STRATIGRAPHY AND TERRESTRIAL TO SHALLOW MARINE ENVIRONMENTS THE POTSDAM GROUP IN THE SOUTHWESTERN OTTAWA EMBAYMENT

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INTRODUCTION

This field trip showcases the stratigraphy and sedimentology of the Potsdam Group exposed along the southwestern Ottawa Embayment, south of the St. Lawrence River in Jefferson and St. Lawrence County of New York State (Figures 1, 2). The trip will highlight some important regional unconformities which have been used to correlate the Potsdam Group from this area to the north and east, as well as two contrasting fluvial styles in the Potsdam Group: braided perennial fluvial and sheet-like perennial fluvial. Refer to figure 2 for stop locations. We will begin at Wellesley Island and travel a loop that covers some classic Potsdam sections along Highways 37 and 12.

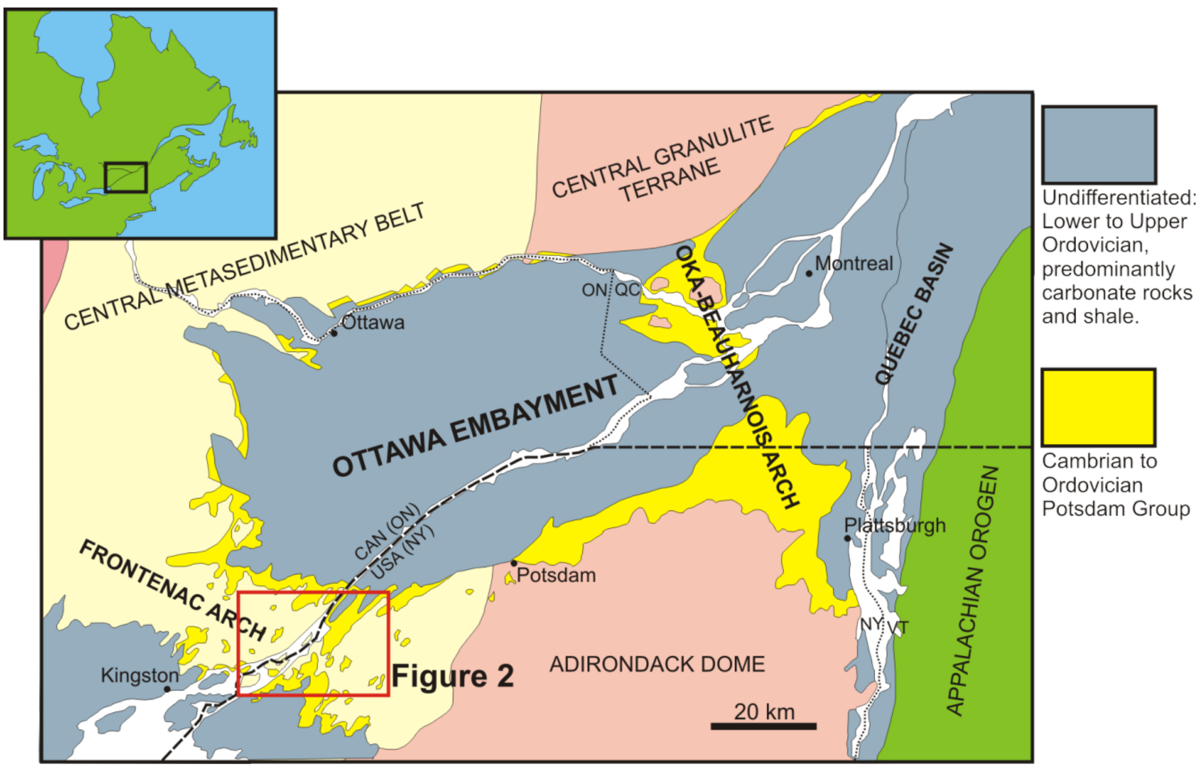

Figure 1. Base geologic map of the Ottawa Embayment-Quebec Basin and surrounding areas showing the outcrop distribution of the Potsdam Group. Today's trip will focus on the stratigraphy and sedimentology of the Potsdam Group in the southwestern margin of the Ottawa Embayment, along the southeastern extension of the Frontenac Arch (see Figure 2).

