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Pre-Cairnside Formation carbonate-rich sandstone: evidence for a Cambrian carbonate platform in southwestern Quebec?[1]

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Abstract: Logging of cores drilled from the Unimin quarry, near St.-Canut, southwestern Quebec, revealed bioclastic, dolomitic sandstone lithofacies below the upper Cambrian Cairnside Formation, upper Potsdam Group. This lithofacies is distinctly different from any previously known lithology of the Covey Hill Formation (lower Potsdam Group). Preliminary local and regional lithostratigraphic correlations suggest that the pre-Cairnside Formation, mixed siliciclastic-carbonate unit extends eastward as far as the St. Croix village, about 50 km southeast of the Québec City. Based on these correlations, two scenarios explaining possible regional depositional episodes and associated depositional systems tracts are also discussed.

Résumé : La description des carottes de forage provenant de la carrière Unimin, près de Saint-Canut, dans le sud-ouest du Québec, a révélé la présence d'un lithofaciès de grès dolomitique à texture bioclastique sous la Formation de Cairnside (partie supérieure du Groupe de Potsdam) du Cambrien supérieur. Ce lithofaciès est totalement différent de toute autre lithologie de la Formation de Covey Hill (partie inférieure du Groupe de Potsdam) décrite jusqu'à ce jour. Des corrélations lithostratigraphiques préliminaires à l'échelle locale et à l'échelle régionale nous portent à croire que l'unité mixte silicoclastique-carbonatée qui est antérieure à la Formation de Cairnside s'étend aussi loin vers l'est qu'au village de Sainte-Croix, à environ 50 km au sud-est de la ville de Québec. Sur la base de ces corrélations, deux scénarios possibles d'évolution régionale des épisodes de sédimentation et des cortèges de faciès associés sont présentés.

[1] Contribution to the Appalachian Foreland and St. Lawrence Platform Architectures in Quebec, New Brunswick and Newfoundland NATMAP Project

INTRODUCTION

It is generally accepted that the (?)[Late Proterozoic]–Lower Paleozoic succession of the central St. Lawrence Platform (i.e. Ottawa Embayment and southwestern Quebec Basin, Fig. 1) begins with terrestrial 'redbeds' of the Covey Hill Formation, succeeded by a marine sequence represented by clean sandstone of the Cairnside (Nepean in eastern Ontario) Formation and carbonate-dominated succession of the Beekmantown Group (Wilson, 1946; Lewis, 1971; Hofmann, 1972; Williams and Wolf, 1982; Wolf and Dalrymple, 1984; Globensky, 1986, 1987; Sanford, 1993; Dix et al., 1997a, b). Clark (1966, 1972) postulated that the upper part of the Covey Hill Formation (Rivière Aux Outardes Member) in the type area accumulated under shallow-marine conditions based on inorganic sedimentary structures, but later work consistently supports a fluvial depositional environment for the formation in southwestern Quebec (Hofmann, 1972; Globensky, 1986, 1987).

This paper recognizes a carbonate-rich lithostratigraphic unit which separates the typical Cairnside Formation from the Covey Hill Formation in the region north of Montréal (St.-Canut, Quebec, Fig. 1). This unequivocally confirms the existence of pre-Cairnside Formation shallow-marine conditions in southwestern Quebec.

At this stage, we do not give the unit a formal name, but consider it as part of Clark's (1966) Rivière Aux Outardes Member. We informally subdivide Clark's (1966) Rivière Aux Outardes Member into two (?)laterally equivalent units, unit A is assigned to a carbonate-free unit in the type area of Covey Hill, south of Montréal (*see* Salad Hersi and Lavoie (2000) for further description of this unit) and unit B to the carbonate-rich part mentioned in this paper (Fig. 2). Recognition of unit B prompts us to lend a new look to the Lower Paleozoic stratigraphy and consideration of a possible Cambrian carbonate platform in southwestern Quebec. Cambrian carbonate platforms are well known in the neighboring regions of New York (Fisher, 1977) and western Newfoundland (James and Stevens, 1986)

