LOWER PALEOZOIC SEDIMENTARY SUCCESSION OF THE ST. LAWRENCE RIVER VALLEY, NEW YORK AND ONTARIO

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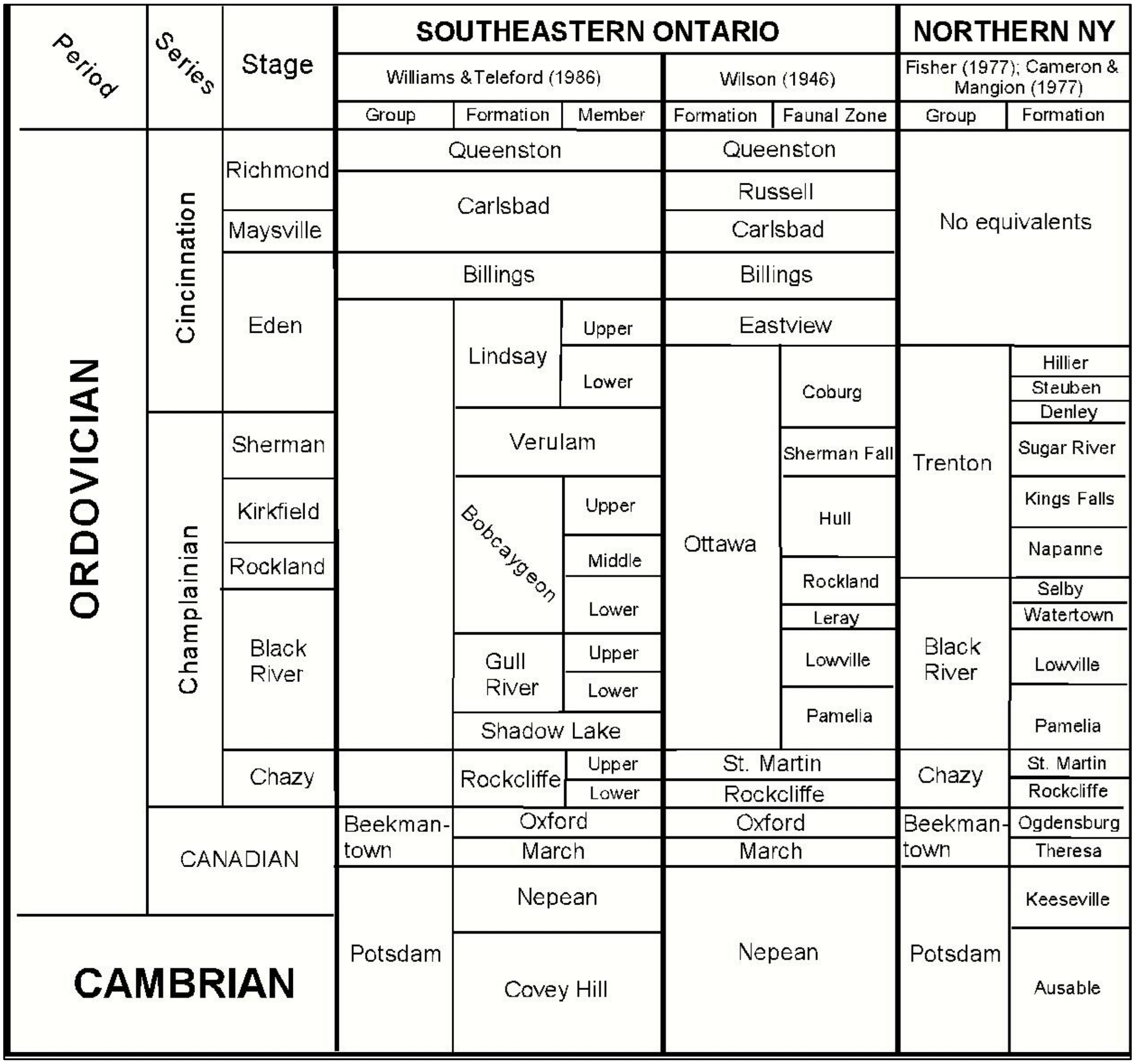
INTRODUCTION

Our fieldtrip to the St. Lawrence River valley in New York and Ontario will showcase the two Lower Paleozoic formations outcropping along the river (Fig. 1.), the middle to upper Cambrian Potsdam Sandstone, and lower-middle Ordovician Theresa (March in Ontario) Sandstone. We will be able to examine the non-conformable contact between Potsdam Sandstone and the underlying Proterozoic basement of the Grenville orogeny, the disconformable contact between Theresa and Potsdam Sandstones, different primary sedimentary structures, trace fossils, and microbial structures preserved within the formations.

Figure 1. Map showing locations of field trip stops in St. Lawrence Lowlands.

Potsdam Formation represents the earliest marine onlap of the Proterozoic Grenville basement and is exposed in the circum-Adirondack region of New York, and bordering areas of Quebec and Ontario (Landing, 2012) (Figs. 2, 3). The timing of the onlap is problematic due to general lack of macrofossils in the lower part of the formation (Ausable Member); the upper age bracket of this member is the Middle Cambrian based on the *Crepicephus* Zone trilobites reported from the overlying basal Keeseville Member (Lochman, 1968, Landing et al., 2009). In addition to trilobites recorded in the lowermost Keeseville Member, the Middle to Upper Cambrian age of the upper Potsdam Formation is indicated by abundant findings of trace fossils (e.g., Bjerstedt and Erickson, 1989; Erickson, 1993a, b; Erickson and Bjerstedt, 1993; Erickson et al., 1993; MacNaughton et al., 2003; Hoxie and Hagadorn, 2005; Getty and Hagadorn, 2006; Landing et al., 2007) and locally stranded medusae (Hagadorn et al., 2007).



