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Contributions to the sedimentology of the Strites Pond Formation, Cambro-Ordovician Philipsburg Group, southwestern Quebec[1]

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[1] Contribution to the Appalachian Foreland and St. Lawrence Platform NATMAP Project

Abstract

The Cambro-Ordovician Strites Pond Formation of the Philipsburg Goup overlies the Rock River Formation with an apparent tectonic contact and is disconformably overlain by the Wallace Creek Formation. The Strites Pond Formation consists of a lower dolostone member characterized by bioclastic, oolitic dolopackstone to grainstone and pervasively coarse-crystalline dolostone, and an upper limestone member of thickly bedded mudstone and thrombolitic bioherm interbeds. Subordinate carbonate-rich sandstone and shale layers occur in both members. Microbially laminated dolostone also occurs within the uppermost part of the formation. Sedimentological attributes of the Strites Pond Formation suggest a subtidal to intertidal ooid and bioclast shoals to a subtidal environment dominated by mound-building microbial organisms. High-order sea-level fluctuations and vicinity of terrestrial siliciclastic supply area are manifested by numerous coarse-grained sandstone interbeds throughout the formation. The overlying Wallace Creek Formation accumulated in a deeper marine setting suggesting a sea-level rise after deposition of the Strites Pond Formation.

Résumé

La formation cambro-ordovicienne de Strites Pond du Groupe de Philipsburg est séparée de la formation sous-jacente de Rock River par un contact tectonique apparent et est recouverte en discordance par la Formation de Wallace Creek. La Formation de Strites Pond comporte un membre inférieur de dolomie caractérisé par la présence de packstone dolomitique et de grainstone oolithiques et bioclastiques et de dolomie à grains grossiers omniprésents, et un membre supérieur de calcaire composé d'interstrates de mudstone épais et de bioherme à calcaire grumeleux. Des couches moins importantes de grès carbonaté et de shale se rencontrent dans les deux membres. De la dolomie à laminations microbiennes se rencontre également dans la partie sommitale de la formation. D'après ses caractéristiques sédimentologiques, la Formation de Strites Pond se serait accumulée dans un milieu allant d'un haut-fond intertidal à subtidal à ooïdes et à bioclastes à un milieu subtidal dominé par des organismes microbiens constructeurs de monticules. Les nombreuses interstrates de grès à grain grossier dans la formation témoignent de fluctuations importantes du niveau de la mer et de la proximité d'une source terrestre de matériau silicoclastique. La formation sus-jacente de Wallace Creek s'est accumulée dans un milieu marin plus profond, indiquant qu'une phase de montée du niveau de la mer a suivi l'accumulation de la Formation de Strites Pond.

INTRODUCTION

The Philipsburg Group is a tectonically transported succession of sedimentary rocks that outcrops as a northeast-trending tectonic slice (Philipsburg slice, Clark (1934, 1936)) of the Appalachian Province. The slice straddles the Quebec–Vermont border, east of the Missisquoi Bay of the Lake Champlain (**Fig. 1**). The Philipsburg Group consists of 10 formations ranging from (?)Middle Cambrian to Lower Ordovician (**Fig. 2**). Stratigraphic and sedimentological knowledge of this group is very scant due to poor and tectonized outcrops and lack of detailed study of what is exposed as natural outcrops and quarries.

A NATMAP project launched by the Québec Geoscience Centre, Québec, reassesses the stratigraphic, sedimentological, and structural evolution of the Laurentian margin along specific transects. Our study is focused on a northwest-southeast oriented Montréal–Mégantic transect of southwestern Quebec. Sedimentary strata underlying this region includes the Cambro-Ordovician succession of the St. Lawrence platform and few allochthonous slices (e.g. Philipsburg and Stanbridge slices). Our initial mapping of the allochthonous units targeted the (?)Cambro-Ordovician Strites Pond Formation of the Philipsburg Group which is well exposed in several quarries and natural outcrops. We present here a preliminary report on the stratigraphic and sedimentological attributes of the Strites Pond Formation obtained from four sections in the studied region (localities 1–4, **Fig. 1**).

GEOLOGICAL SETTING

The Philipsburg slice is a tectonic unit bounded to the west by the Appalachian frontal thrust known as 'Logan's Line' overlying the much younger Late Ordovician Sainte-Sabine Formation (Fig. 1). To the east, the Philipsburg slice is overthrusted by the Stanbridge slice (Fig. 1). The Philipsburg Group is the stratigraphic unit preserved in the Philipsburg tectonic slice. The group consists of a (?)Middle Cambrian to Middle Ordovician sequence of limestone and dolostone units with subordinate sandstone lithofacies, and comprises 10 formations (**Fig. 2**; Globensky, 1981). The stratigraphic continuity of these rocks are not well documented, and it appears that a tectonic contact occurs between the Milton and Rock River formations (*see* Fig. 1), as well as between the latter and the Strites Pond Formation (*see* below). The Milton and Rock River formations consist of a shallow marine, locally brecciated sandstone, sandy dolostone, and dolostone lithofacies (Globensky, 1981). The overlying Strites Pond Formation consists of shallow-marine dolostone and limestone lithofacies with subordinate sandstone intercalations. The Wallace Creek Formation consists of thinly bedded to laminated shale and limestone deposited in an upward-deepening marine setting.