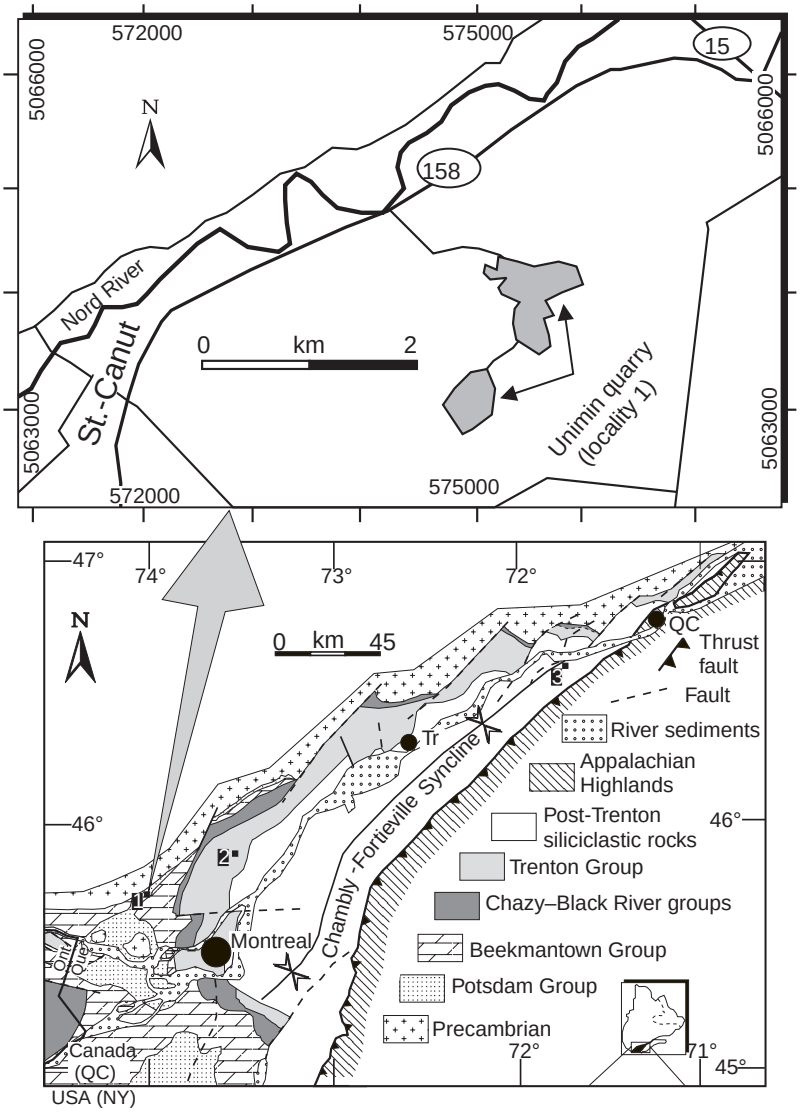

Figure 1.

Geological map of southwestern Quebec and locations mentioned in the text. Carbonate-rich sandstone samples collected from cores drilled within the premises of the Unimin quarry (locality 1, see *the expanded part of the map for detailed geographic location of the quarry) were petrographically studied and reported in the text.*