Period	Series	Stage	SOUTHEASTERN ONTARIO					NORTHERN NY	
			Williams &Teleford (1986)			Wilson (1946)		Fisher (1977); Cameron & Mangion (1977)	
			Group	Formation	Member	Formation	Faunal Zone	Group	Formation
ORDOVICIAN	Cincinnation	Richmond	Queenston			Queenston		No equivalents	
			Carlsbad			Russell			
		Maysville				Carlsbad			
		Eden	Billings			Billings			
				Lindsay	Upper	Eastview			
					Lower	Ottawa	Coburg	Trenton	Hillier
									Steuben
									Denley
	Champlainian	Sherman		Verulam			Sherman Fall		Sugar River
		Kirkfield		Bobcaygeon	Upper		Hull		Kings Falls
		Rockland			Middle				Napanne
		Black River			Lower		Rockland	Black River	Selby
							Leray		Watertown
				Gull River	Upper		Lowville		Lowville
					Lower		Pamelia		Pamelia
				Shadow Lake					
		Chazy		Rockcliffe	Upper	St. Martin		Chazy	St. Martin
					Lower	Rockcliffe			Rockcliffe
	CANADIAN		Beekman-town	Oxford		Oxford		Beekman-town	Ogdensburg
				March		March			Theresa
			Potsdam	Nepean		Nepean		Potsdam	Keeseville
CAMBRIAN				Covey Hill					Ausable

Figure 2. Nomenclature and correlation of Cambro-Ordovician lithostratigraphic units in southeastern Ontario and northern New York after Williams et al. (1992).

The basal, lower part of the Potsdam Formation (Ausable Member, not visited on this trip) is characterized by four non-marine lithofacies (McRae, 1985), including massive matrix-supported conglomerate, bedded grainsupported conglomerate, conglomerate-arkose, and pebble conglomerate-arkose fining-upward sequences, interpreted to represent debris flows, proximal gravelly braided-stream deposits, intermediate-to-distal gravelly braided-stream deposits, and proximal sandy braided-stream deposits, respectively. These basal, arkosic deposits are both compositionally and texturally immature and contain detritus derived from the underlying weathered Proterozoic surface (McRae, 1985; Selleck, 1997). The terrestrial, braided-stream and braided alluvial plain deposition was terminated by the subsequent (Middle?) Cambrian cratonic transgression that deposited the “classic”, upper Potsdam quartz arenites of the Keeseville Member. At Alexandria Bay and its vicinity (stops 1-4 of this field trip), as well as in the Redwood-Hammond area, the extreme textural maturity, lack of terrigenous silts and clays, lack of fossils, large scale of bedding, presence of silcreted sandstone breccias, and the sharp, clast-free contact with the underlying basement all suggest subaerial, possibly eolian, beach-berm-coastal dune depositional environment (Selleck, 1975) (Fig. 3). McRae (1985) argues that the provenance, compositional and textural maturity, large-scale high-angle planar cross-bedding, absence of fossils, and close association with braided fluvial deposits were consistent with interpreting these strata in the vicinity of Alexandria Bay and in Hannawa Falls as eolian. Based on provenance analysis of detrital zircon (Gaudette et al., 1981) and basal conglomerate clasts of the lower Potsdam Formation (Kirschgasser and Theokritoff, 1971; McRae, 1985; Blumberg et al., 2008), the framework grains originated from Adirondack, Superior, and Grenville provinces (Hagadorn et al., 2013). Contrary to the lower part of the Keeseville Member in the St. Lawrence Lowlands, the upper part of this member, composed of medium- to very thin-bedded, calcite- and silica-cemented fine-to-medium grained quartz arenite, clearly indicates subaqueous, nearshore, tidal deposition (Bjerstedt and Erickson, 1989). This is indicated both by presence of current ripples, herringbone cross bedding, mudcracks, soft sediment deformation, trace fossil assemblages of low-level suspension feeders of the *Skolithos* ichnofacies (*Diplocraterion sp.*, *Monocraterion* sp., *Skolithos* sp.) (Bjerstedt and Erickson, 1989), as well as by rare presence of the inarticulate brachiopod *Lingulepis acuminate* (Selleck, 1984). The Potsdam Formation varies in thickness from a few tens of meters at southern localities of the New York promontory region, to more than 650 m north of Plattsburg, New York (Landing, 2012).

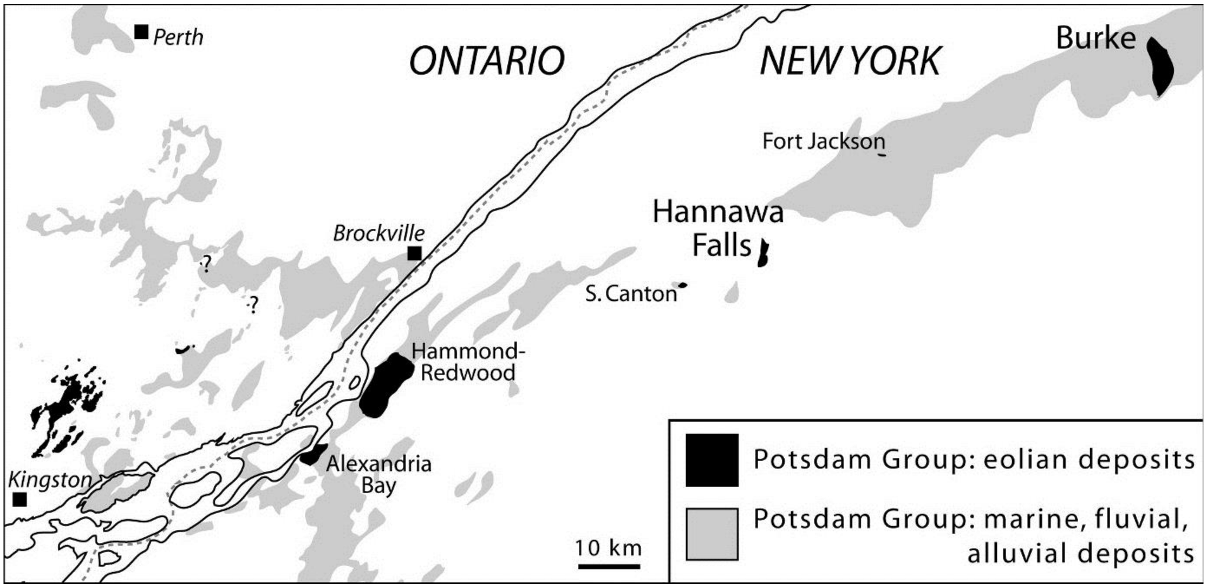


Figure 3. Map showing all Potsdam Fm. outcrops in St. Lawrence Lowlands. Modified from Hagadorn et al. (2011).

