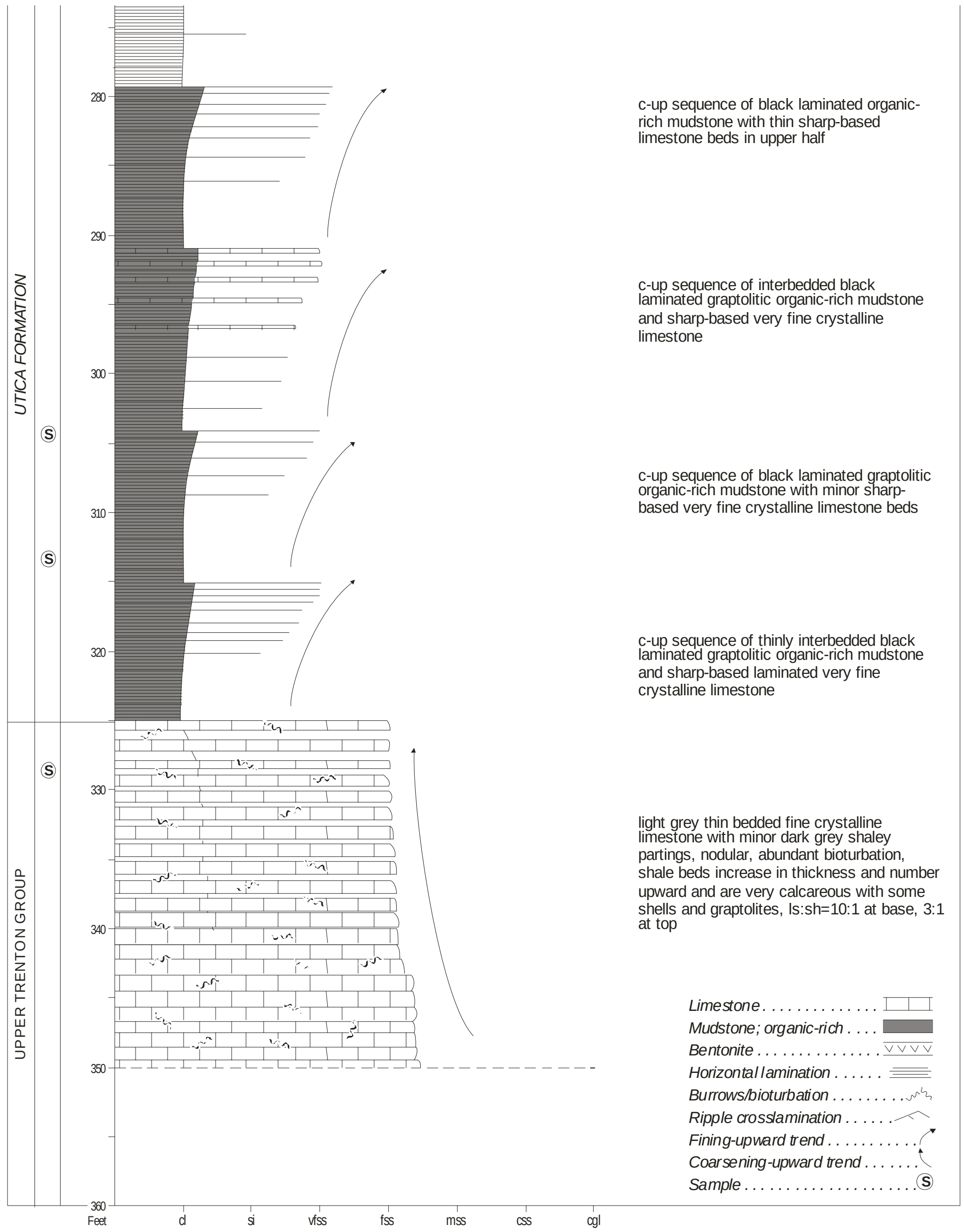
ANNEX 1 – 4 pages

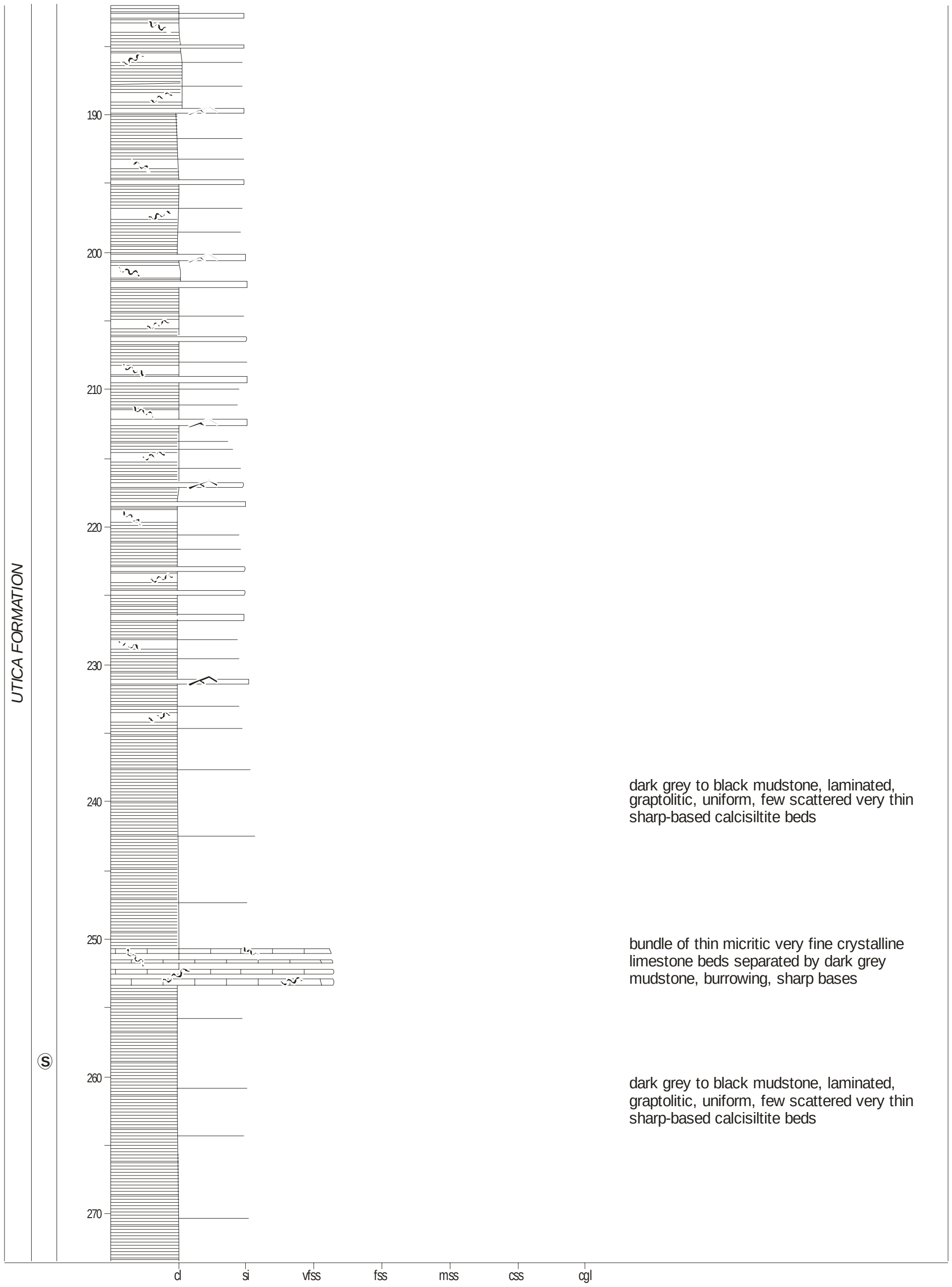
Bald Mountain Cap Santé #1

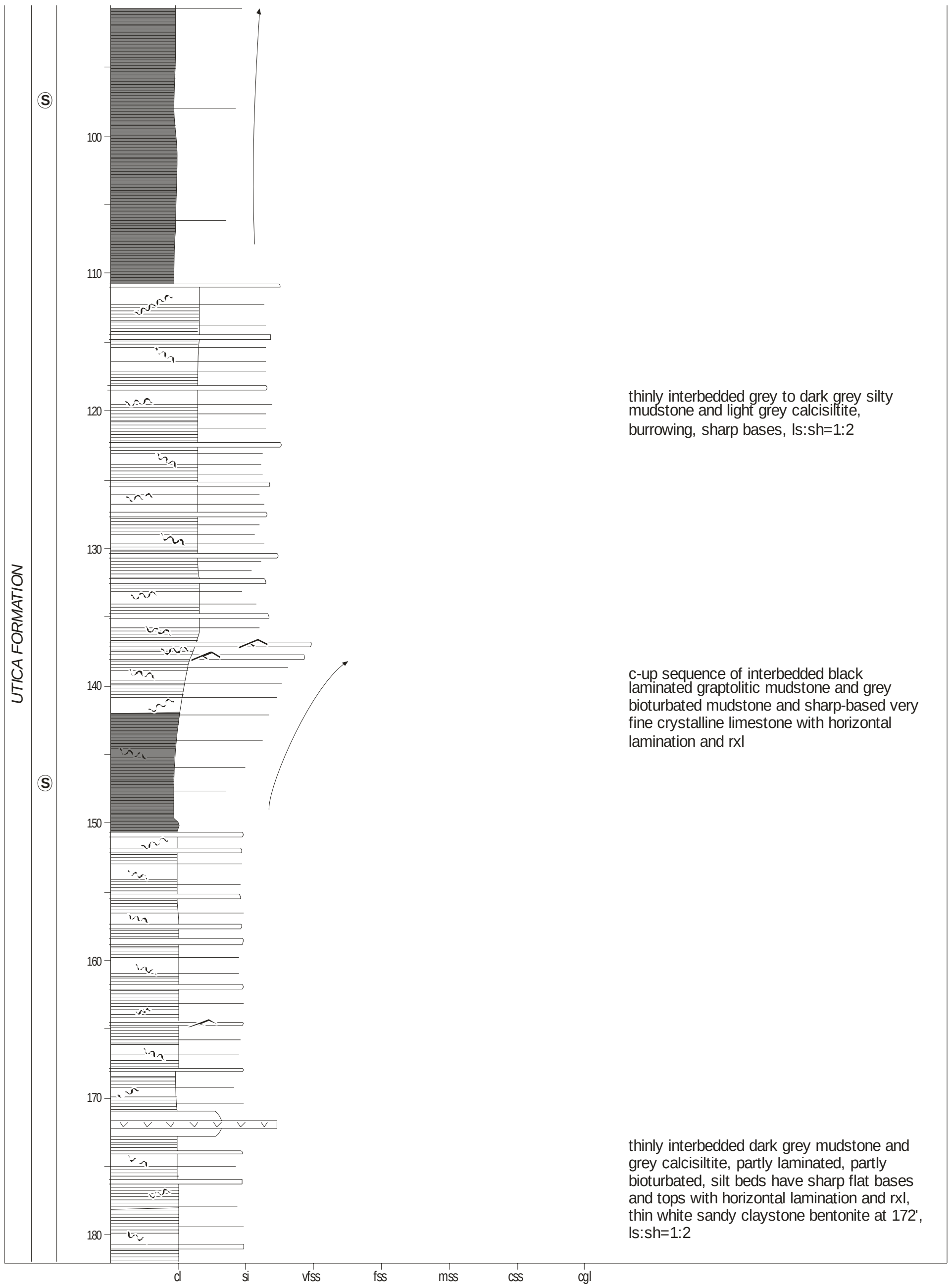
North shore of St. Lawrence River, southwest of Quebec City

46.68°N, 71.78°W

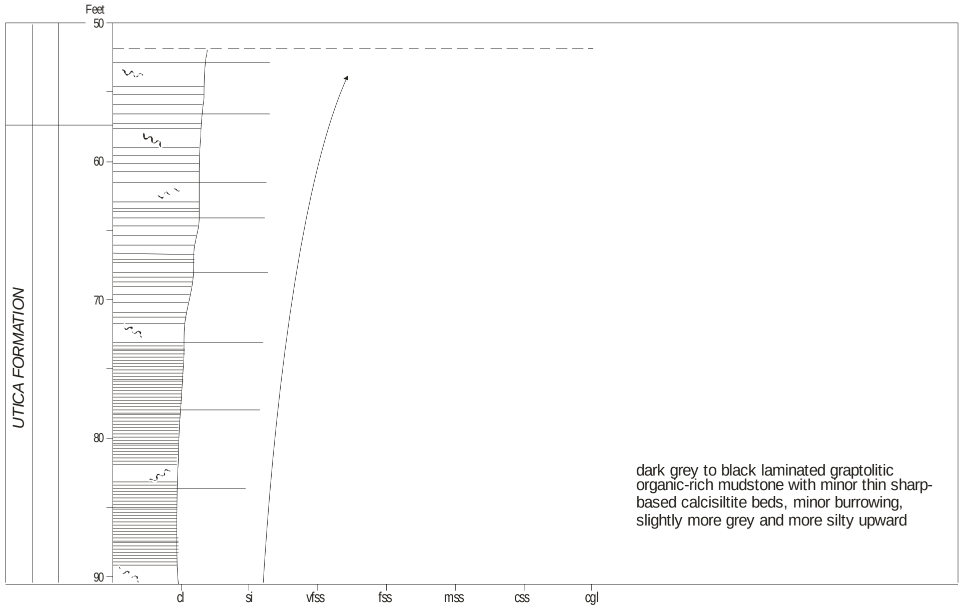


Bald Mountain Cap Santé #1
North shore of St. Lawrence River, southwest of Quebec City
46.68°N, 71.78°W


UTICA FORMATION
S
190
200
210
220
230
240
250
260
270
cl
si
vfss
fss
mss
css
cgl
dark grey to black mudstone, laminated, graptolitic, uniform, few scattered very thin sharp-based calcisiltite beds
bundle of thin micritic very fine crystalline limestone beds separated by dark grey mudstone, burrowing, sharp bases
dark grey to black mudstone, laminated, graptolitic, uniform, few scattered very thin sharp-based calcisiltite beds