REGIONAL SETTING

The Cambrian to Ordovician Potsdam Group is a composite siliciclastic unit dominated by sandstone with subordinate conglomerate and exposed on the along the edge of the Ottawa Embayment and Quebec Basin, an east-west extension of the St. Lawrence platform in eastern Ontario, northern New York and western Quebec (Figure 1). Today we will be focusing on outcrops exposed along the Frontenac Arch in the southwestern Ottawa Embayment. The Potsdam Group is ≤ 25 m thick in this area, but thickens to ~ 700 m in the Quebec Basin along the Oka-Beauharnois Arch.

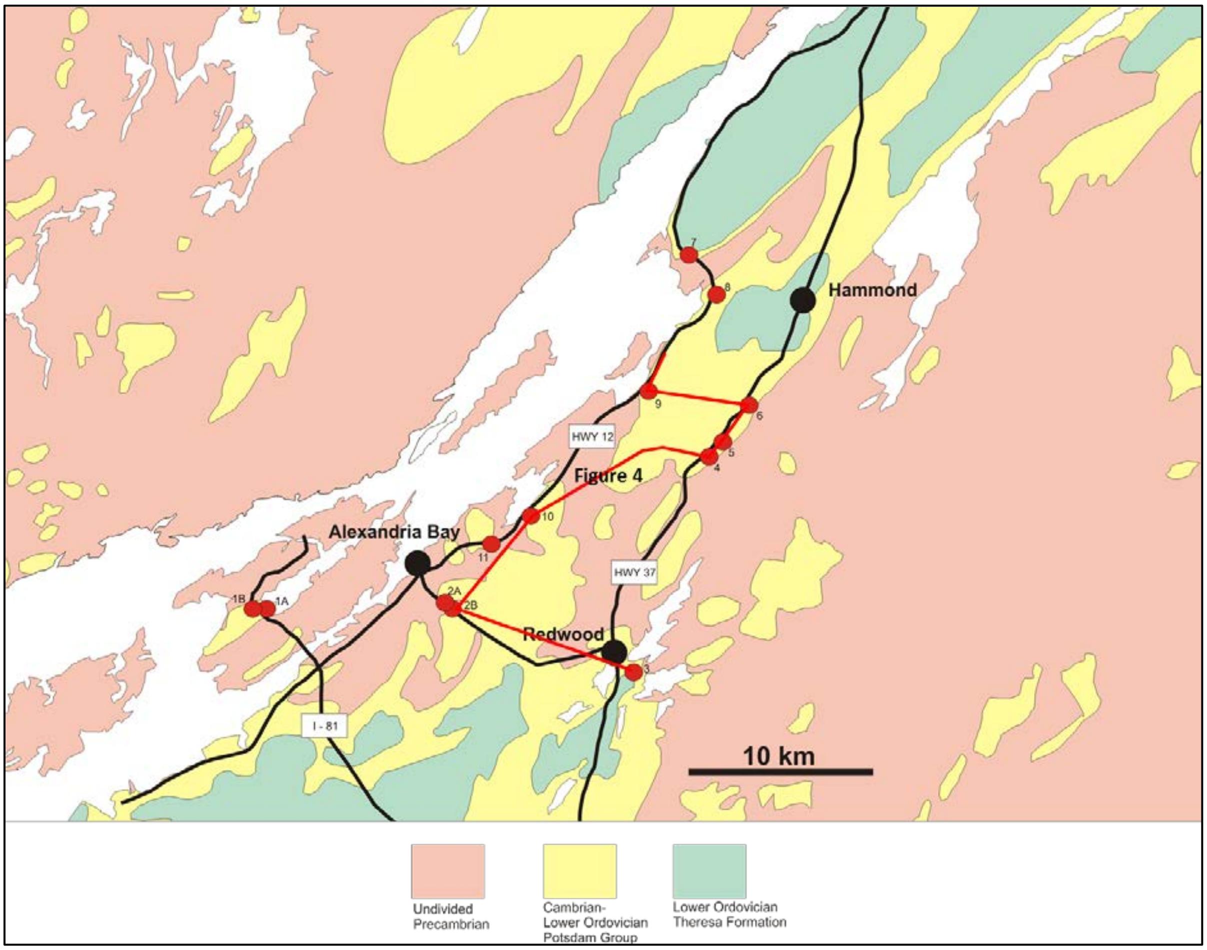

Figure 2. General geologic map focussing on the southwestern margin of the Ottawa Embayment along the southeastern extension of the Frontenac Arch, and showing today's field trip stops (red dots). The red outline shows the outcrops used to generate the more detailed cross-section in Figure 4.