Deposition of the Wallace Creek Formation was followed by a gradual sea-level fall and establishment of a shallow-marine carbonate platform. Preservation of this platform is recorded in the strata of Morgan Corners to Naylor Ledge formations (Fig. 2). The Morgan Corners Formation is exclusively made up of dolostone of supratidal to intertidal environment (Globensky, 1981). Lithology of the overlying Hastings Creek and Naylor Ledge formations consist of massive to microbially laminated limestone punctuated by dolostone beds with subordinate shale and sandy limestone, and fine crystalline, massive limestone, respectively (Globensky, 1981). Both formations were deposited in a supratidal to subtidal environment (Gilmore, 1971; Globensky, 1981). The top of the Naylor Ledge Formation is marked by the Sauk–Tippecanoe regional unconformity (Knight et al., 1991) produced by the westward sweeping peripheral bulge of the Taconian Orogeny. The Luke Hill, Solomons Creek, and Corey formations are thus the earliest accumulations of a foreland basin setting. The Luke Hill Formation consists of bioclastic, fine crystalline limestone, siltstone, sandy limestone, and sandstone in its lower part and nodular, fine crystalline limestone with thin shale and dolostone interbeds in its upper part (Globensky, 1981). The Solomons Creek Formation consists of a lower part dominated by fine crystalline, nodular limestone and an upper part of interbedded nodular and thickly bedded, fine crystalline limestone (Globensky, 1981). The highest Corey Formation consists of dense, fine crystalline, pure limestone with rare calcirudite limestone, and is locally sandy and/or dolomitic. The Luke Hill, Solomons Creek, and Corey formations were deposited in an intertidal to subtidal environment (Gilmore, 1971; Globensky, 1981).

STRITES POND FORMATION

The Strites Pond Formation overlies the Rock River Formation and is overlain by the Wallace Creek Formation. Nowhere is the lower contact of the Strites Pond Formation exposed, however, at locality 3 (Fig. 1), a covered, flat distance of about 80 m separates a small hill of brecciated, somewhat massive

Rock River Formation from a small quarry of bedded, bioclastic, oolitic dolostone unit of the Strites Pond Formation. We hypothesize that the two formations are either separated by a fault contact within this 80 m covered interval or the contact is an unconformable one with the Strites Pond beds leaning against the Rock River strata beneath this covered interval. The upper contact of the Strites Pond Formation is disconformable with the overlying Wallace Creek Formation. The contact is exposed at localities 3 and 4 (**Fig. 1**) and is characterized by an erosional surface separating lower, thickly bedded, light to medium grey, lime mudstone of the Strites Pond Formation from medium to thin interbeds of bioclastic lime packstone and shale of the Wallace Creek Formation (**Fig. 3**, **4**).

Total thickness of the Strites Pond Formation is not known as no complete section is available. Gilmore (1971) measured several incomplete sections leading to a maximum thickness of about 72 m, whereas Globensky (1981) gave an estimated thickness of 128 m for the formation. During our mapping of the formation we have measured a 233 m thick section of the Strites Pond Formation exposed along a composite section of recently cleared surface, natural outcrops, and quarries (locality 3, Fig. 1). At this preliminary stage of our research, we informally subdivide the formation into two members, a lower member of predominantly dolostone strata of various lithofacies and subordinate sandstone and limestone, and an upper member formed by limestone and minor sandstone and dolostone (Fig. 4). Limestone interbeds within the upper part of the lower dolostone member indicate a transitional nature between the two members. Lithofacies within each member are described here below.

Lower dolomite member

This member is exposed at locality 3 only (Fig. 4, **5**), and consists of two dolostone lithofacies (lithofacies 1 and 2), dolomitic sandstone to sandy dolostone (lithofacies 3), nodular limestone (lithofacies 4), and shale (lithofacies 5).

Lithofacies 1: bioclastic, oolitic dolopackstone and grainstone

This lithofacies consists of medium to thickly bedded, medium grey, coarsely crystalline intraclastic, peloidal, bioclastic, oolitic packstone to grainstone. Crosslaminations and planar laminations are present but poorly preserved. The lithofacies is intensely dolomitized and original grains are barely visible under normal petrographic microscope; however, using a simple technique of placing a white sheet of paper under the thin sections, outlines of original framework grains are better observed. This lithofacies is present in the lower part of the member (**Fig. 5)**.

Lithofacies 2: coarse crystalline dolostone

Lithofacies 2 consists of thickly bedded, medium to light grey, coarse- to very coarse-grained crystalline dolostone. Dolomite replacement is pervasive, and no pre-existing textures are preserved. Dolomite rhombs are generally equigranular, subhedral to euhedral crystals and form a mosaic of idiotopic to hypidiotopic fabric. Stylolites and rare burrows are locally present. Fractures are common in this lithofacies and are mostly filled by chert, quartz, and dolomite cements. This lithofacies is dominant in the upper part of the lower member (Fig. 5).

Lithofacies 3: dolomitic sandstone to sandy dolostone

This lithofacies is volumetrically very subordinate and consists of isolated medium beds of medium- to coarse-grained dolomitic sandstone and sandy dolostone. Colour is generally light grey on both fresh and weathered surfaces. Framework grains are exclusively quartz; they are well rounded to subrounded and well sorted. Stylolites and fractures are present. This lithofacies is interbedded with lithofacies 1 in the lower part of the member (Fig. 5).

Lithofacies 4: nodular, dolomitic limestone

This lithofacies consists of light to medium grey, thickly bedded, somewhat nodular, peloidal, dolomitic lime mudstone to packstone. Dolomitization occurred along irregular streaks and patches, and gives the rock a mottled appearance. Dolomite crystals are similar to those of lithofacies 2. This lithofacies is volumetrically subordinate, associates with lithofacies 2, and occurs within the upper part of the lower dolostone member of the formation (Fig. 5).