UTICA FORMATION
S
100
110
120
130
140
150
160
170
180
thinly interbedded grey to dark grey silty mudstone and light grey calcisiltite, burrowing, sharp bases, ls:sh=1:2
c-up sequence of interbedded black laminated graptolitic mudstone and grey bioturbated mudstone and sharp-based very fine crystalline limestone with horizontal lamination and rxl
thinly interbedded dark grey mudstone and grey calcisiltite, partly laminated, partly bioturbated, silt beds have sharp flat bases and tops with horizontal lamination and rxl, thin white sandy claystone bentonite at 172', ls:sh=1:2
cl
si
vfss
fss
mss
css
cgl

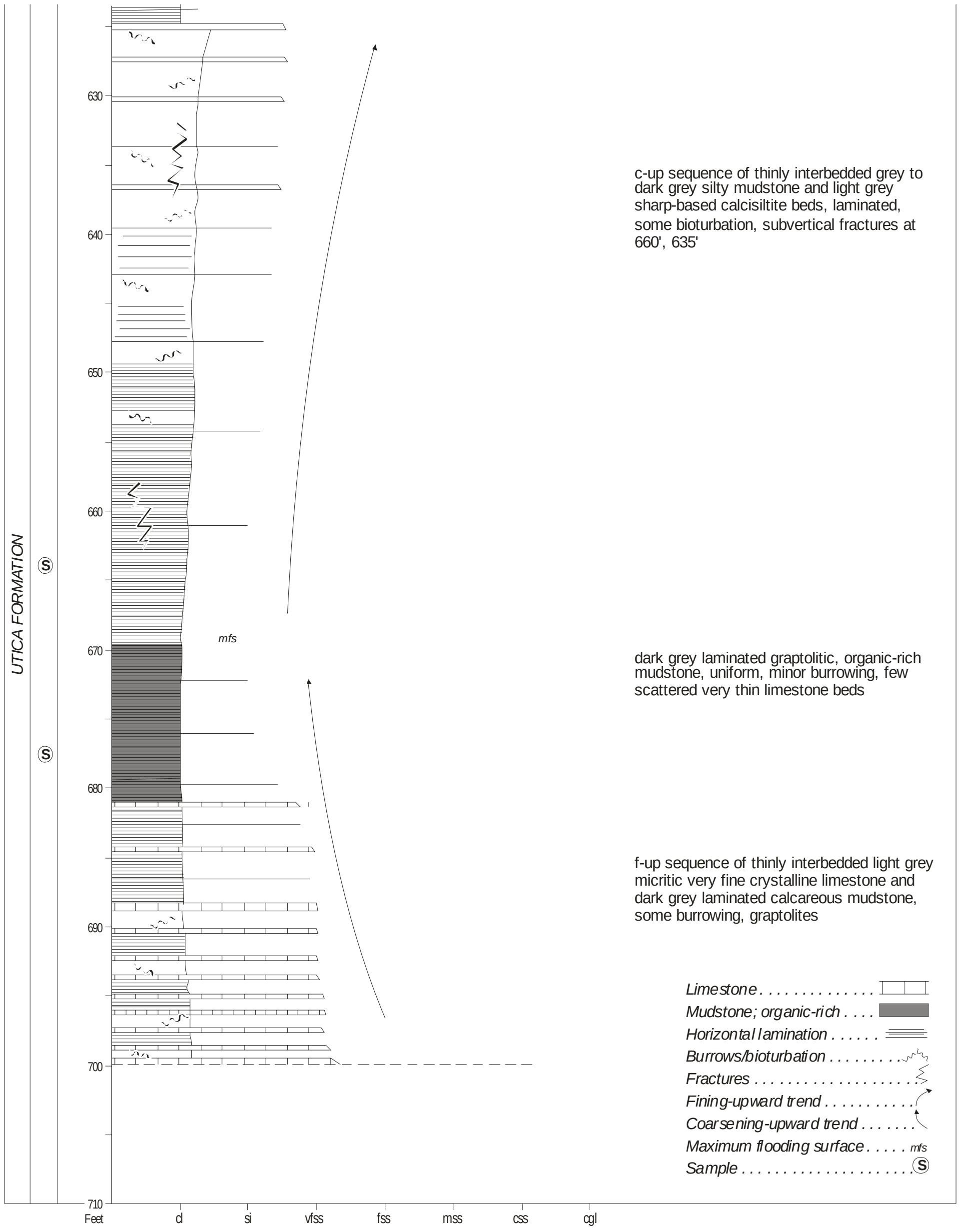

Feet
50
60
70
80
90
UTICA FORMATION
cl
si
vfss
fss
mss
css
cgl
dark grey to black laminated graptolitic organic-rich mudstone with minor thin sharp-based calcisiltite beds, minor burrowing, slightly more grey and more silty upward