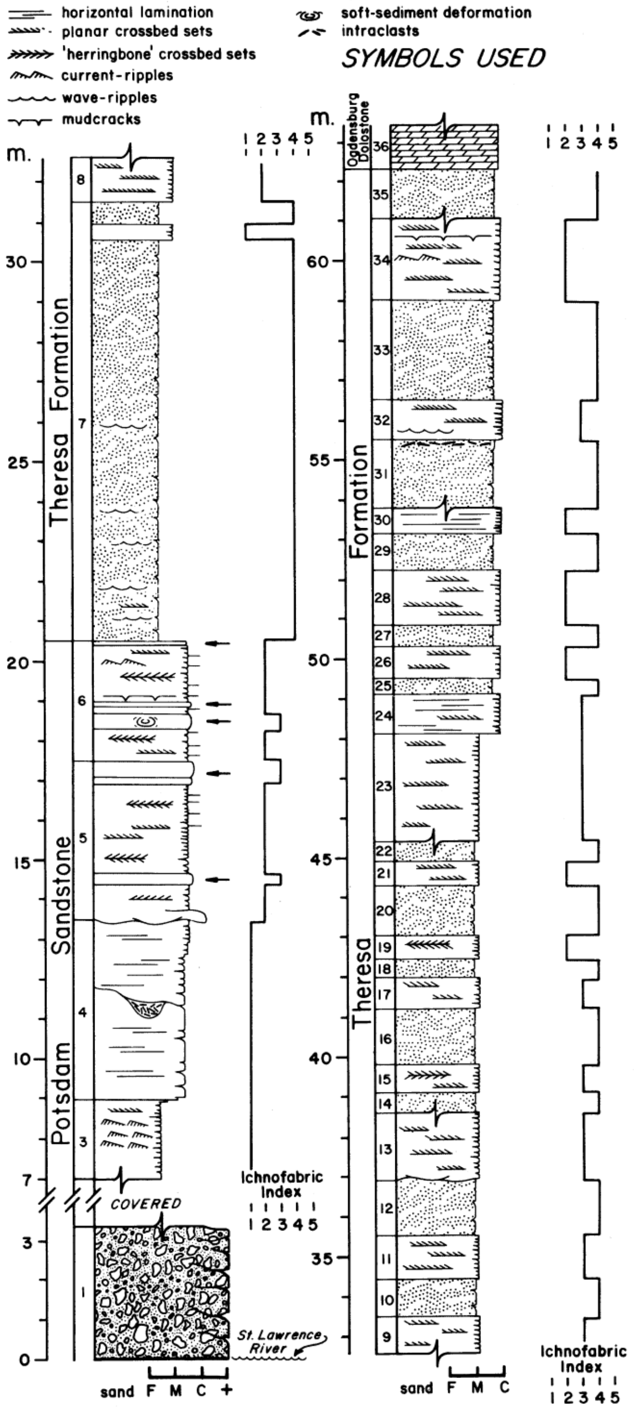


Figure 4. Composite section of the Potsdam and Theresa Formation in the St. Lawrence River valley in New York after Bjerstedt and Erickson (1989). Ichnofabric index indicates endobenthic disruption of primary sedimentary lamination (Droser and Bottjer, 1988); it is low (1-2) in white cross-bedded sandstone, and increases in burrowed gray quartz arenite (index 4-5). Arrows indicate presence of Diplocraterion burrows in upper Potsdam Formation.

Uppermost Cambrian and lowermost Ordovician strata are absent in the St. Lawrence River valley, indicating a long hiatus between the Potsdam and Theresa Formations (Landing, 2012) (Fig. 4). This contact is indicated by an abrupt increase in carbonate content, and a shift from sandy, tidal-flat facies to subtidal shelf/lagoon facies (Selleck, 1984; Woodrow et al., 1989). The middle Early Ordovician age of the lower Theresa Formation is indicated by Stairsian (*Macerodum dianae* Zone) conodonts (Salad Hersi et al., 2003). The formation is informally subdivided into lower, middle, and upper parts. The lower part is thoroughly bioturbated fine-grained quartz arenite cemented by calcite. The middle and upper parts of the formation are characterized by two sharply defined lithofacies that alternate in vertical sequence. These include gray, thick-bedded to massive, intensely burrowed, poorly sorted medium-to-coarse grained calcareous quartz arenite, and white to pale tan thin-to-medium bedded, fine-to-medium grained, siliceous to calcareous, planar and herringbone cross-bedded quartz arenite (Bjerstedt and Erickson, 1989). The maximum estimated thickness of the Theresa Formation in northwest New York varies from 28 m (Selleck, 1984) to 43 m (Cushing, 1916). In Ontario, its equivalent March Formation is up to 45 meters thick (Greggs and Bond, 1971).