Lithofacies 5: shale

This lithofacies is volumetrically less important than lithofacies 3 and 4. It consists of green to greenish-grey shale. It is represented by a single 15 cm thick bed in the lower dolostone member of the formation, and separates two beds of lithofacies 2 in the upper part of the member. Lithofacies 5 is better developed in the upper limestone member and is manifested as thin shaly partings or as thin laminae or punch of laminae punctuating the other lithofacies (*see* Fig. 5, 6). It is locally sandy and associated with the calcareous sandstone to sandy limestone lithofacies (lithofacies 9, *see* below) of the upper member.

Upper limestone member

The upper limestone member consists of two limestone lithofacies (lithofacies 6 and 7), microbially laminated, dolostone lithofacies (lithofacies 8), a calcareous sandstone to sandy limestone lithofacies (lithofacies 9), and shale lithofacies (lithofacies 5, *see* above for the description of this lithofacies).

Lithofacies 6: microbially laminated lime mudstone

This lithofacies forms thin to thick ledges of very light grey to white, internally laminated lime mudstone. Fenestral (birdseye) fabric, burrows, stylolites, calcite nodules, and shaly partings are present. Coarse quartz grains are locally disseminated. This lithofacies occurs in the middle part of the member ('middle white unit' of **Fig. 5**, **6**).

Lithofacies 7: thrombolite bioherms

This lithofacies consists of medium to very thick beds of light to medium grey, fine crystalline limestone. This lithofacies is characterized by small, irregularly interwoven, light grey and medium grey patches of dense micrite which gives a mottled appearance and clotted bioherms. Looking from the bedding surface, these bioherms form rounded, ellipsoidal, and irregular mounds with stylolitic boundaries (**Fig. 7A**). In a vertical cross-section, the mounds are locally well visible at the upper termination of the thrombolitic unit where sandstone and mudstone layers fill the intermound spaces (**Fig. 7B**, **C**). Horizontally well burrowed, stylolitic mudstone is the common intermound fill (Fig. 7A). Thus, where the mound morphology is less evident in a vertical cross-section, the rock appears as discrete zones (50 cm to >100 cm wide, height varies with bed thicknesses) of burrowed and stylolitized mudstone and less burrowed, thrombolitic mudstone mostly defined by stylolitic boundaries. The burrows seldom pierce through the thrombolitic bioherm bodies. Other sedimentary structures in this lithofacies inlude stromatactoids (centimetre-sized, flat to irregular sparry calcite crusts, “sheet crack” of some workers (e.g. Bourque and Boulvain, 1993), **Fig. 7D**), calcite nodules, shaly partings, fenestral (birdseye) fabric, and poorly developed wave (with possibly unidirectional component) ripple marks (**Fig. 7A**). This lithofacies is common throughout the upper limestone member. Beds with stromatactoid structure are confined within the ‘middle white unit’ (**Fig. 5**, **6**).

Lithofacies 8: microbially laminated dolostone

This lithofacies consists of medium to thick, isolated beds of coarse- to fine-crystalline, microbially laminated, light to medium greenish-grey dolostone. It weathers orange-grey to greenish grey. The lithofacies is volumetrically subordinate and is represented by three separate beds in the upper part of the member (Fig. 5, 6); however, these beds are good marker beds for correlating the mapped sections (**Fig. 4**).

Lithofacies 9: calcareous sandstone to sandy limestone

This lithofacies consists of thin to medium beds of coarse-grained, medium to light greenish-grey calcareous sandstone to sandy limestone. Framework grains are exclusively well rounded to subrounded, well sorted quartz. The matrix is lime micrite. Sedimentrary structures include tabular crosslaminations, normal grading from calcareous sandstone to sandy limestone, inverse grading from sandy limestone to calcareous sandstone, shaly partings, stylolites, erosional lower contacts, and sharp upper boundaries. Besides individual beds, this lithofacies is also expressed as irregular sandstone bodies filling in karstic features, lenses, and subhorizontal to irregular laminae (**Fig. 7B**, **C**). The karst-filling sandstone bodies show thin laminations draping the underlying erosional surfaces. Sand- to cobble-size limestone breccia of possibly collapse origin are associated with the karst-filling sandstone. Although volumetrically subordinate, this lithofacies occurs in many levels of the upper limestone member (**Fig. 4**, **5**, **6**).

Depositional evironment of the Strites Pond Formation

Sedimentological attributes of the Strites Pond Formation suggest that the formation accumulated in a shallow-marine carbonate platform. The lower oolitic and bioclastic dolopackstone to grainstone lithofacies (lithofacies 1) represents subtidal to possibly intertidal oolitic and bioclastic shoals with an intermittent siliciclastic flux extending on these shoals during relative sea-level fall. Depositional environment of the coarse-crystalline dolostone is not clear but the minor interbeds of the nodular, peloidal mudstone to packstone lithofacies (lithofacies 4) may suggest a subtidal setting. An agitated shallow subtidal environment is envisaged for the thrombolite-dominated upper limestone member of the Strites Pond Formation. Lower Paleozoic thrombolite reefs are commonly interpreted as shallow subtidal build-ups (Pratt, 1982; Glumac and Walker, 2000). The Strites Pond Formation appears to be similar to the “shelf cycles” of the Upper Cambrian of western Newfoundland (Cowan and James, 1993) and could be equivalent to “Grand Cycle C” of Chow and James (1987).

The many coarse-grained sandstone interbeds suggest vicinity of a siliciclastic source and high sea-level fluctuations. Karstic features and associated sandstone fills at the tops of the thrombolitic limestone indicates shallowing upward and exposure of these bioherms. The mineralogical and textural maturity of the sandstone lithofacies may suggest recycling of a nearby sand-sandstone body. This siliciclastic body could be the Cairnside Formation which appears to be chronostratigraphically equivalent with the Strites Pond Formation (**Fig. 2**). If this interpretation is correct, the westward tectonic displacement of the Philipsburg slice may therefore be minimum.