AGE

The depositional age of the Potsdam Group is poorly resolved due to a general paucity of age diagnostic fossils. In the western Ottawa Embayment there is no age limit on the lowermost Potsdam strata due to the absence of any age diagnostic fossils, but farther east the lowermost Potsdam Group is no older than latest Early Cambrian, and it has been suggested that this is the oldest age of deposition regionally (Landing et al. 2009).

It has been suggested that the age of the uppermost Potsdam is not younger than Late Cambrian based on the interpretation of a regional Potsdam-Theresa unconformity and correlation to other unconformities in the Laurentian Platform succession (Salad Hersi et al., 2002; Dix et al. 2004). However, new biostratigraphic analyses from this study (Nowlan, 2013) indicate that an interval stratigraphically below the uppermost Potsdam Group (the Riviere Aux Outardes Mb of the Covey Hill Fm) is Lowermost Ordovician (Early Tremadocian) (Figure 3). We therefore consider the uppermost Potsdam in the western Ottawa Embayment to be of Lower Ordovician age (e.g. Greggs and Bond, 1971; Brand and Rust, 1977; Sanford and Arnott, 2010).

STRATIGRAPHY

This study uses allostratigraphy (correlation of unconformity-bound units) to subdivide and correlate the Potsdam Group. A correlation scheme is shown on Figure 3, with proposed lithostratigraphic revisions superimposed on the allostratigraphy to reconcile existing cross-border inconsistencies with the nomenclature, following the North American stratigraphic code. Also shown are the depositional environments determined from detailed facies analysis. Four allomembers are recognized in the Potsdam Group. Correlations are in part aided by characterization of detrital zircon assemblages, but those are not discussed in detail in this field trip guide.

Allomember 1: Altona Formation: uppermost Early Cambrian to Middle Cambrian: is only recognized in the Quebec basin, along and to the east of the Oka-Beauharnois Arch (Figures 1, 3). It consists of wave/storm-dominated marine shoreface/shelf deposits. We will not visit outcrops of allomember 1 today. The Altona Formation is described in more detail by Landing et al. (2009).

Allomember 2: Ausable Formation (proposed revision): Middle to lower Upper Cambrian: consists of fluvial arkose that reach a thickness of ~600 m along the axis of the Oka-Beauharnois Arch and is exposed as outliers elsewhere (the Covey Hill Member, proposed) and of red bed aeolian quartz arenites, primarily present as locally preserved outliers, ≤ 20 m thick, along the southern and southwestern Ottawa Embayment (Hannawa Falls Member, proposed). We will see a few outcrops of the Hannawa Falls Member today that highlight the unconformity between allomembers 2 and 3 (Stops 3 and 9). This unconformity is correlated to the Sauk II – Sauk III boundary, representing a major early Late Cambrian lowstand on the Laurentian margin and adjoining Michigan and Appalachian basins (Lavoie, 2008; Sanford and Arnott, 2010).

Allomember 3: Chippewa Bay and Riviere Aux Outardes Members of the Keeseville Formation (proposed revision): Upper Cambrian to Lowermost Ordovician: consists of widespread but thin (≤ 20 m) quartz arenites and quartz cobble-boulder conglomerates of fluvial origin (Chippewa Bay Member, proposed) overlain in the northern Ottawa Embayment by marine sandstones with local mudstone and carbonate interbeds (Riviere Aux Outardes Member, proposed). The fluvial Chippewa Bay member of allomember 3 makes up the thickest part of the Potsdam in this area (Figure 4), and consists of braided perennial (Stops 1, 2, 6 and 10) and ephemeral (Stops 2 – 6 and 8 – 11) depositional facies associations. The Riviere Aux Outardes Member is not present here, but constrains the age of allomember 2, which is otherwise terrestrial and devoid of fossils. A nodular to massive silcrete horizon of probable groundwater origin and intraclast breccias within the horizon of probable tectonic origin is present at the top of allomember 3 in this area.