In the St. Lawrence River Valley of New York, the Theresa Formation yields an association of peritidal facies characterized by a poor body fossil assemblage but rich biogenic structures. Road-cut stratigraphy is complicated due to the patchy character of exposed sections, but a characteristic vertical sediment sequence of lower, middle, and upper Theresa can be recognized. Bioturbated facies of the gray calcareous sandstone contains a *Cruziana* ichnofacies of abundant deposit feeders (Bjerstedt and Erickson, 1989). *Scolithos* ichnofacies is present in the white cross-bedded sandstone. The white sandstone in the upper Theresa Formation is also characterized by wave ripples, herringbone cross-stratification and horizontal lamination. Microbial structures distinguished by wavy laminated stromatolite growth structures are common in the white quartz sandstones of the middle Theresa Formation (Donaldson and Chiarenzelli, 2007; Husinec et al., 2008). Vertical sections of stromatolites exhibit predominantly space-linked hemispheroids with close-linked hemispheroids as a microstructure in the constituent laminae. Hemispheroids vary both in amplitude and in shape, i.e. from low-amplitude (5-10 cm) and gently convex, to higher-amplitude (up to 20 cm), steeply convex to slightly rectangular, vertically stacked hemispheroids. Subcircular, concentrically stacked spheroids up to 30 cm in diameter, with laminae composed of close-linked hemispheroids are observed in plan view. The facies stacking pattern observed within the microbial structure-rich part of the Theresa Formation likely represents shallowing-upward parasequences composed of gray, intensely bioturbated, restricted subtidal facies, capped by microbial laminites of tidal flats. Some parasequences are capped by thin breccia-conglomerate horizons suggesting periodic subaerial exposure of tidal flats. The alternating vertical stacking pattern of the two facies is complicated by their common interfingering in the upper Theresa, suggesting facies mosaics. In the Thousand Islands region, Theresa Formation is unconformably overlain by the Ogdensburg dolomite. Near Morristown, NY, Selleck (1984) recorded wavy-bedded, rather pure dolomite overlying the quartz arenite, and mapped it as contact between the Ogdensburg and Theresa Formations. The Ogdensburg Dolomite is best preserved in local quarries, where it commonly contains stromatolites (Kerans, 1977; Selleck, 1984; Van Diver, 1976) formed in upper intertidal to supratidal setting (Kerans, 1977).

STOP 1. NONCONFORMITY BETWEEN PROTEROZOIC BASEMENT AND POTSDAM SANDSTONE AT ALEXANDRIA BAY, NEW YORK

Latitude 44°20'42.54"N; Longitude 75°52'38.82"W

Road Log

Cumulative Mileage	Mileage from Previous Point	Route Description
0.0	0.1	Meet at Bonnie Castle Resort parking lot (31 Holland St, Alexandria Bay). Head south on Holland St
0.1	0.1	Continue onto 2nd St
0.2	0.4	Turn left onto Walton St
0.6	0.2	Continue onto Old Goose Bay Rd
0.8	1.4	Turn left onto NY-12 N. Stop 1 will be on the left. Park on the right shoulder and use caution when crossing on the left (north) side of NY-12 N.

Estimated driving time: 4 minutes

One of the best exposures of the non-conformable contact between the Potsdam Formation and the underlying Proterozoic basement in northwestern New York is in a road cut located approximately 1.5 miles northeast of Alexandria Bay, where New York State route 12 (NY-12), a two-lane undivided roadway cuts into a hill some 360 m (1,180 ft) west of the Cranberry Creek bridge (Fig. 5). The basal Potsdam Formation is in sharp contact with the Proterozoic gneiss that shows signs of alteration (illite, Fe-chlorite, and siderite; Selleck, 1993). The basal ~2 meters of Potsdam Sandstone weather into thin and friable slabs that are composed of low-angle cross-laminated (Fig. 6), non-arkosic and non-conglomeratic quartz arenite that is overall moderately sorted and contains some coarse grains within the predominantly fine- to medium-grained framework. Sorting increases up-section, and the sandstone becomes more massive. No body fossils or trace fossils are present in the Potsdam Formation at this stop.

Figure 5. South face of a road cut showing nonconformable contact (red dashed line) between Proterozoic basement and the overlying Potsdam Formation. Stop 1, Alexandria Bay, New York.

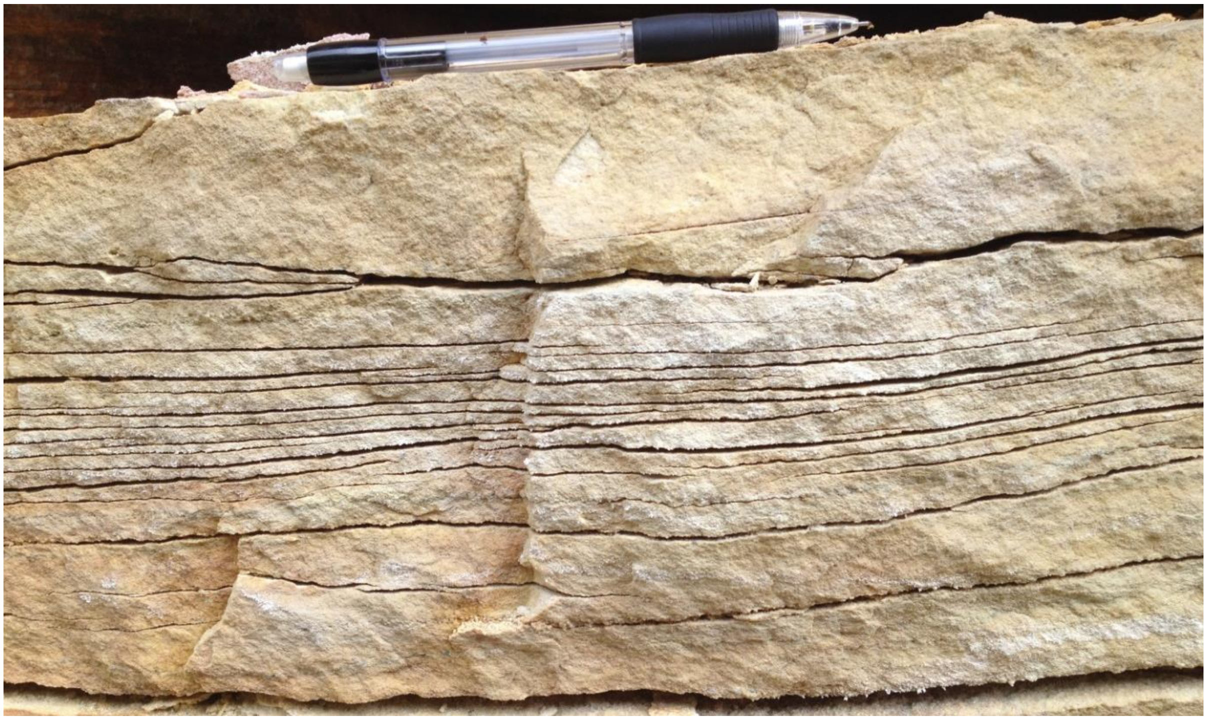


Figure 6. Low-angle cross-lamination in lower Potsdam Formation. Pencil for scale is 6 in (15cm) in length. Stop 1, Alexandria Bay, New York.