The Wallace Creek Formation documents a much deeper marine setting than that of the Strites Pond Formation. This suggests a significant sea-level rise following a sea-level fall which caused termination of the Strites Pond deposition and development of its upper unconformable contact. The Strites Pond–Wallace Creek sequence and its depositional array could be a southwestward continuation, but slightly younger, of the Corner-of-the Beach carbonate platform and the overlying deep marine deposits of the Murphy Creek Formation in the Percé area, Gaspésie, Quebec (Lavoie 2001).

CONCLUSIONS

The Strites Pond Formation overlies the Rock River Formation with apparent tectonic contact, and is overlain by the Wallace Creek Formation with a well developed erosional disconformable contact. An incomplete composite section of the formation exposed along a recently cleared surface, natural outcrops, and quarries allowed us to measure 223 m of strata for the formation — a maximum thickness so far reported for the formation.

We informally divide the formation into two members, a lower dolostone member and an upper limestone member. The lower dolostone member consists of a lower unit dominated by bioclastic and oolitic dolopackstone and grainstone lithofacies with subordinate dolomitic sandstone and sandy dolostone interbeds, and an upper unit of pervasively coarse-crystalline dolostone lithofacies with subordinate peloidal dolomitic lime mudstone to packstone interbeds in its upper part. The upper limestone member is characterized by thickly bedded, thrombolitic bioherms, microbially laminated mudstone, thin- to medium-bedded, coarse-grained calcareous sandstone to sandy limestone, shale, and subordinate microbially laminated dolostone.

Sedimentological attributes of the various lithofacies and their vertical arrangements suggest sedimentation of the Strites Pond Formation changed from subtidal and/or intertidal shoals in its lower part to subtidal to supratidal setting in its upper part. High-frequency sea-level fluctuations are manifested by the siliciclastic influx into the depositional site. The lower dolostone member of the formation accumulated as subtidal to possibly intertidal ooid and bioclast shoals, whereas the upper limestone member was deposited in a calm to moderately agitated intertidal to subtidal setting dominated by flourishing microbial bioherms and lime mudstone accumulation. Microbially laminated dolostone as well as sandstone lithofacies-filling karstic features in the upper part of the formation suggest intermittent subaerial episodes.

The textural and mineralogical maturity of the sandstone interbeds suggest recycling of a nearby sand or sandstone body. The latter could be the Cairnside Formation which we envisage to be chronostratigraphically equivalent with the Strites Pond Formation. This may suggest a minimal westward tectonic displacement for the Philipsburg slice.

The overlying Wallace Creek Formation documents a significant environmental change from shallow-marine carbonate platform to a calm, deeper marine depositional setting dominated by accumulations of fine siliciclastic and carbonate material.

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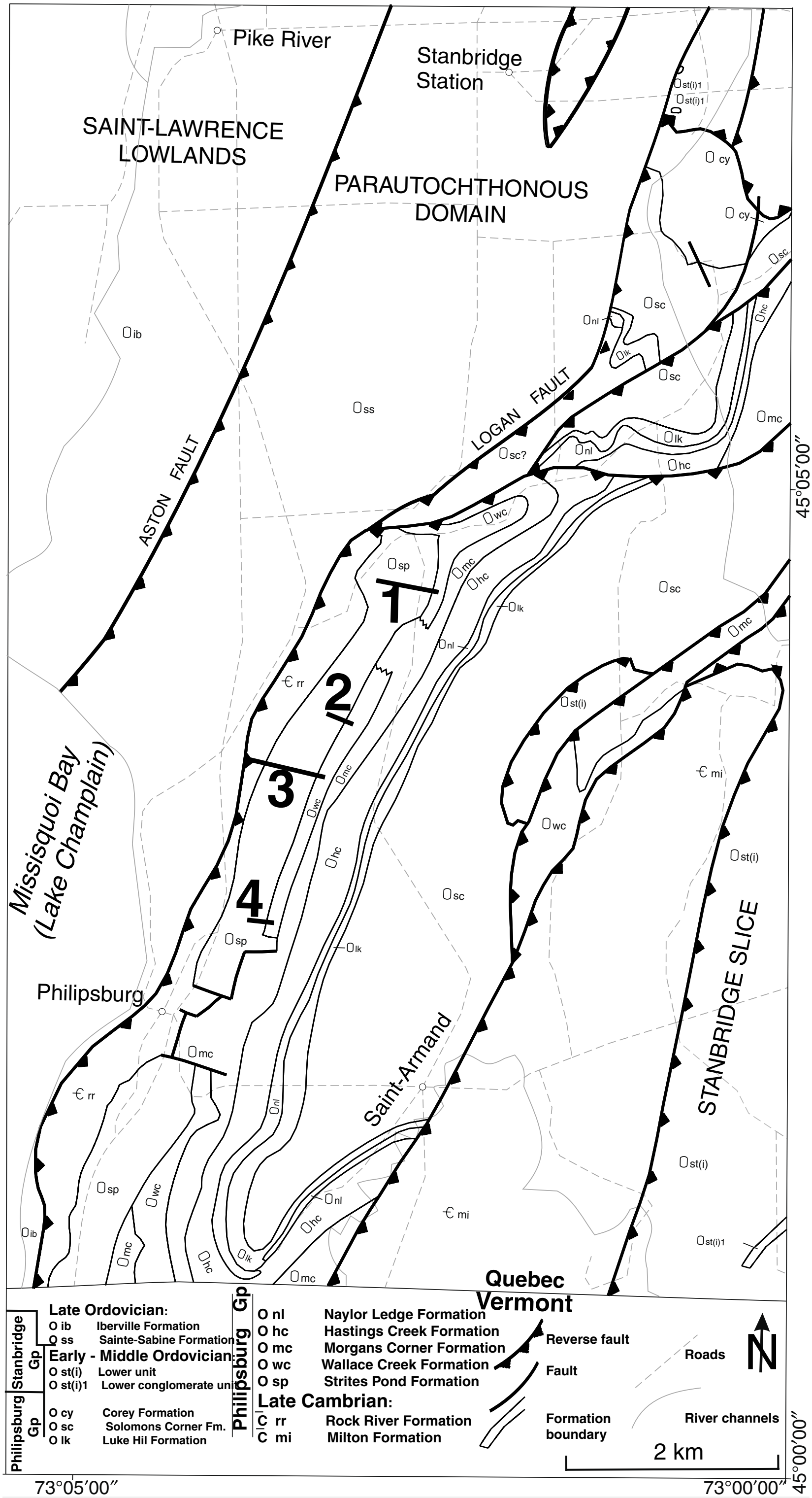