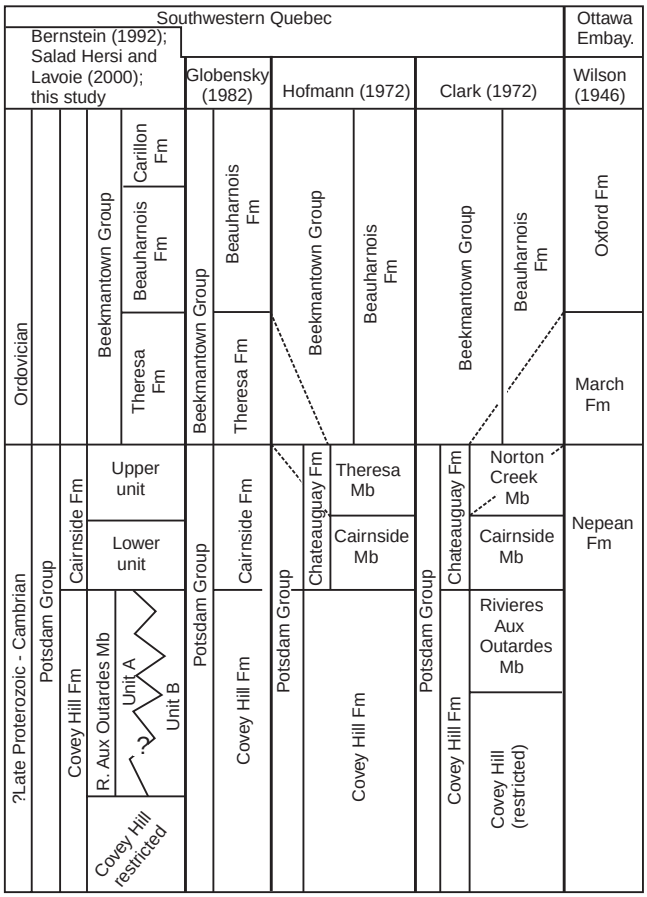

Figure 2. *Correlation chart showing stratigraphic terminologies applied to the lower Cambro-Ordovician strata in southwestern Quebec and the Ottawa Embayment. In the first column, subdivision of the Potsdam Group is from Salad Hersi and Lavoie (2000), as well as this paper, whereas division of the Beekmantown Group is from Bernstein (1992).*

REGIONAL GEOLOGICAL SETTING

The (?)[Late Proterozoic]–Lower Paleozoic sedimentary cover of the Central St. Lawrence Platform (southwestern Quebec and the Ottawa Embayment) is part of Sloss's (1963) Sauk and Tippecanoe tectonostratigraphic sequences. The succession accumulated during Late Proterozoic (Hadrynian), Cambrian and Ordovician systems under rift to passive continental margin basins (Sauk Sequence) and foreland basin (Tippecanoe Sequence) (Fisher, 1977; Doolan et. al., 1982; Sanford, 1993; Dix et al. 1997a) environments. The sedimentary strata preserved in the southwestern Quebec Basin (Montréal region) are more than 3000 m thick, and include seven groups of which the lower two (i.e. Potsdam and Beekmantown groups) belong to the late Proterozoic–Middle Ordovician Sauk Sequence, and the remaining five (Chazy, Black River, Trenton, Lorraine, and Queenston groups) include the Middle–Upper Ordovician Tippecanoe Sequence I (Bernstein, 1992; Sanford, 1993; Dix et al., 1997a). Rifted depressions in southwestern Quebec–eastern Ontario (in connection with the opening of the Iapetus Ocean, Doolan et. al., (1982)), followed by a well developed passive continental margin (Laurentian margin), became traps for siliciclastic debris eroded from the uplifted shoulders of the Grenvillian basement rocks. Alluvial fan and shallow-marine siliciclastic deposits (Potsdam Group) were predominant in these earliest stages ((?) Late Proterozoic to Cambrian) of the basin fill. In Early Ordovician time, carbonate sedimentation gained momentum gradually, and became dominant throughout the rest of the Sauk Sequence (Beekmantown Group, Bernstein, (1992)). By the end of the Beekmantown sedimentation, the Iapetus Ocean began to converge, and the Sauk–Tippecanoe unconformity developed after a peripheral bulge swept across the continental margin (Bernstein, 1992; Sanford, 1993; Lavoie, 1994; Dix et al., 1997a).

The Tippecanoe Sequence I, accumulated in a foreland basin setting, begins with basal siliciclastic-dominated succession (Ste-Thérèse Member of the Laval Formation in southwestern Quebec (Hofmann, 1963, 1972; Clark, 1972; Globensky, 1987) and the Rockcliffe Formation in the Ottawa Embayment, (Wilson, 1946; Dix et al., 1997a, b)). This is followed by upper Middle Ordovician to Trentonian, carbonate-dominated sedimentation with minor sandstone interbeds in the lower part (Clark, 1972; Globensky, 1987; Lavoie, 1992, 1993, 1994; Salad Hersi, 1997; Salad Hersi and Dix, 1997). During the late Late Ordovician, siliciclastic input from the eastern Appalachian front (Lorraine and Queenston groups in southwest Quebec and equivalent Billings, Carlsbad, and Queenston formations in the Ottawa Embayment) overstepped the carbonate platform and led to its final collapse (Sanford, 1993; Lavoie, 1994; Dix et al., 1997a, b).

UNIT B, RIVIÈRE AUX OUTARDES MEMBER, COVEY HILL FORMATION

Samples for petrographic studies were collected from drill cores at the Unimin quarry near the village of Saint-Canut, north of Montréal, Quebec (Fig. 1, locality 1). The company, Unimin, exploits the pure quartz arenite sandstone of the Cairnside Formation for silica production. About 10 m of clean sandstone are exploited in the quarry. Shallow wells drilled from the quarry show that below the typical, clean quartz arenite of the Cairnside Formation lies a medium brownish-gray rock which the quarry-men call "the maroon beds". This unit is a marker horizon which the company uses as a guide-limit of the exploitable strata. Globensky (1982) put the Covey Hill–Cairnside formation contact at the top of this maroon unit with no further description of this presumably upper Covey Hill strata. The company allowed us to log and sample their cores for detailed geological studies. The Covey Hill–Cairnside formation contact in the six logged cores is characterized by an erosional to sharp surface. One sample for conodont analysis was also collected, but it not yet processed. Core logs (Fig. 3) and petrographic descriptions of this 'maroon unit' are presented below.