STOP 2: PRIMARY SEDIMENTARY STRUCTURES IN BASAL POTSDAM SANDSTONE, GOOSE BAY, NEW YORK

Latitude 44°21'23.39"N; Longitude 75°51'22.67"W

Road Log

Cumulative Mileage	Mileage from Previous Point	Route Description
2.2	1.4	Head east on NY-12 N toward Log Hill Rd. Stop 2 will be on the right.

Estimated driving time: 2 minutes

The northwest face of this road cut nicely exposes lowermost approximately 2.5 meters of Potsdam Sandstone (Fig. 7). The basal ~1.5 meters is a cross-laminated medium- and fine-grained quartz arenite showing tabular cross-bedding with curved bases and sharp erosive tops. The overlying ~40-cm-thick tabular quartz-arenite bed is characterized by planar to very low-angle cross lamination. The topmost set exhibits discontinuous, faint wavy (possible erosive bases) and parallel stratification, and becomes more massive updip. The exposed section is barren of body and trace fossils and contains no obvious microbially formed structures.

Figure 7. Planar cross-lamination (bed A) and parallel stratification (beds B and C) in lower Potsdam sandstone. Note curved base and sharp erosive top of bed A, flow to the right. Stop 2, Goose Bay, New York.

STOP 3: NONCONFORMITY BETWEEN PROTEROZOIC BASEMENT AND POTSDAM SANDSTONE AT GOOSE BAY, NEW YORK

Latitude 44°22'5.69"N; Longitude 75°50'20.93"W

Road Log

Cumulative Mileage	**Mileage from Previous Point**	**Route Description**
3.6	1.2	Head northeast on NY-12 N toward Goose Bay. Stop 3 will be on the right.

Estimated driving time: 1 minute

The road cut on the southeast side of the road exposes the nonconformity between Potsdam Sandstone and the underlying Grenville basement rock (Fig. 8). The contact is sharp but irregular, and displays heavily weathered, friable Proterozoic basement rock below the unconformity. Basal Potsdam Sandstone is a quartz arenite composed of poorly sorted and angular grains without any fossils. The lower 50-60 cm is white to light gray in color; the color changes in the upper part of the outcrop to pink and red. The reddish color around detrital grains and within secondary silica and illite cements is due to presence of finely crystalline hematite, goethite and anatase that formed by breakdown of detrital magnetite and ilmenite grains (Selleck, 1993). This basal, low-angle cross-laminated sandstone weathers more easily than the overlying, more massive quartz arenite that we observed at Stop 1, but is missing at this outcrop.

Figure 8. Nonconformable contact (red dashed line) between Proterozoic basement and the overlying Potsdam Formation. Stop 3, Goose Bay, New York.

STOP 4: POTSDAM SANDSTONE AT SCHERMERHORN HARBOR, HAMMOND, NEW YORK

Latitude 44°24'36.20"N; Longitude 75°47'14.94"W

Road Log

Cumulative Mileage	Mileage from Previous Point	Route Description
4.8	3.9	Head northeast on NY-12 N toward Shannon Rd. Stop 4 will be on the right. Stop 4 will be on the left. Park on the right shoulder and use caution when crossing on the left (northwest) side of NY-12 N.

Estimated driving time: 4 minutes

Note that between this stop and Alexandria Bay, all the outcrops are either Proterozoic Grenville basement or Potsdam Sandstone, indicating that Potsdam Formation blanketed topographic lows of the Proterozoic surface. Topographically higher areas likely were not sites of Potsdam deposition, or alternatively, sandstone was subsequently eroded from these areas. At this an unconformity within Potsdam Sandstone is exposed, (Fig. 9). The basal 3 meters above the unconformity is characterized by cross bedding (Fig. 10), with alternating poorly sorted, coarse- (up to very coarse in places) to medium-grained quartz arenite. This basal sandstone characteristically weathers into thin slabs. Upward in the section, the sandstone becomes more massive.

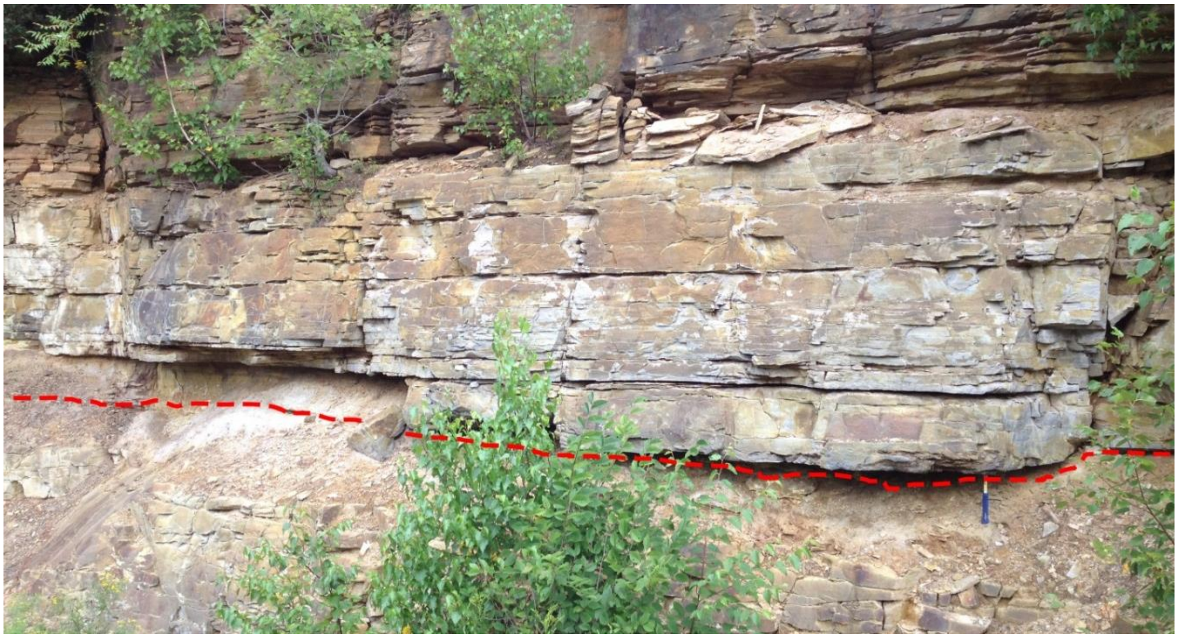


Figure 9. Unconformity within Potsdam sandstone (red dashed line). Stop 4, Schermerhorn Harbor, Hammond, New York.