Figure 1. Geological map of the Philipsburg Slice, southern Quebec. Locations of stratigraphic sections metioned in the text are shown. *Modified from* Séjourné and Melo (2001) and Globensky (1981).

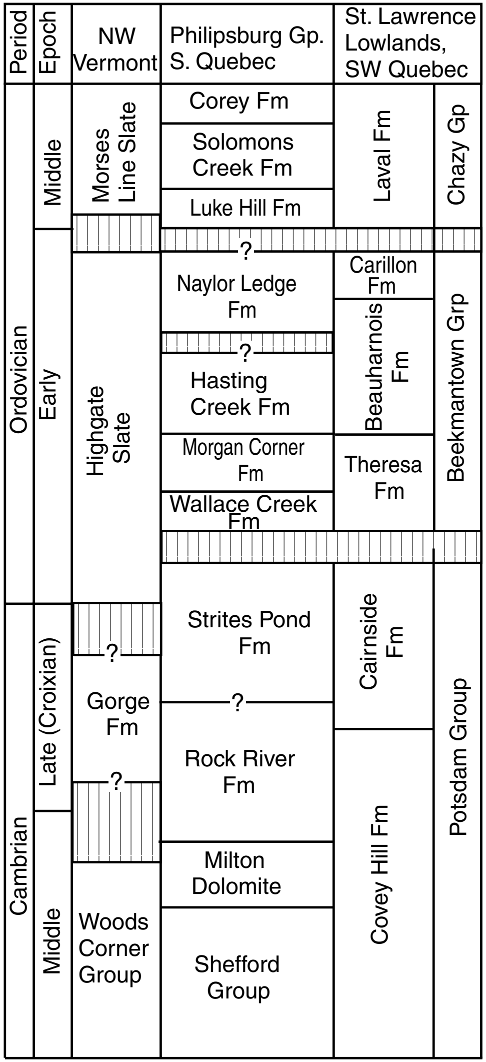

Figure 2. Chart showing the stratigraphic nomenclature of the formations within the Philipsburg Group of southern Quebec. Correlative strata in the adjacent regions of northwestern Vermont (U.S.A.) and the St. Lawrence platform of southwestern Quebec are also shown. *Modified from* Globensky (1981). Nomenclature from northwestern Vermont is adopted from Shaw (1958).

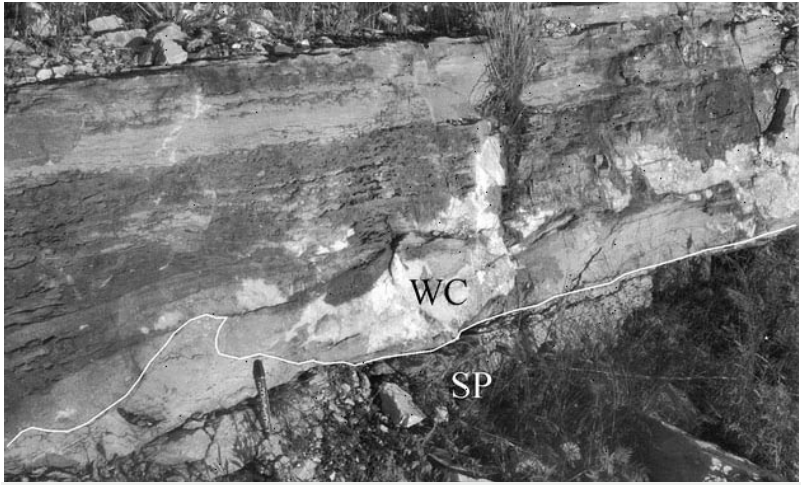

Figure 3. Outcrop photograph showing the disconformable nature of the Strites Pond (SP)–Wallace Creek (WC) contact exposed at locality 1 (Omya quarry, Saint Armand, Quebec). This erosional contact separates lower, thickly bedded, light grey, fine-crystalline lime mudstone of the Strites Pond Formation from medium- to thinly bedded, medium grey, bioclastic lime packstone and shale interbeds of the Wallace Creek Formation. The marker is 13 cm long.