Lithology

The strata lying beneath the typical Cairnside Formation beds at Unimin quarry (hereafter called unit B of the Rivière Aux Outardes Member) consist of two lithofacies. Lithofacies I consists of medium-gray (somewhat dark and brownish locally), medium- to coarse-grained, bioclastic, dolomitic sandstone with a fine-grained dolostone matrix. Rip-up dolomudstone fragments, as well as patches of dolomudstone which merge with the matrix, are common. Small white spots filled by calcite and/or dolomite (fenestral birdseye structures), scour surfaces, vertical to subhorizontal burrows, millimetre-scale shaly partings, and bands of microbial incrustation which bound the framework grains together are all present. The lithofacies is locally calcareous and appears to be due to relatively higher calcite cement. Framework grains of lithofacies I are dominated by quartz. The latter is fine to very coarse sand size, moderately sorted, and well to moderately rounded. Other important grains in this facies are bioclasts, and belong to three types, oncolites, mollusks (gastropods), and calcareous algae (Fig. 4A–C). These bioclasts range from coarse sand to pebble size, and are generally unbroken. The oncolites have well preserved internal semiconcentric laminae, and develop as single isolated grains

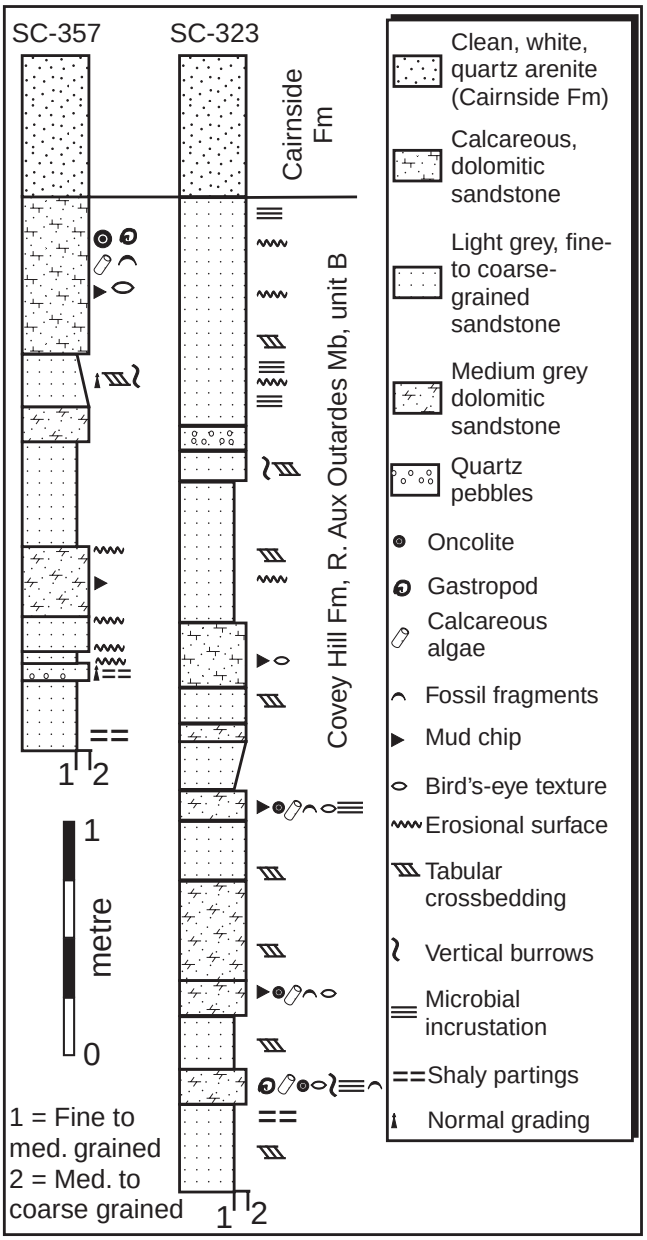

Figure 3. *Lithostratigraphic correlations of two cores logged from shallow wells drilled from the Unimin quarry. The wells were drilled within the premises of the quarry, but their specific locations were not disclosed to us. Despite the short distance (within a kilometre) between the two wells, no detailed lithological correlation can be satisfactorily carried out. This is probably due to erosion which is common at the top of pre-Cairnside Formation sandstone. Many cores show erosional surface at the unit B–Cairnside Formation contact.*