ANNEX 2 – 4 pages

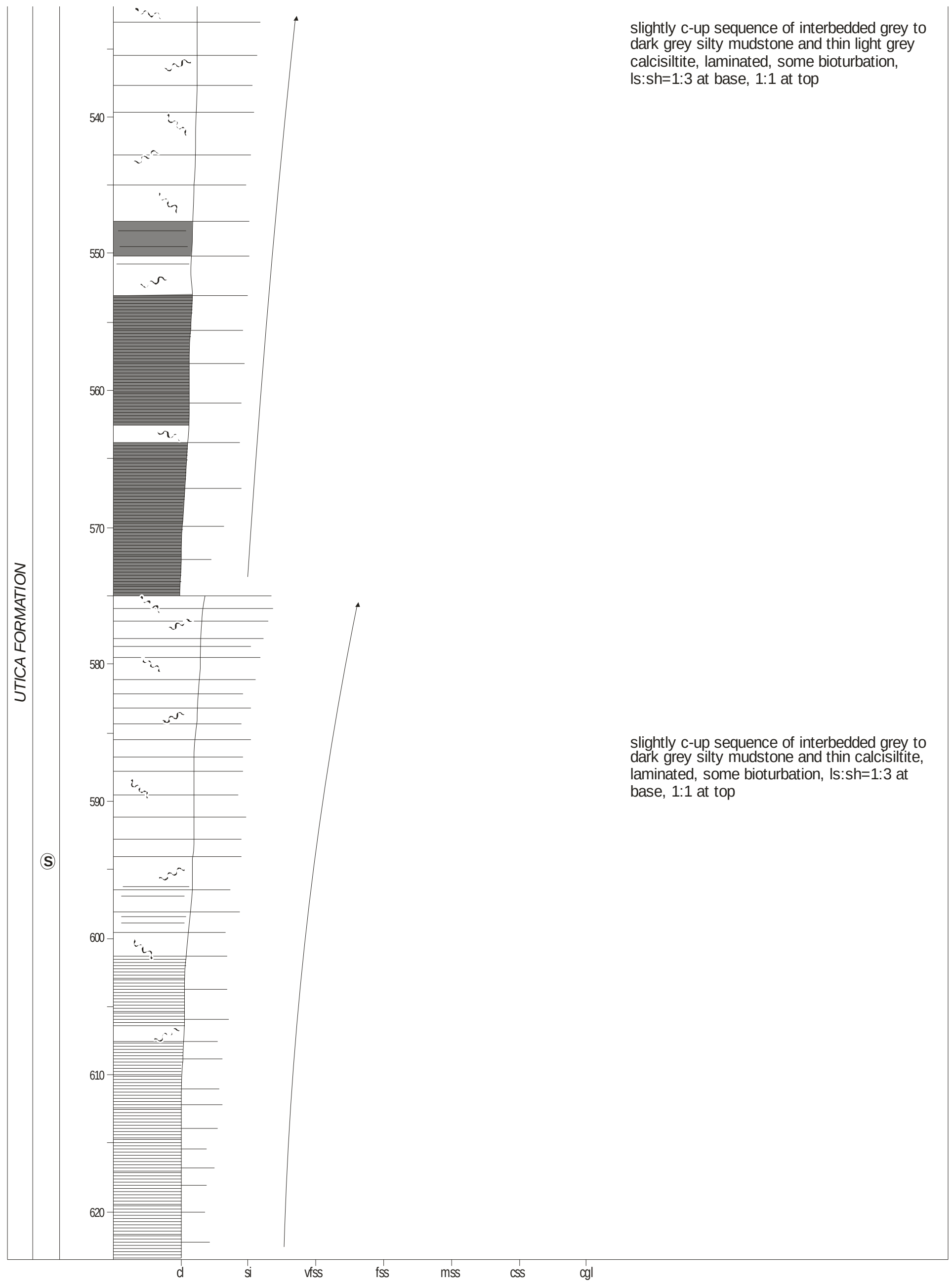
Bald Mountain Portneuf #1

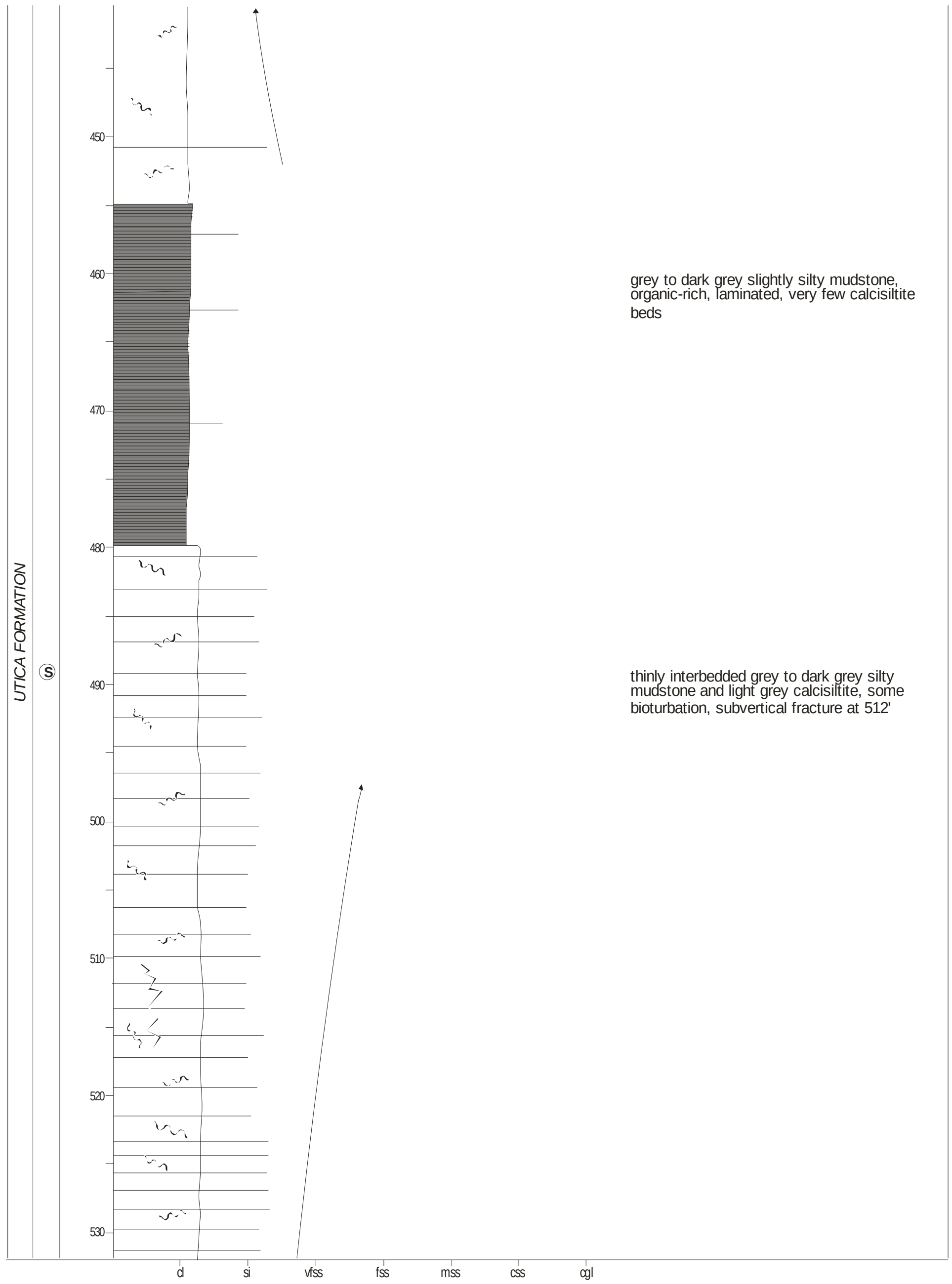
North shore of St. Lawrence River, southwest of Quebec City