Figure 10. Cross-laminated basal Potsdam Formation showing tabular cross-bedding. Pencil for scale is 6 in (15cm) in length. Stop 4, Schermerhorn Harbor, Hammond, New York.

STOP 5: DISCONFORMITY BETWEEN POTSDAM SANDSTONE AND THERESA FORMATION AT CHIPPEWA BAY, NEW YORK

Latitude 44°28'2.44"N; Longitude 75°45'48.70"W

Road Log

Cumulative Mileage	Mileage from Previous Point	Route Description
8.7	5.0	Head northeast on NY-12 N toward Factory Rd. Stop 5 will be on the right.

Estimated driving time: 5 minutes

The disconformity between the Theresa Formation and Potsdam Sandstone is spectacularly exposed near Chippewa Bay, New York (Fig. 11). An unconformity without angular discordance (dashed line in Figure 11) is marked by a thin, vegetated interval on top of the Potsdam Formation. The contact between two formations is sharp and indicated by a change in color from white to pale tan silica-cemented Potsdam below, to carbonate-cemented dark gray Theresa sandstone above. Unlike the lower part of the Potsdam Formation that on previous stops is devoid of any biogenous structures, its uppermost part exposed at this stop contains abundant *Diplocraterion* and *Skolithos* trace fossils (Fig. 12), clearly indicating a shallow-marine setting. The basal part of Theresa is extensively burrowed, and most primary sedimentary structures are completely obliterated. In addition to biogenous structures, Selleck (1993) recorded numerous fragments of the brachiopod *Lingulepis* in both the upper Potsdam and lower Theresa at this location.

Figure 11. Southwest face of a road cut showing disconformable contact (red dashed line) between Proterozoic basement and the overlying Potsdam Formation. Stop 5, Chippewa Bay, New York.

Figure 12. Abundant "U"-shaped Diplocraterion burrows in an ~30 cm (1 ft) thick quartz arenite bed in uppermost Potsdam Formation. Stop 5, Chippewa Bay, New York.

STOP 6: LOWER THERESA FORMATION NORTH OF CHIPPEWA BAY, NEW YORK

Latitude 44°30'10.21"N; Longitude 75°45'22.62"W

Road Log

Cumulative Mileage	Mileage from Previous Point	Route Description
13.7	2.7	Head northwest on NY-12 N toward Dubois Rd. Stop 6 will be on the right.

Estimated driving time: 3 minutes

The road cut on the northeast side of the NY-12 exposes extensively burrowed lower Theresa Formation (Fig. 13). Individual burrows, and possible pseudomorphs after evaporite minerals, are clearly visible as molds on weathered face of the oucrop (Fig. 14), and contribute to overall high porosity of this facies. Medium-grained quartz arenite is cemented by carbonate and is moderately to well sorted. The dark gray color is typical for the lower Theresa, with rare thin yellowish intervals that follow the bedding.

Figure 13. Southwest face of a road cut showing planar bedding in dark gray quartz arenite in the lower Theresa Formation. Stop 6, Chippewa Bay, New York.

Figure 14. Vuggy, highly burrowed sandstone of the lower Theresa Formation. Pencil for scale is 6 in (15cm) in length. Note probable molds of halite crystals (arrows point to a few of the largest ones).

STOP 7: MICROBIAL STRUCTURES IN THERESA FORMATION NORTH OF CHIPPEWA BAY, NEW YORK

Latitude 44°32'59.22"N; Longitude 75°41'58.60"W

Road Log

Cumulative Mileage	**Mileage from Previous Point**	**Route Description**
16.4	4.4	Head northwest on NY-12 N toward Riverledge Rd. Stop 7 will be on the right.

Estimated driving time: 5 minutes

The road cuts at this stop expose microbial structures preserved within the white, medium-grained quartz arenites of the middle Theresa Formation. These structures are exposed on both sides of NY-12, and are distinguished by wavy-laminated stromatolite growth structures that are common in the white quartz sandstones of the middle Theresa Formation. Vertical sections of stromatolites exhibit predominantly space-linked hemispheroids with close-linked hemispheroids as a microstructure in the constituent laminae (Fig. 15). Hemispheroids vary both in amplitude and in shape, i.e. from low-amplitude (5-10 cm) and gently convex, to higher-amplitude (up to 20 cm), steeply convex to slightly rectangular, vertically stacked hemispheroids. Subcircular, concentrically stacked spheroids up to 30 cm in diameter, with laminae composed of close-linked hemispheroids are observed in plan view (Fig. 16). Their shape closely resemble intertidal forms from Shark Bay (cf. Tucker & Wright 1990, p. 150, fig. 4.50B).

Figure 15. Vertical sections of stromatolites in the middle Theresa Formation. Stop 7, Chippewa Bay, New York.

Figure 16. Glacially polished outcrop of quartz arenite showing a bedding-parallel section of well-preserved circular to sub-circular stromatolites. Pencil for scale is 6 in (15cm) in length. Stop 7, Chippewa Bay, New York.

STOP 8: UPPER THERESA FORMATION AT MORRISTOWN, NEW YORK

Latitude 44°34'57.11"N; Longitude 75°38'19.63"W

Road Log

Cumulative Mileage	Mileage from Previous Point	Route Description
20.8	3.5	Head northeast on NY-12 N toward Worden Rd.
24.3	0.5	Continue onto NY-37 E. Park on the right shoulder. We will first focus on the right (east) and then on the left (west) side of the road. Use caution when crossing NY-37 E.