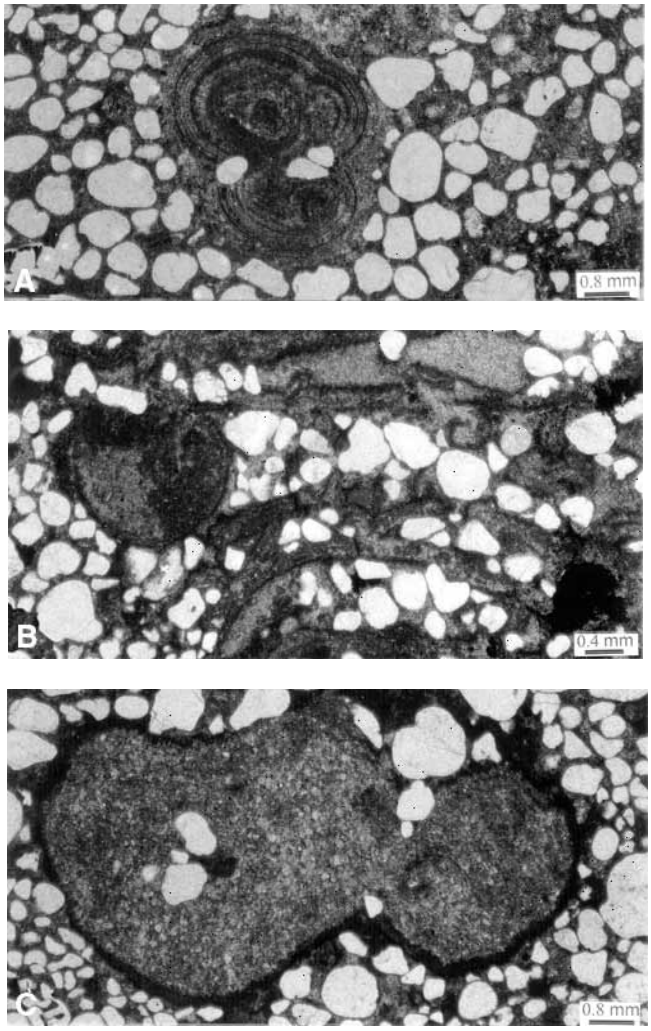

Figure 4. *Coarse-grained bioclasts in a medium- to coarse-grained sandstone of unit B. All photographs are from samples collected from the Unimin cores, locality 1. Fossils are intact and include **A)** oncolite, **B)** gastropod, and **C)** calcareous algae. Note also the micrite envelops the gastropod and the calcareous algae.*

or as composites of two to four coalescing grains (Fig. 4A). Grains of calcareous algae are recrystallized to a degree that any original internal texture is not recognizable. However, micrite envelopes retained well their external shapes (Fig. 4C).

Lithofacies II consists of a medium- to coarse-grained, light grey, nondolomitic to slightly dolomitic sandstone. It is usually crossbedded (tabular crossbedding), locally pebbly and vertically burrowed. Horizontal to irregular shaly partings (millimetre scale) which weather to rusty colour and local dolomudchips are present. Thin sections from this lithofacies are not currently available and no petrographic attributes can be documented at this time.

Depositional environment

The nature and relationship among the carbonate and siliciclastic components of unit B, Rivière Aux Outardes Member, suggest that the depositional setting was favorable for intermixing of the two facies. This mixing could have took place in one of two scenarios, 1) autochthonous generation of carbonate materials (bioclasts and mud) within a terrigenous-dominated shelf (in situ mixing model of Mount (1984)); or 2) interfacies mixing of which the unit represents the "tailoring" zone between two adjacent siliciclastic and carbonate facies (facies mixing model of Mount, 1984). Since a pre-Cairnside Formation, carbonate-dominated unit is not currently known in southwestern Quebec, the first scenario is now preferred. The general depositional setting was most likely subtidal to intertidal. This is suggested by the presence of the birdseye texture, intact bioclasts, dolomudstone matrix, microbial incrustations, mudchips, and horizontal and vertical burrows (King and Chafetz, 1983; Carozzi, 1989). The subtidal-intertidal environment was characterized by alternating levels of high-energy (deposition of the crossbedded sandstone) and low-energy (deposition of the carbonate-rich sandstone) conditions. In the latter case, microbial grain-binding and production of the skeletal material were possible.