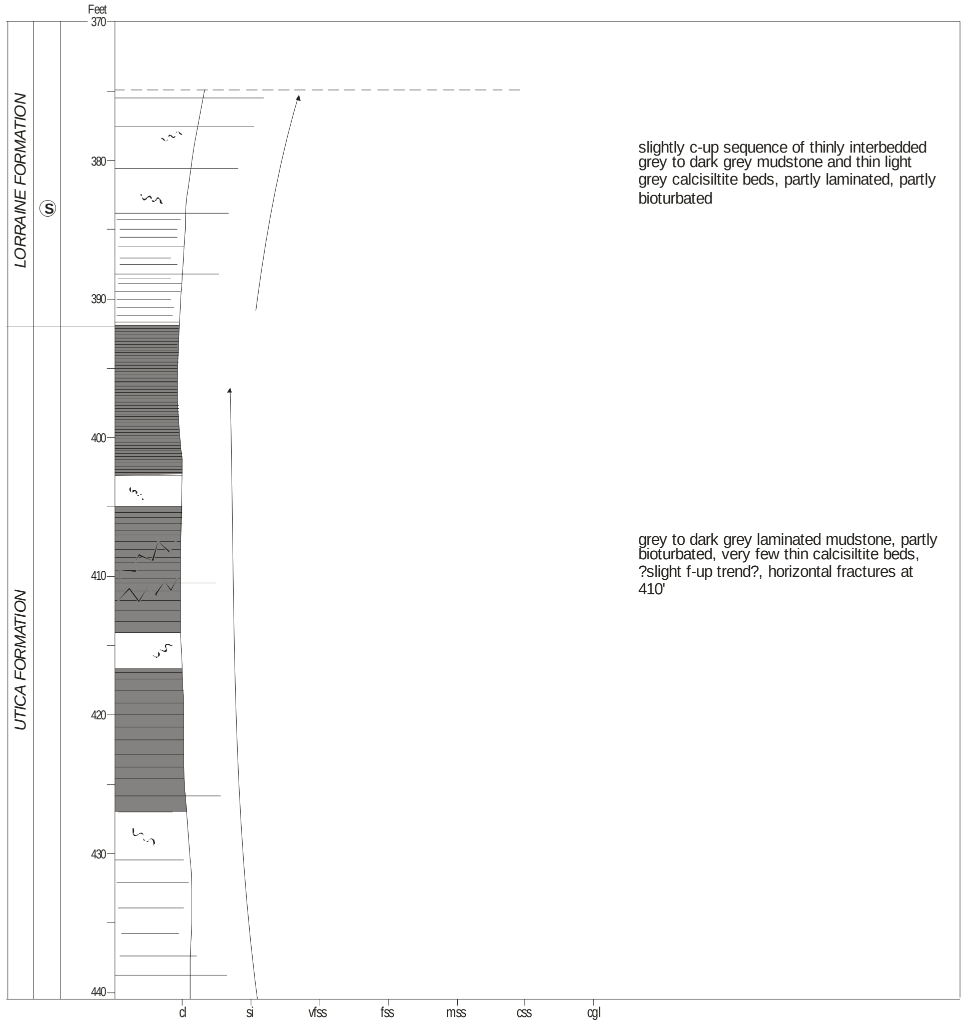
46.68°N, 71.92°W



Bald Mountain Portneuf #1
North shore of St. Lawrence River, southwest of Quebec City
46.68°N, 71.92°W

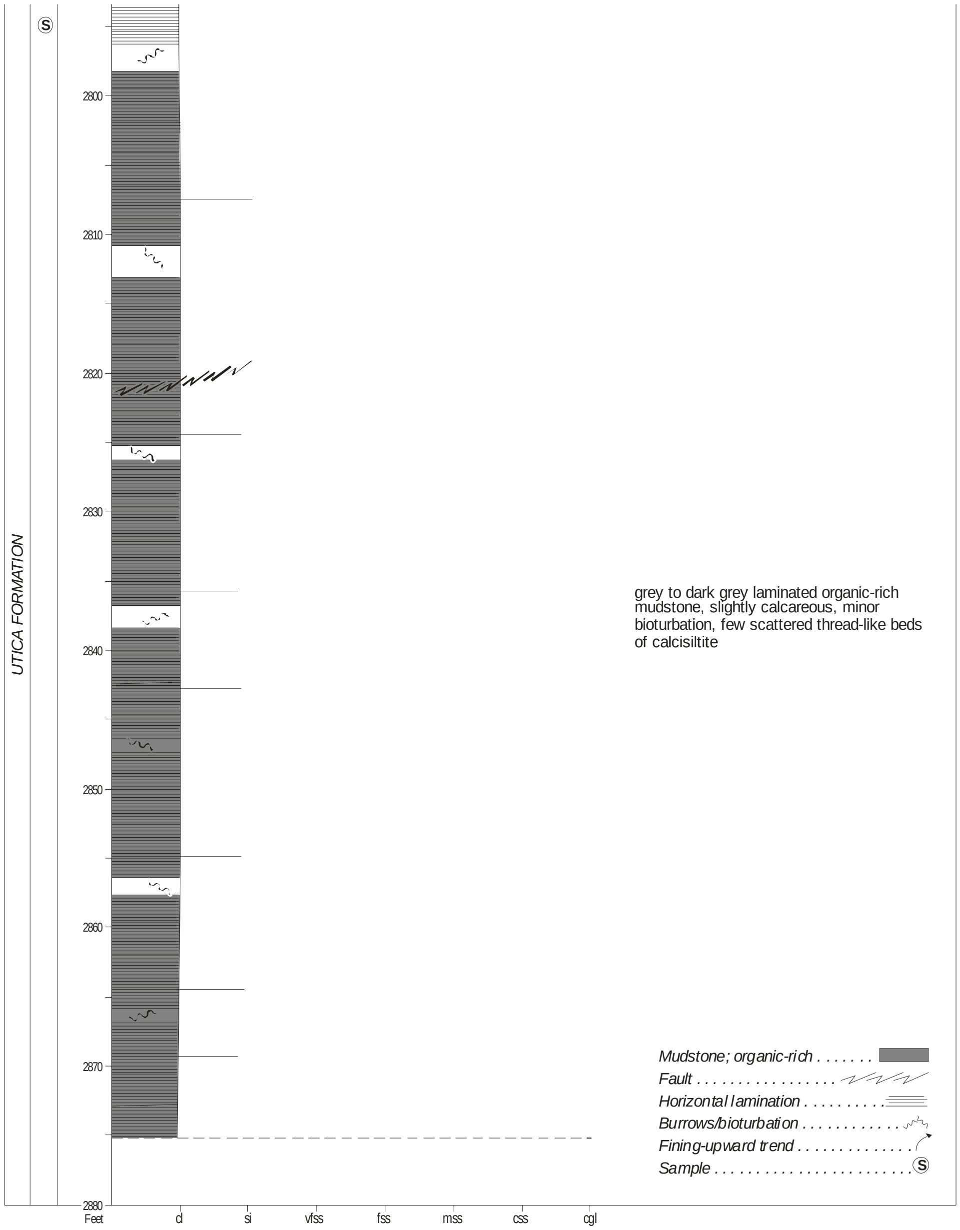

UTICA FORMATION
S
540
550
560
570
580
590
600
610
620
slightly c-up sequence of interbedded grey to dark grey silty mudstone and thin light grey calcisiltite, laminated, some bioturbation, ls:sh=1:3 at base, 1:1 at top
slightly c-up sequence of interbedded grey to dark grey silty mudstone and thin calcisiltite, laminated, some bioturbation, ls:sh=1:3 at base, 1:1 at top
cl
si
vfss
fss
mss
css
cgl


UTICA FORMATION
S
450
460
470
480
490
500
510
520
530
grey to dark grey slightly silty mudstone, organic-rich, laminated, very few calcisiltite beds
thinly interbedded grey to dark grey silty mudstone and light grey calcisiltite, some bioturbation, subvertical fracture at 512'
cl
si
vfss
fss
mss
css
cgl