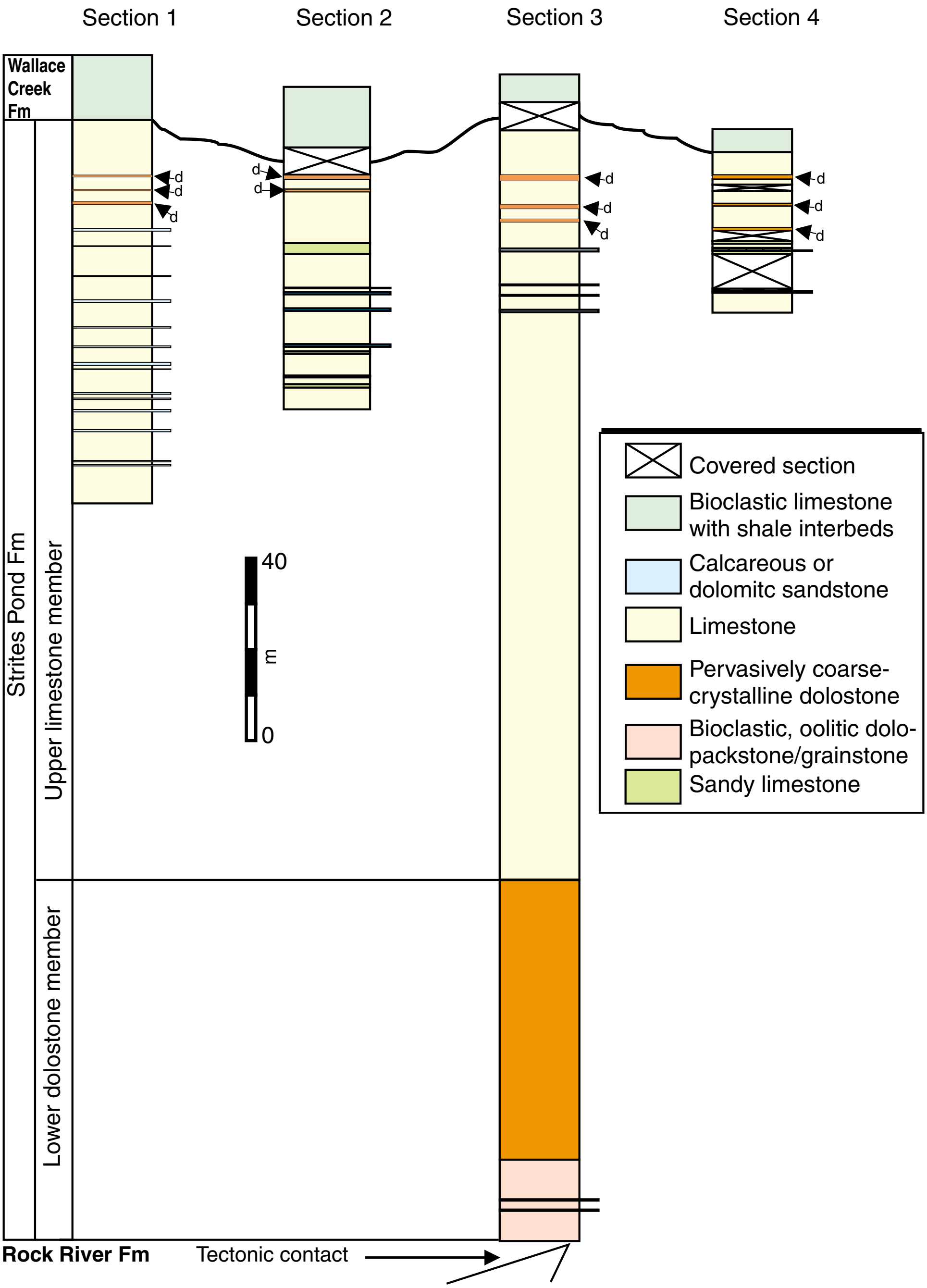

Figure 4. Lithostratigraphic correlation of four sections showing the Strites Pond Formation and its upper contact with the overlying Wallace Creek Formation. The lower contact is not exposed, but field evidences along locality 3 suggest a tectonic or unconformable contact. *See* text for further explanations. d = dolostone marker beds.