Estimated driving time: 4 minutes.

The upper Theresa is nicely exposed in road cuts on both sides of NY-37 immediately south of its intersection with High Street at Morristown, New York. The formation is characterized by thin beds of dark gray and white-yellowish calcareous quartz arenite that irregularly alternate, interfinger and pinch out. Dark gray sandstone is thoroughly burrowed; extensive bioturbation resulted in complete obliteration of primary structures in this subtidal facies. On the contrary, although locally burrowed, the white to yellowish sandstone is characterized by well-preserved sedimentary structures indicating intertidal sand-flat setting with channel fills. Sedimentary structures include ripple cross-lamination, erosional (reactivation) surfaces, herringbone cross bedding, and local conglomerate-filled scours.

Figure 17. Bedding plane view of round-crested symmetrical wave ripples preserved on surface of quartz arenite, upper Theresa Formation. Pencil for scale is 6 in (15cm) in length. Stop 8, Morristown, New York.

Figure 18. Small-scale (ripple) cross-lamination in upper Theresa Formation characterized by thin (<10 cm), planar to slightly curved sets of cross laminae. Pencil for scale is 6 in (15cm) in length. Stop 8, Morristown, New York.

Figure 19. Cross-laminated quartz arenite (upper Theresa Fm.) showing two low-angle erosional (reactivation) surfaces indicated by dashed black lines. Pencil for scale is 6 in (15cm) in length. Stop 8, Morristown, New York.

Road Log to Canada

Cumulative Mileage	Mileage from Previous Point	Route Description
24.8	13.6	Head north on NY-37 toward High St.
38.4	0.9	Turn left onto Trooper Shawn W. Snow St.
39.3	1.5	Continue onto Ogdensburg-Prescott International Bridge. Entering Ontario. Toll Road.

Estimated driving time: 20 minutes.

STOP 9: NONCONFORMITY BETWEEN PRECAMBRIAN BASEMENT AND POTSDAM SANDSTONE AT LYN VALLEY CONSERVATION AREA, ONTARIO

Latitude 44°34'35.21"N; Longitude 75°46'30.98"W

Road Log (Odometer reset at Canadian Customs in Johnstown, Ontario; distance in kilometers)

Cumulative Distance (km)	**Distance from Previous Point (km)**	**Route Description**
0	0	Depart from Canadian Customs
2.0	2.0	Cross over Hwy 401 and turn right to enter cloverleaf for Hwy 401 west
25.0	27.0	Exit Hwy 401 on Stewart St. North in Brockville
0.5	27.5	Left on Parkedale (becomes Old Red Road)
3.5	31.0	Right on Road 46; left at junction with Cty. Rd. 27
2.0	33.0	Left on Cty. Rd. 27 in village of Lyn at intersection with Perth St.
0.2	33.2	Left on Lyn Valley Road
0.2	33.4	Lyn Valley Conservation Area, north side of road

Estimated driving time: 30 minutes.

From the parking area follow the gravel road northward to the start of a footpath that leads eastward through bushes and trees to the base of a 20-metre vertical section of Potsdam sandstone (Fig. 20). This cliff displays almost flat-lying beds with pebble interbeds (clasts of quartz sandstone), ripple marks and low-angle crossbedding that reflect deposition in water rather than by wind. Elsewhere within the Potsdam, large-scale steeply inclined crossbedding in pebble-free Potsdam sandstone in areas to the west reflects eolian transport. Trace fossils plus a wide range of directions of crossbed inclination indicate a shallow-water marine environment. Curled biofilm structures (Fig. 21) plus desiccation cracks reflect occasional subaerial exposure. Surface patches of gravel and sand cemented to the outcrop surface mark places where crossbedded Pleistocene outwash was once in contact with this Paleozoic cliff, reflecting the rapid rate at which unconsolidated deposits can be locally lithified.

Figure 20. Horizontally bedded quartz sandstone in the lower part of the Potsdam Group, exposed in a cliff north of the entrance gate to the Lyn Conservation Area.

Figure 21. Close-up view of the western end of the cliff exposure shown in Fig. 20, showing prominent wavy biofilm structures above (and a few below) the coin.

Figure 22. View looking southward at array of boulders and blocks derived from nearby glacial till. They provide a sampling of rocks to the north: mainly Paleozoic sandstone, limestone and dolomite plus Proterozoic igneous and metamorphic rocks from the Grenville Province, although a few have come from Archean terrain of the Superior Province.

Distinctive roll-up structures, especially prominent near the western end of this outcrop (Fig. 21), record the curling of sheets of sand grains bound by tenacious films of cyanobacteria in response to desiccation. Although the sands were deposited in water, the presence of such structures indicates intermittent episodes of subaerial exposure sufficiently long to allow drying, shrinking and curling of such coherent thin sheets of biofilm-bound sand. Elsewhere in eastern Ontario and northern New York State, similar curled biomats are overlain by sequences of continuous biomat layers that trapped successive interlayers of quartz sand to form distinctive domal stromatolites, indicating more persistent subaqueous conditions. Impressive examples occur within the city limits of Ottawa, Ontario (Hilowle et al., 2000, Donaldson et al., 2002)

On the return trip to the bus, check a few of the numerous boulders and blocks (Fig. 22) arrayed along the west side of the gravel roadway. Extracted from nearby outwash deposits, they provide examples of Precambrian igneous and metamorphic rocks from the Canadian Shield in addition to samples from the Paleozoic cover. The Precambrian boulders display pegmatite dykes, crosscutting relationships, inclusions, foliation, lineation and fractures (some with minor fault offsets).

Figure 23. Glacially striated and polished outcrop, one of several adjacent to telephone pole shown in Figure 22.

Between the margin of the gravel road and the telephone pole in Figure 22, immediately north of the largest boulder, a cluster of small glacially polished and striated outcrops of Grenville basement rock displays near-vertical foliation (Fig. 23). Distinct lithologic interlayers suggest a sedimentary provenance for these Precambrian rocks, with the compositional layering probably marking original bedding.