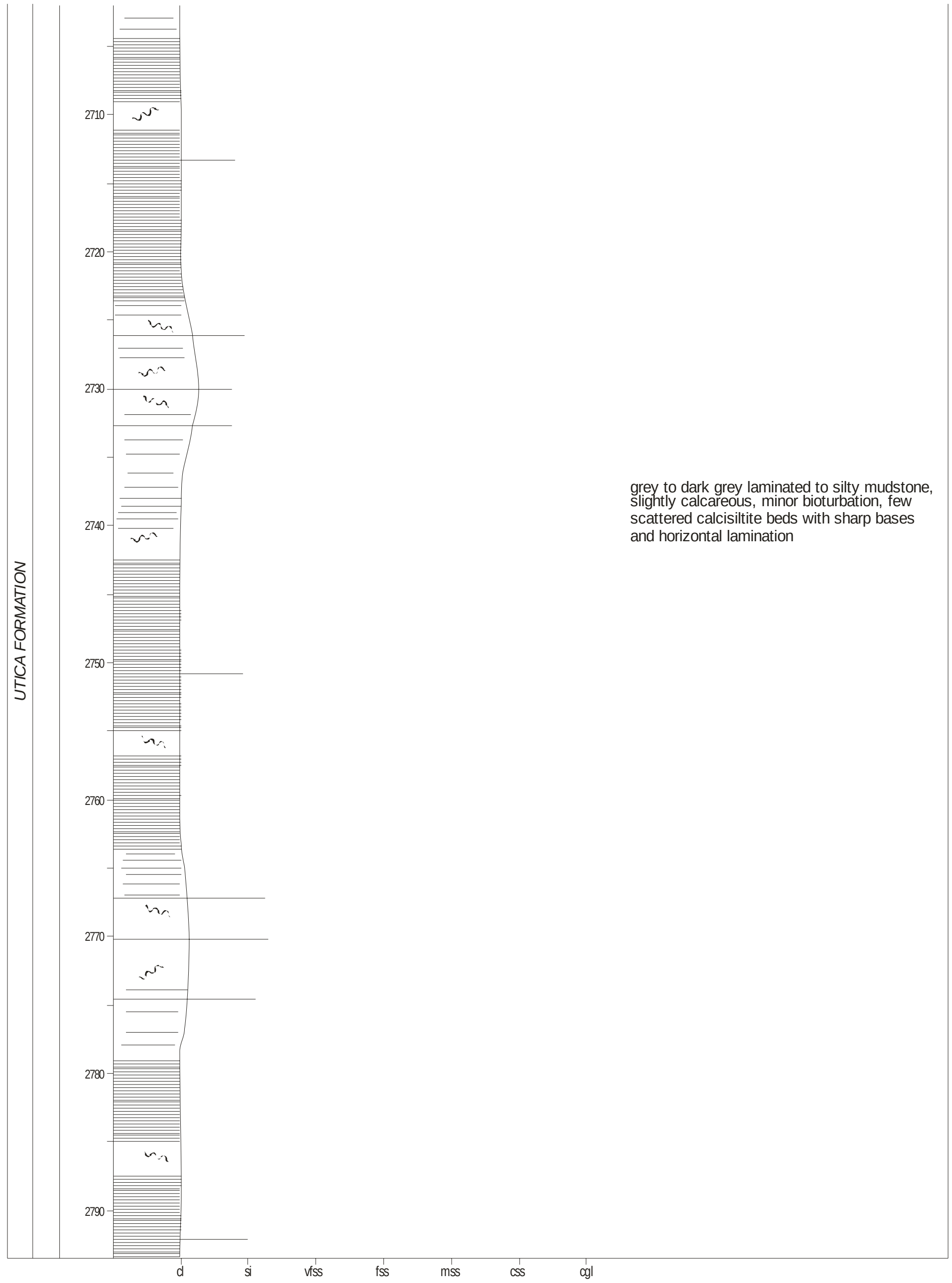

Feet
370
380
390
400
410
420
430
440
LORRAINE FORMATION
UTICA FORMATION
S
slightly c-up sequence of thinly interbedded grey to dark grey mudstone and thin light grey calcisiltite beds, partly laminated, partly bioturbated
grey to dark grey laminated mudstone, partly bioturbated, very few thin calcisiltite beds, ?slight f-up trend?, horizontal fractures at 410'
cl
si
vfss
fss
mss
css
cgl