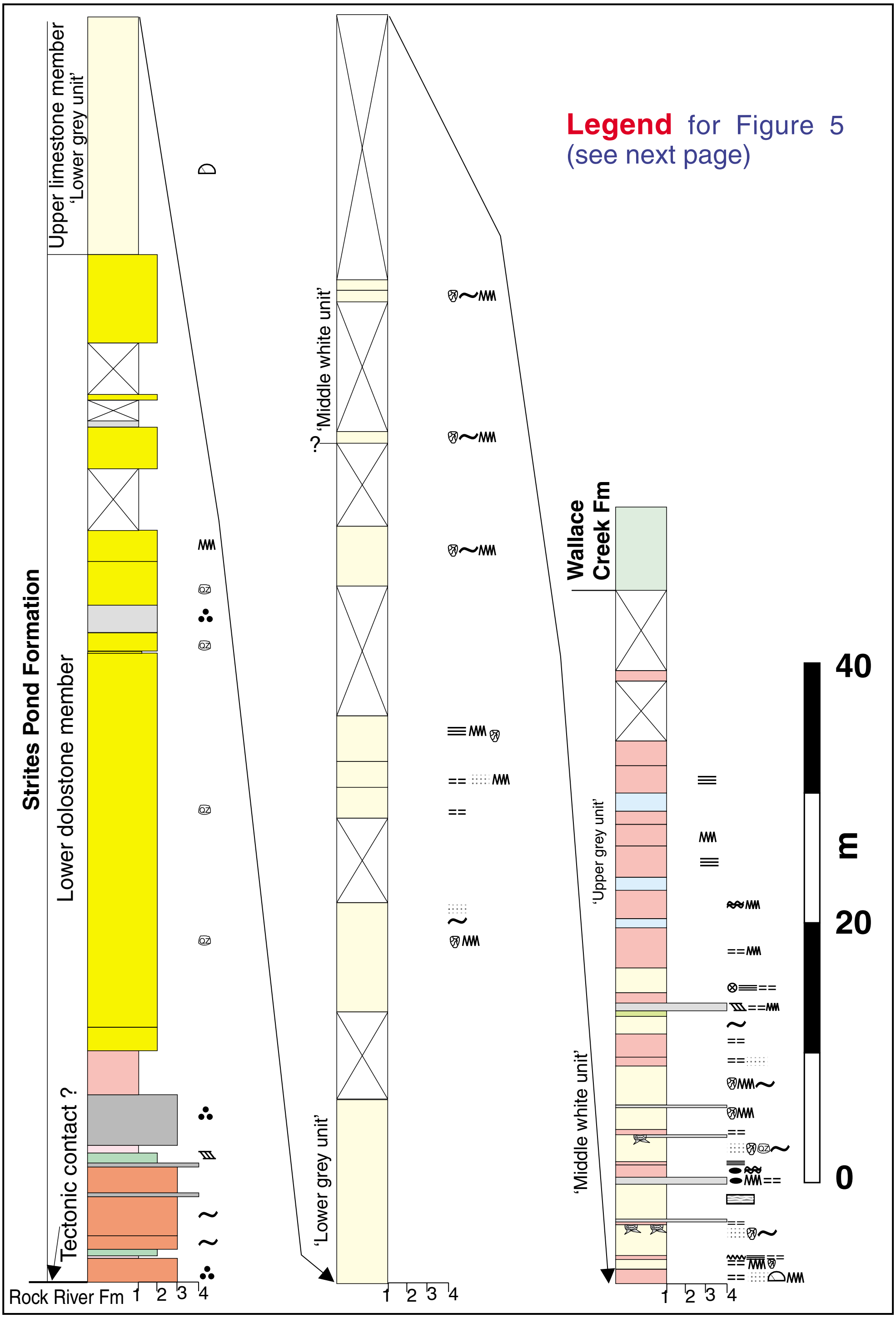

Figure 5. Stratigraphic log from section 3 showing the lower dolostone member and the upper limestone member of the Strites Pond Formation. The terms 'lower grey unit', 'middle white unit', and 'upper grey unit' are informal unit names used by the quarrymen. Contact with the overlying Wallace Creek Formation is concealed under a 6.20 m thick covered section.

LEGEND FOR FIGURE 5

Covered
Wallace Creek Fm
Thin shale-limestone interbeds
Marker dolostone beds (lf-8)
Fine crystalline dolostone (lf-8)
Thrombolitic bioherm (lf-7)
Lime mudstone (lf-6)
Shale (lf-5)
Calcareous dolostone/dolomitic limestone (lf-4)
Dolomitic sandstone (lf-3)
Sandy dolostone/limestone (lf-3/9)
Coarse-crystalline dolostone (lf-2)
Bioclastic, ooliticdolopack-/grainstone (lf-1)
Peloids
Intraclasts
Interwoven texture of thrombolites
Sandstone liminae
Shale laminae/shaly partings
Fenestral (birdseye) fabric
Chert nodules or fracture-fills
Erosional surface
Laminations
Burrows
Stylolites
Stromatactoid structure
Sandstone-filled karsts
Crosslaminated
Nodular to lenticular bedding
Calcite/dolomite nodules