STOP 10: HERITAGE STONE BUILDING ON WEST MAIN ST., LYN VILLAGE, ONTARIO

Latitude 44°34'36.53"N; Longitude 75°47'4.11"W

Road Log

Cumulative Distance (km)	Distance from Previous Point (km)	Route Description
33.4	0.4	From Conservation Area, return to Lyn Village via Lyn Valley Road, turning right on West Main Street. Just before the intersection with Perth St., turn left into the parking on the north side of a small stone building, one of many in this region. This one houses a public library and the meeting room for the local Masonic Lodge.

Estimated driving time: 2 minutes.

Its walls of Potsdam sandstone are replete with an impressive array of trace fossils, with *Diplocraterion* and *Skolithos* predominating. A few blocks, especially those in the north wall, show syndepositional deformation of these trace fossils in vertical section, comparable to the syndepositional overturn of crossbeds.

Figure 24. Historic building currently used as a meeting hall and public library in Lyn Village. It is on the west side of Main St., about 50 metres south of a T-junction with Perth St.

Figure 25. Close-up view of Potsdam sandstone blocks in north wall of building shown in Fig. 24. Most show excellent examples of Diplocraterion (note that some blocks have been installed upside down). Some blocks installed with bedding parallel to the wall reveal solitary ichnotraces of Monoocraterion and Skolithos as well as the characteristic paired tubes of Diplocraterion.

STOP 11: PALEOZOIC-PRECAMBRIAN UNCONFORMITY, QUABBIN HILL

Latitude 44°28'20.50"N; Longitude 75°54'52.41"W

Road Log

Cumulative Distance (km)	Distance from Previous Point (km)	Route Description
33.8	8.2	Follow Hwy. 27 through Yonge Mills to junction with Hwy. 2.
41.0	6.0	Turn right on Hwy. 2
47.0	3.0	Turn right on Quabbin Road (Hwy. 4) Drive through the village of Mallorytown, site of former glass-making factory that utilized high-quality Potsdam sandsone. Park on north shoulder of Hwy. 4, just beyond intersection with Quabbin Hill Road (road on south side of Hwy. 4 at start of hill)

Estimated driving time: 15 minutes.

The rock cut on the north side of the highway on Quabbin Hill directly exposes the regional nonconformity between Potsdam sandstone and the underlying Grenville basement rock. The latter displays excellent spheroidal weathering of the basement (Fig. 26, 27), which here is a massive intrusive mafic rock. The Potsdam contains trace fossils perpendicular to bedding, just like those seen at STOPS 9 and 10, but the underside of beds on the south side of the highway display a different variety of trace fossils: sinuous trails parallel to bedding (Fig. 28).

Figure 26. Looking north across Quabbin Hill Road at the nonconformity between Potsdam sandstone and underlying Grenville basement rock.

Figure 27. Close-up view of spheroidal weathering in mafic intrusive rock beneath the nonconformity. This 3 m wide by 2 m high view is immediately left of the white signpost bar, lower right side of Figure 26.

Figure 28. Sinuous tubular traces, their patterns accentuated by weathering of the underside of an overhanging bed, mark the paths of soft-bodied vermiform organisms that browsed on bedding-parallel organic mats.

Of particular interest in the south-side roadcut are two independent indications of repeated subaerial exposure: bedding-parallel nodular zones within bioturbated silty layers that probably represent tropical soil horizons (Fig. 29), and desiccation patterns on several bedding surfaces. The unconformity surface marks a gap in the geological record of at least half a billion years. During this time, the land may have been elevated so that no rock record accumulated, although it is possible that post-Grenville Proterozoic strata were indeed deposited, but subsequently removed by erosion before the onset of Paleozoic sedimentation.

Figure 29. Highly bioturbated silty sandstone beds with prominent stylolites probably initiated along biomat layers. Sporadic nodular patches are inferred to represent thin paleosols.

STOP 12: PRECAMBRIAN BASEMENT EXPOSURE WITHIN COMMUNITY AT ROCKPORT BOAT LINE, ROCKPORT

Latitude 44°22'51.67"N; Longitude 75°55'55.26"W

Road Log

Cumulative Distance (km)	Distance from Previous Point (km)	Route Description
50.0	8.0	Turn left on Blue Mountain Road.
58.0	4.0	Turn left on Hwy 2. Drive eastward.
62.0	5.0	Turn right on Mallorytown Road (Hwy 5).
67.0	2.0	Cross Hwy 401.
69.0	2.0	Left on Parkway.
71.0	4.0	Turn right at entrance to "Rockport Boathouse". Turn left between Boathouse and parking lot. Follow paved road parallel to St. Lawrence River.
75.0	1.0	Stop 12.

Estimated driving time: 17 minutes.

This outcrop displays lit-par-lit sills of pink to white granite pegmatite and aplite that were injected parallel to the foliation of fine-grained gray to black gneiss and schist of presumed sedimentary provenance (Figure 30). Similar magmatic fluids were injected along crosscutting dykes during multiple episodes that can be put in sequence by observing crosscutting relationships. The metamorphic foliation of the host rock for these intrusions may have developed along the bedding of an original clay-rich sedimentary rock, such as mudstone or siltstone. Although foliation is typically vertical or dips steeply in most exposures or Grenville metamorphic rocks, it here is almost horizontal, perhaps due to location along the hinge of a fold, or to low-angle thrust faulting. The pinch-and-swell morphology of some lit-par-lit injections indicates lateral extension that was locally sufficient to form several boudinage (Figure 31). Note also the prominent sub-ice hydraulic scouring that created sculpted and polished benches along the outcrop during deglaciation.

Figure 30. Outcrop of Grenville gneiss on north side of paved road east of Rockport Boathouse.

Figure 31. Close-up view of boudinage in central lower part of Grenville gneiss shown in Figure 30.

Road Log back to USA

Cumulative Distance (km)	**Distance from Previous Point (km)**	**Route Description**
76.0	1.0	Return to Rockport Boathouse entrance; turn left on Thousand Islands Parkway.
77.0	3.0	Turn left at Selton to access International Bridge for our return to New York State via Hwy 81.

Estimated driving time: 3 minutes.

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