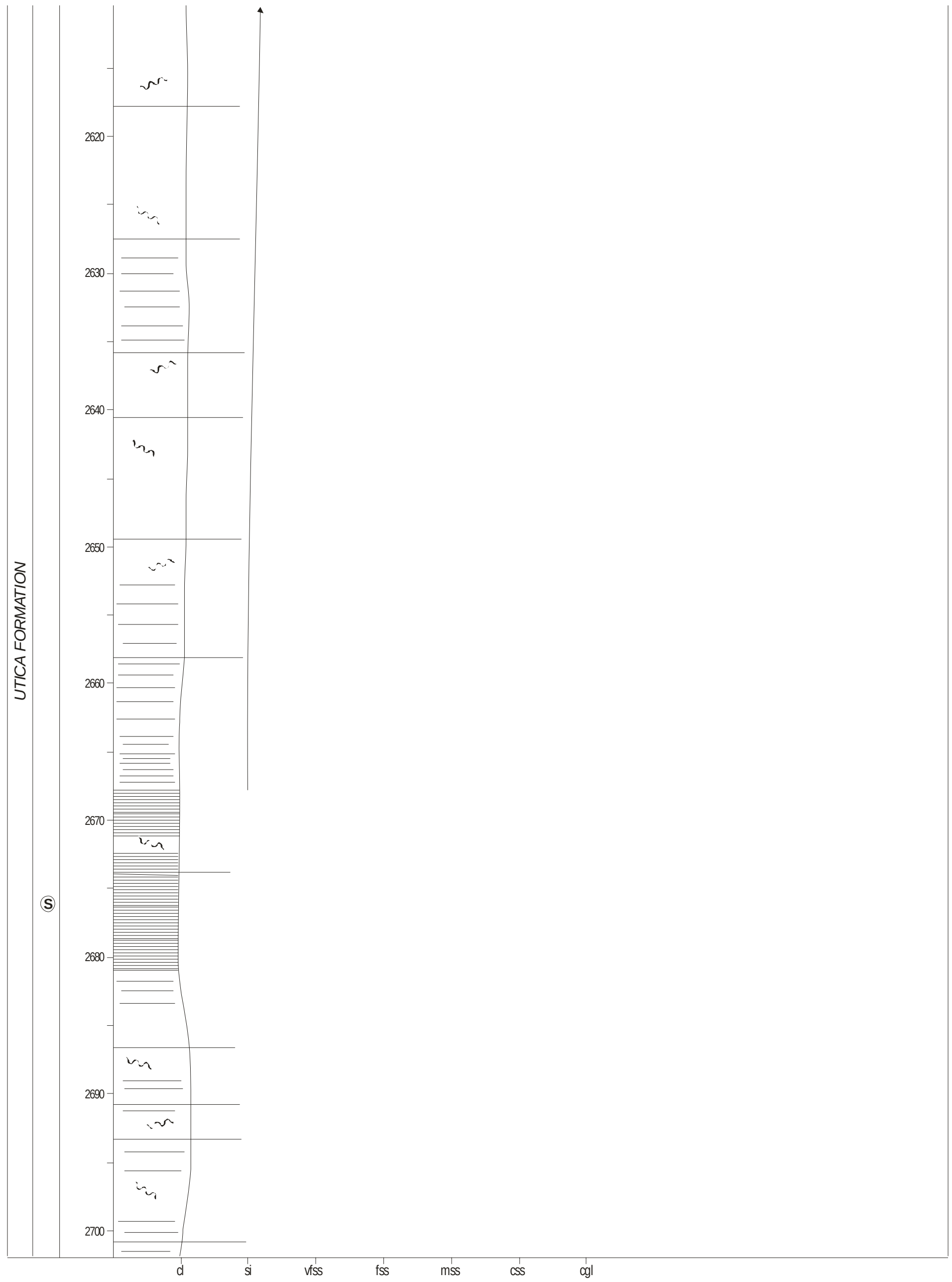
ANNEX 3 – 6 Pages

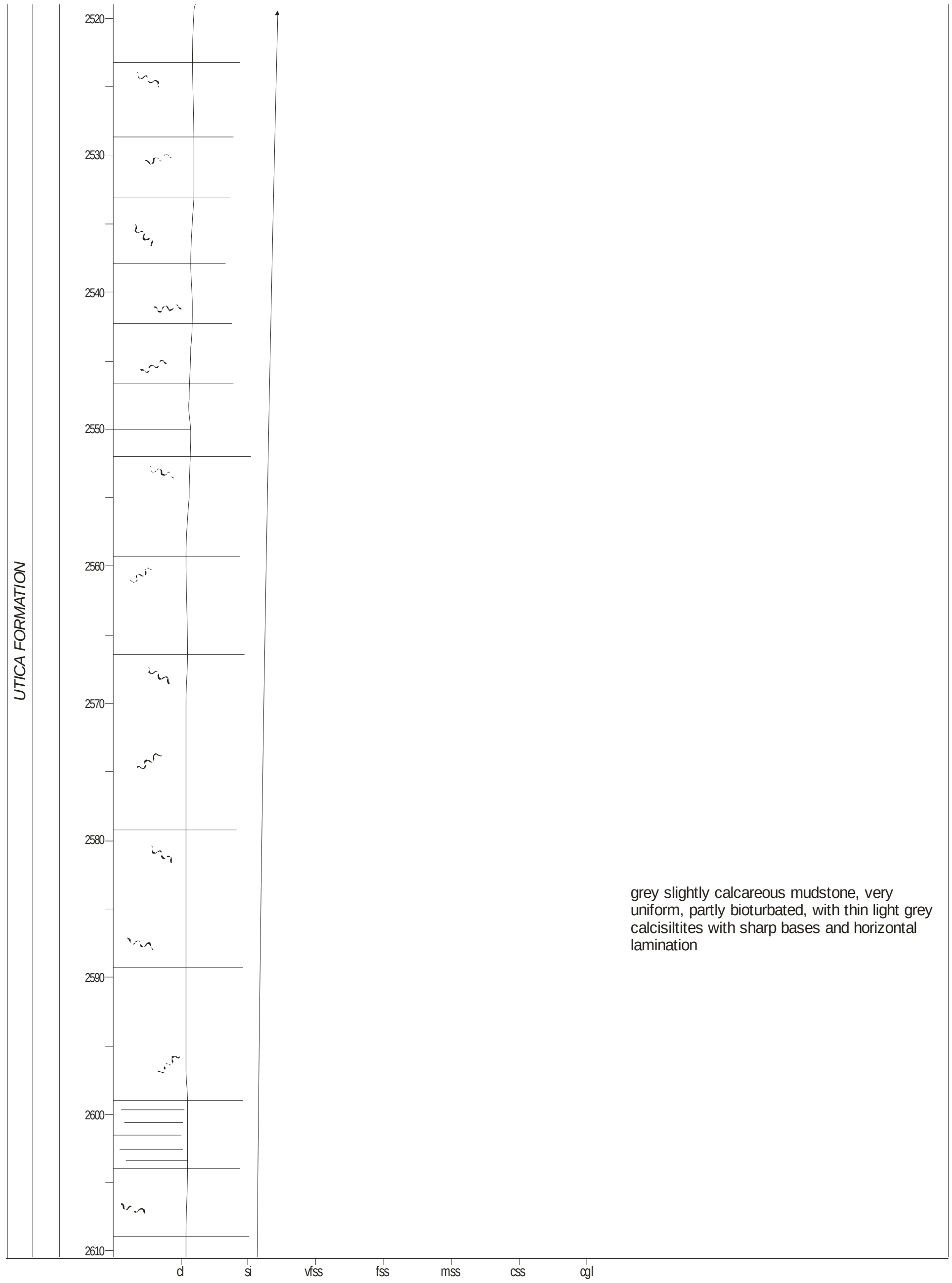
Nicolet #1
South shore of St. Lawrence River, southwest of Cap Santé
46.24°N, 72.55°W



Nicolet #1
South shore of St. Lawrence River, southwest of Cap Santé
46.24°N, 72.55°W


UTICA FORMATION
2710
2720
2730
2740
2750
2760
2770
2780
2790
cl
si
vfss
fss
mss
css
cgl
grey to dark grey laminated to silty mudstone, slightly calcareous, minor bioturbation, few scattered calcisiltite beds with sharp bases and horizontal lamination


UTICA FORMATION
S
2620
2630
2640
2650
2660
2670
2680
2690
2700
cl
si
vfss
fss
mss
css
cgl