1 = Mudstone/shale
2 = Wackestone
3 = Packstone/grainstone
4 = Sandstone

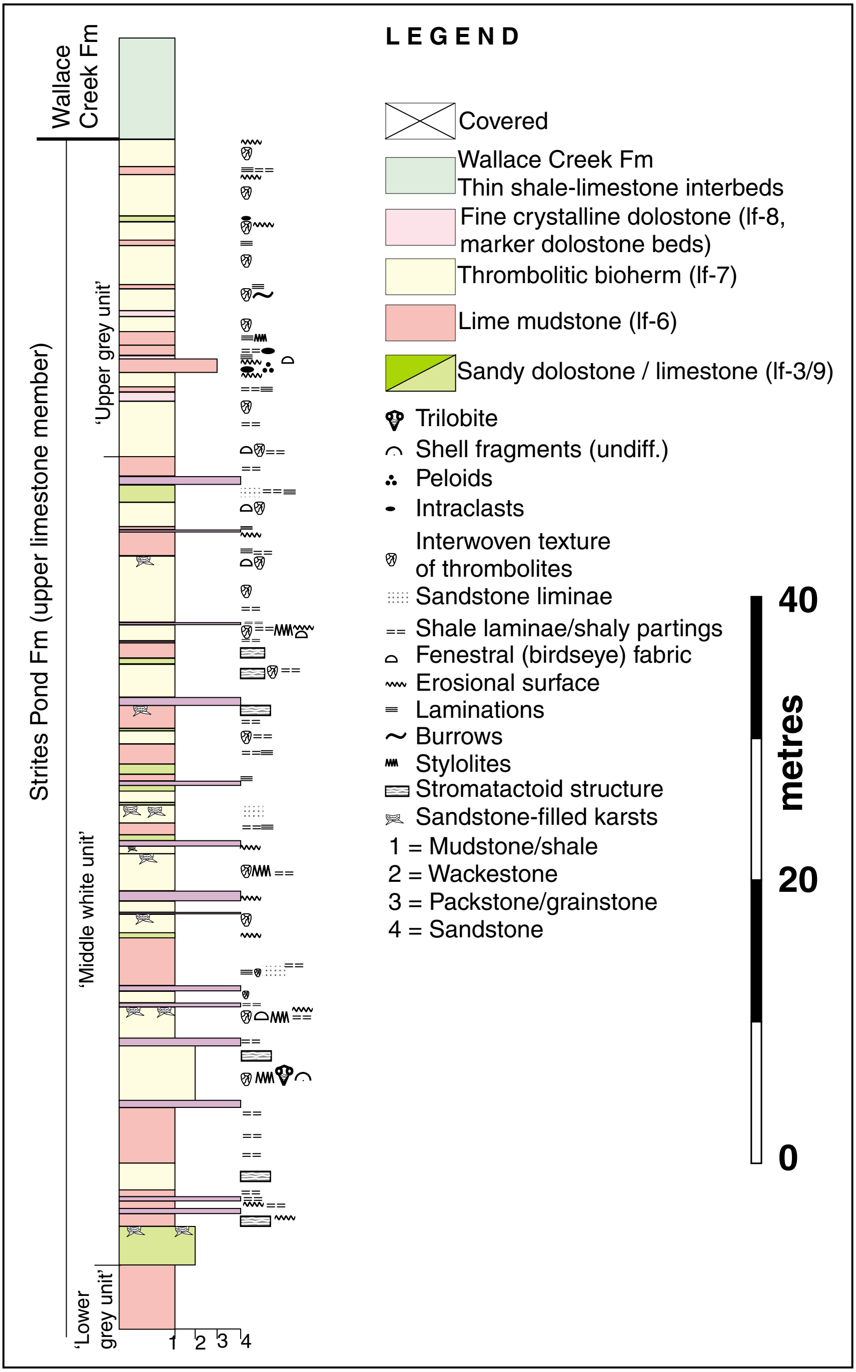

Figure 6. Stratigraphic log from section 1 (Omya quarry at Saint Armand, Quebec) showing most of the upper limestone member of Strites Pond Formation. Note that this part of the formation is dominated by thrombolitic bioherm lithofacies, and that there are also numerous sandstone interbeds partially filling in karstic features. The upper contact with the overlying Wallace Creek Formation is well exposed and characterized by a disconformable erosional surface (*see* Fig. 3).

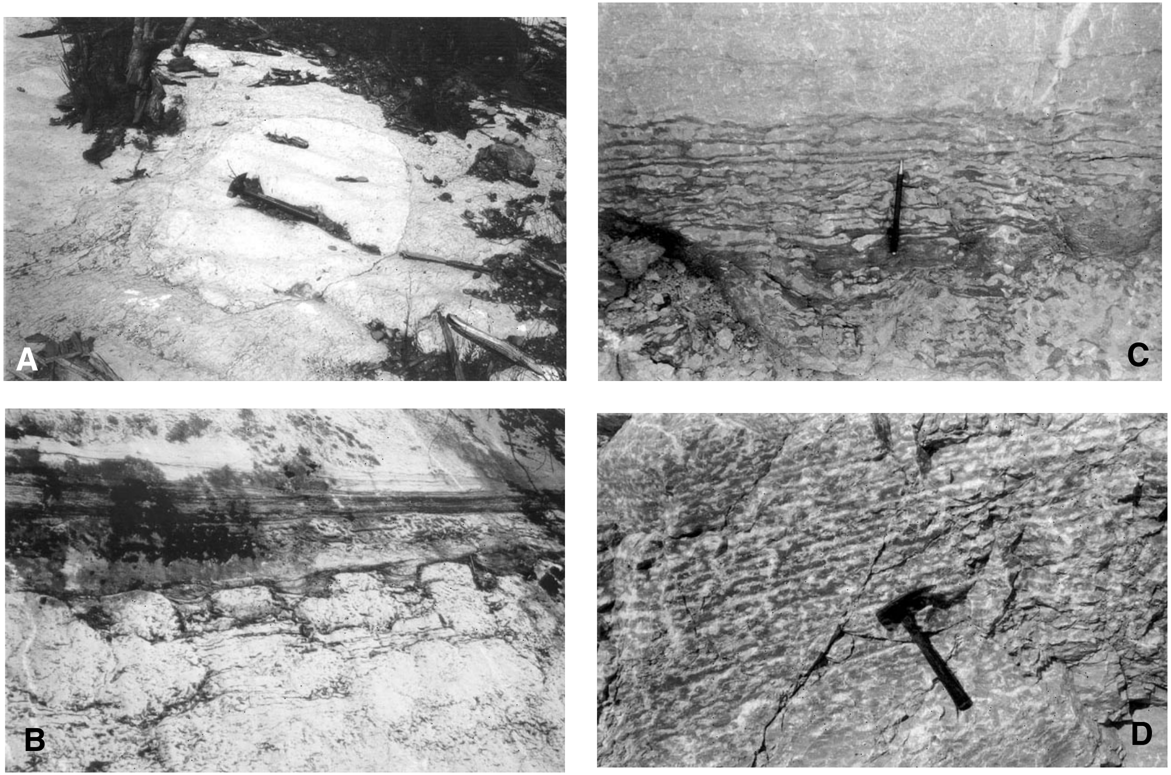

Figure 7. Outcrop photographs showing various sedimentary structures within the upper limestone member of the Strites Pond Formation. Photographs **A**) and **B**) are top view (bedding plane) and lateral (cross-sectional) view, respectively, of mudstone mounds within the upper limestone member of the formation. Note that in B irregular to laminated sandstone lithofacies fill in karstic features in the upper part of the lower thrombolitic (thick, light grey part of the lower half of the photograph) unit. The sand content increases upward and becomes interlaminated with greenish shale lithofacies. These shale and sandstone laminae, along with their karstic-fill counterparts, separate thick beds of thrombolite bioherms and indicate periods of subaerial exposures. Both A and B are from locality 3. Photograph **C**) shows details of the karst-filling sandstone lithofacies at locality 2. Photograph **D**) shows stromatactiod sedimentary structures that are present in certain levels of the upper limestone member. This photograph is from locality 2.