DISCUSSION

Correlations

The Unimin cores that penetrate through the upper part of the Rivière Aux Outardes Member (i.e. unit B) are shallow, however, they stimulated a new re-evaluation of the stratigraphic sequence and consideration of a possible Cambrian carbonate platform in southwestern Quebec. As part of our effort to assess the Lower Paleozoic strata in the region, we logged one well drilled near Mascouche, Quebec (Quinto-International No. 1 Mascouche, Fig. 1, locality 2). In this well, beds that Clark (1972) considered to be Covey Hill Formation are

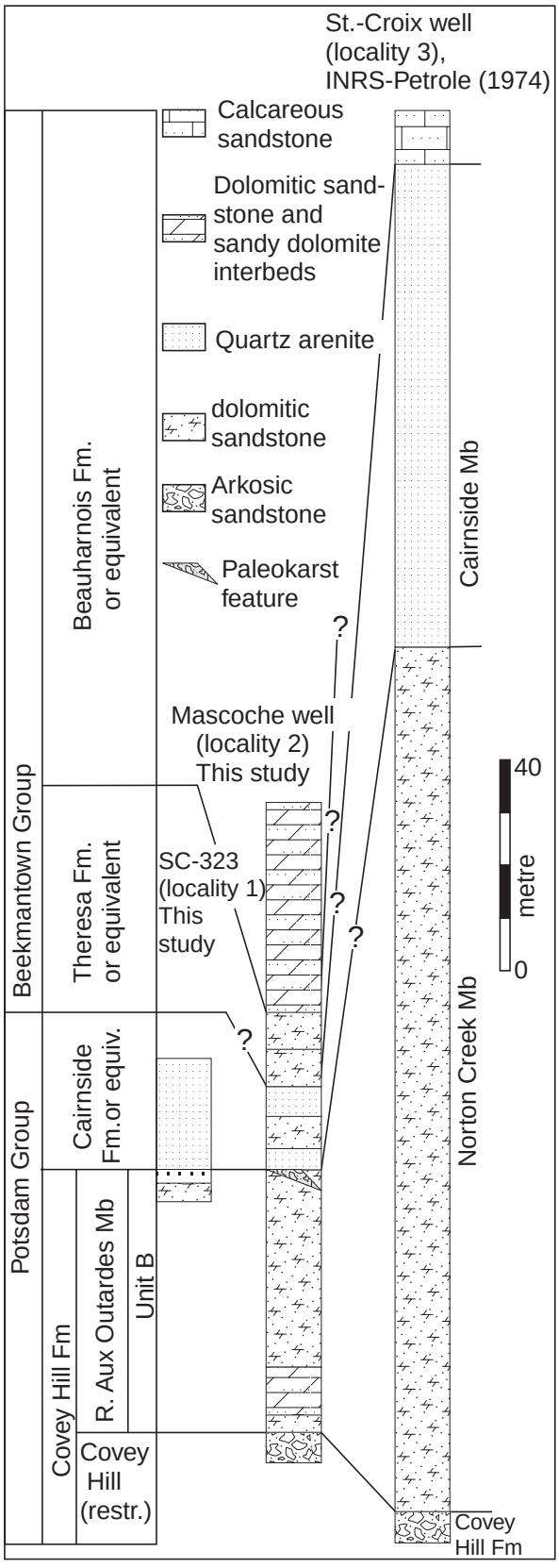

Figure 5. *Possible lithostratigraphic correlations between one of the Unimin cores and other two cores from localities 2 and 3. Section from locality 3 is redrawn from Institut National de la Recherche Scientifique-Pétrole (1974). The nomenclature shown on the right side of the St.-Croix well is the one proposed by Institut National de la Recherche Scientifique-Pétrole (1974).*

overlain by a 50 m thick section of medium-grey, well burrowed and nonburrowed, dolomitic sandstone and sandy dolostone. The upper contact of the unit is erosional, and a karstified zone with breccia occurs near the top. This unit is overlain by a 15 m thick unit of interbedded coarse-grained, "Cairnside-like" lithofacies and dolomitic sandstone lithofacies. This is in turn succeeded by sandy dolostone and dolomitic sandstone interbeds of the Theresa Formation (Fig. 5). It is our preliminary correlation that the pre-Cairnside Formation dolomitic sandstone of unit B in the cores of Unimin is correlative with the lower dolomitic sandstone unit overlying the Covey Hill Formation in the core of the Mascouche well. The Cairnside Formation probably subdivides laterally (eastward) into thinner units which interfinger with the relatively impure sandstone in the middle part of the Mascouche section (Fig. 5).