UTICA FORMATION
2520
2530
2540
2550
2560
2570
2580
2590
2600
2610
cl
si
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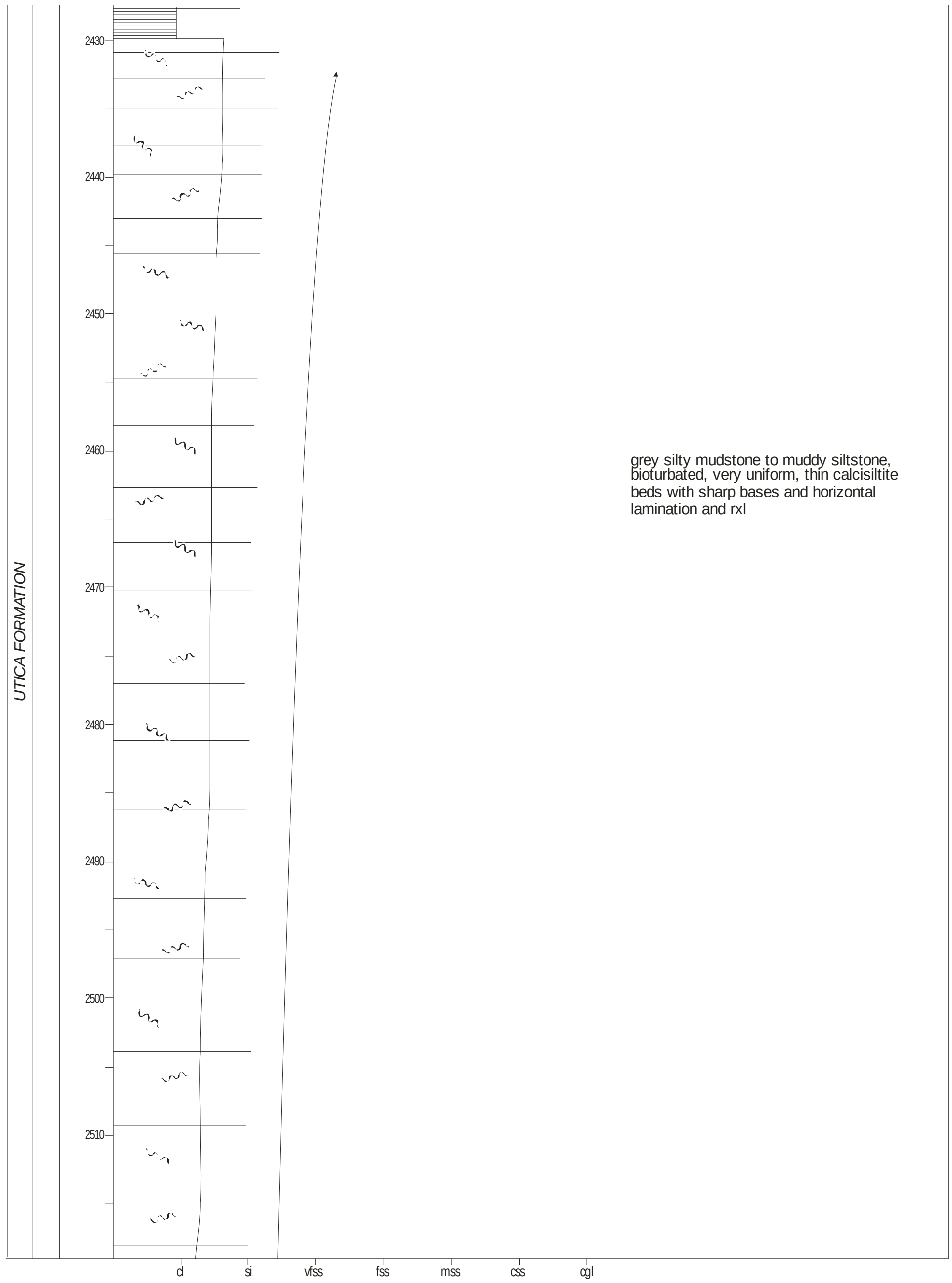
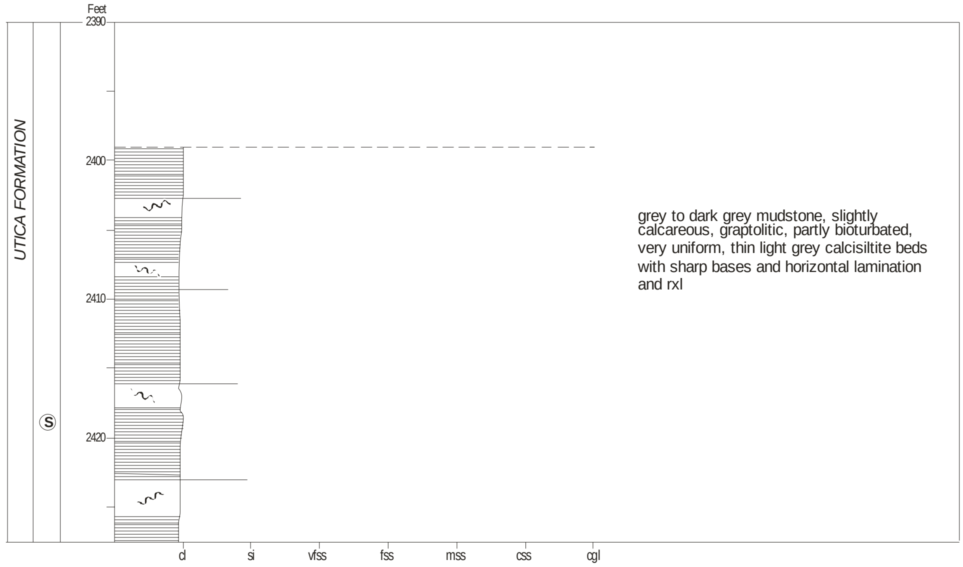
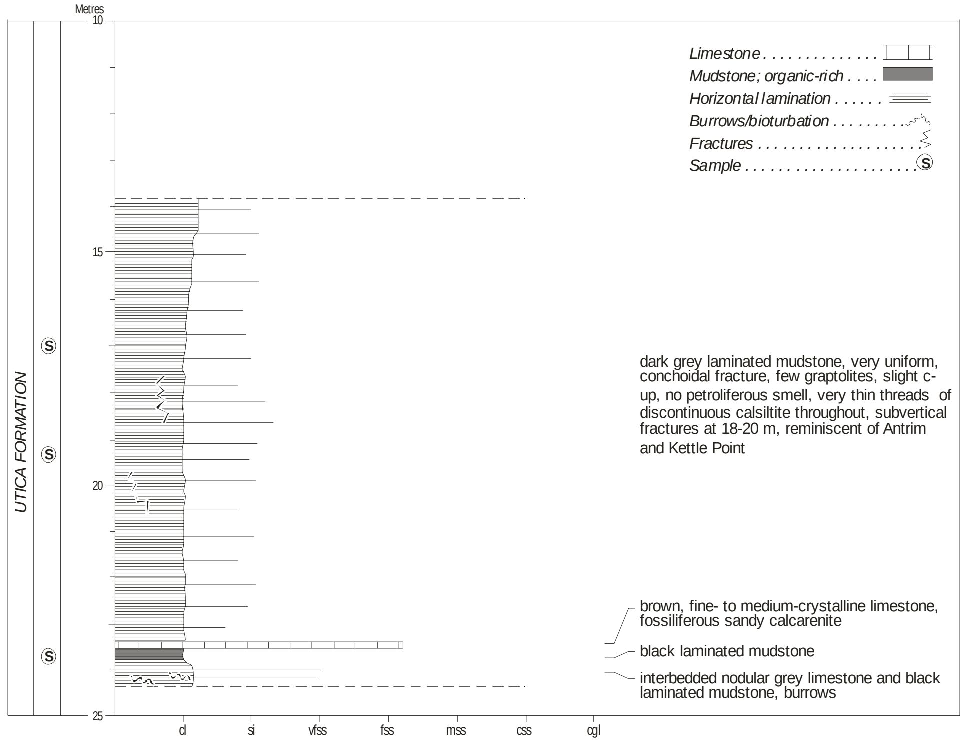
mss
css
cgl
grey slightly calcareous mudstone, very uniform, partly bioturbated, with thin light grey calcisiltites with sharp bases and horizontal lamination


UTICA FORMATION
2430
2440
2450
2460
2470
2480
2490
2500
2510
grey silty mudstone to muddy siltstone, bioturbated, very uniform, thin calcisiltite beds with sharp bases and horizontal lamination and rxl
cl
si
vfss
fss
mss
css
cgl


Feet
2390
2400
2410
2420
UTICA FORMATION
S
cl
si
vfss
fss
mss
css
cgl
grey to dark grey mudstone, slightly calcareous, graptolitic, partly bioturbated, very uniform, thin light grey calcisiltite beds with sharp bases and horizontal lamination and rxl

ANNEX 4 - 1 page

SNC Soligaz Montréal-Est #3
East of Montréal
45.62°N, 73.55°W



SNC Soligaz Montréal-Est #3
East of Montreal
45.62°N, 73.55°W