Another correlation also suggests that unit B of the Rivière Aux Outardes Member extends eastward as far as the Ste-Croix area, Quebec. Geological report of a core from a well drilled by SOQUIP (SOQUIP Shell Ste-Croix No. 1, about 10 km east of Ste-Croix, Fig. 1, locality 3) documents that a dolomitic sandstone unit intervenes between rocks of Covey Hill and Cairnside formation lithologies (Institut National de la Recherche Scientifique-Pétrole, 1974, Fig. 5). Despite the stratigraphic arrangement between the lower dolomitic sandstone and the overlying "Cairnside-type" facies in this well, Institut National de la Recherche Scientifique-Pétrole (1974) applied Norton Creek Member (equivalent to the Theresa Formation) to the lower dolomitic sandstone, and Cairnside Member to the overlying clean sandstone. At this stage, we envisage that there is no stratigraphic 'inversion'. The Cairnside Formation and the underlying dolomitic sandstone in the region north of Montréal (Unimin and Mascouche cores) are correlative with the Institut National de la Recherche Scientifique-Pétrole's (1974) Cairnside Member and underlying 'Norton Creek Member', respectively.

Regional depositional episodes

Based on the limited available information, and proposed correlations, two scenarios of possible regional depositional episodes are hypothesized. The first scenario considers two depositional episodes (Fig. 6A). Episode I — deposition of the subaerially accumulated, (?)Hadrynian to Cambrian lower Covey Hill Formation (rift-basin fill; lowstand systems tract) is truncated by an unconformity which marks the base

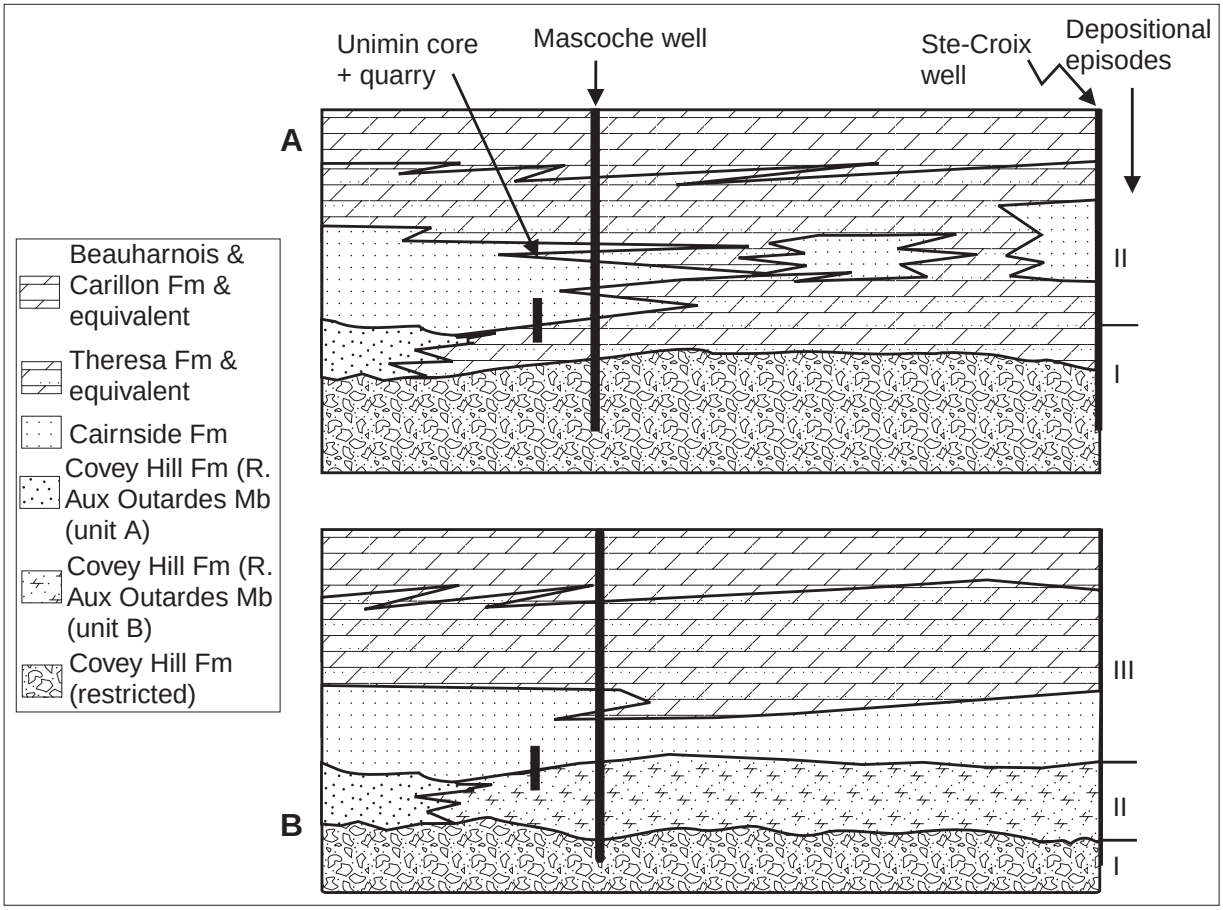

Figure 6. *Sketches showing two hypothetic scenarios to explain possible depositional episodes for the (?)Hadrynian–Cambrian–Lower Ordovician strata in southwestern Quebec (*see *text for further explanation). Not to scale.*

of the earliest transgressive, shallow-marine succession. Episode II — shallow-marine strata (Cambrian to Ordovician) includes all siliciclatic and carbonate strata from the top of the sediments of episode I to the top of the Beekmantown Group (transgressive systems tracts and highstand systems tracts, respectively).

The other scenario hypothesizes three depositional episodes (Fig. 6B). Episode I is similar to that of the first scenario (lowstand systems tract). Episode II comprises shallow-marine strata (Cambrian) of all or part of the Rivière Aux Outardes Member (units A and B, transgressive systems tracts and highstand systems tracts). After deposition episode II, regression took place, and an unconformity developed on the top of the sediments of episode II. The erosional and karstic features at the top of unit B in the Unimin and Mascouche cores are related to this unconformity. Episode III includes strata from the Cairnside Formation to the top of the Beekmantown Group. The Cairnside Formation is shallow marine in southwestern Quebec but its equivalent in the Ottawa Embayment, the Nepean Formation, includes basal fluvial sandstone units overlain by shallow-marine facies (Wolf and Dalrymple, 1984). Thus, the Cairnside–Nepean formations may partially represent a lowstand systems tract, whereas the overlying Beekmantown Group corresponds to transgressive and highstand systems tracts.

CONCLUSIONS

Cores drilled from the Unimin quarry, near St.-Canut north of Montréal, show a distinct lithostratigraphic unit occurring below quartz arenite lithofacies of the Cairnside Formation. Although previous work considered this pre-Cairnside Formation unit as Covey Hill Formation, our work shows that it is different from any previously known lithofacies of the Covey Hill Formation. However, at this stage, we apply an informal term (unit B) for this unit and consider as part of the Rivière Aux Outardes Member of the Covey Hill Formation. Unit B consists of interbedded crossbedded, medium- to coarse-grained, nondolomitic to slightly dolomitic sandstone and burrowed, bioclastic, dolomitic sandstone. Sedimentary structures preserved in the unit, and the nature and relationships among its framework grains led us to infer a subtidal to intertidal depositional setting. In situ carbonate production within a terrigenous-dominated shelf caused mixing of the siliciclastic and carbonate grains.

Preliminary local and regional correlations suggest that unit B extends eastward as far as St. Croix village, Quebec. Based on these correlations, two scenarios of depositional episodes were hypothesized. The first one envisages one depositional sequence in which the subaerially deposited lower Covey Hill Formation represents a lowstand systems tract, and the overlying marine succession (Rivière Aux Outardes Member, Cairnside Formation, and the Beekmantown Group) as transgressive and highstand systems tracts. The other alternative scenario considers two sequences separated by the possibly unconformable surface below the Cairnside Formation. In this case, the lower depositional sequence includes the subarially accumulated part of the Covey Hill Formation (lowstand systems tract) and the Rivière Aux Outardes Member (units A+B, transgressive systems tract, and highstand systems tract). The upper depositional sequence is represented by the Cairnside–Nepean (partially subaerial in the Ottawa Embayment) formations (lowstand systems tract) and the overlying Beekmantown Group (transgressive systems tract and highstand systems tract).

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