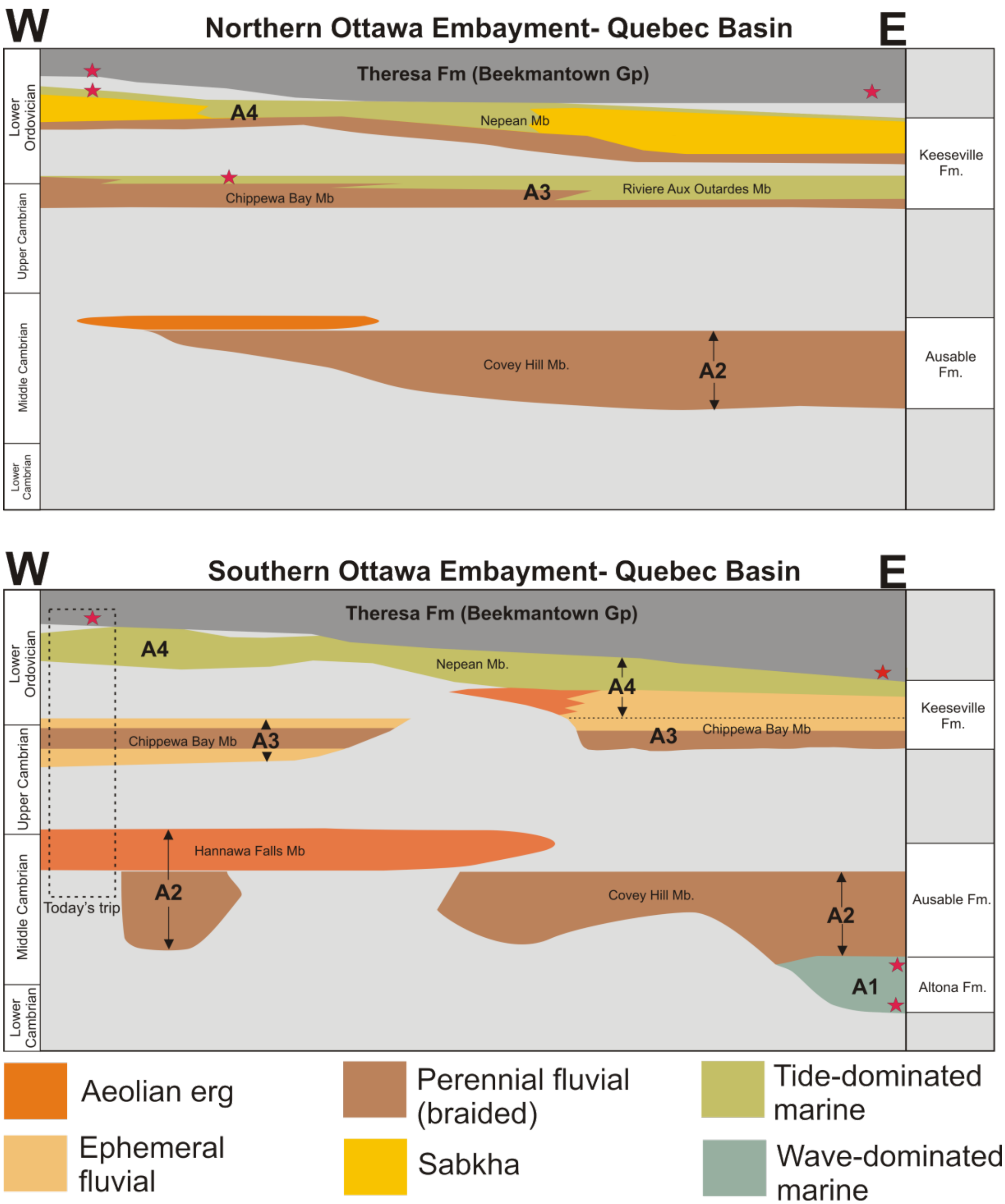

Figure 3. East-west allostratigraphic correlations of the Potsdam Group in the northern and southern Ottawa Embayment-Quebec Basin. Existing biostratigraphic age controls are shown by the red stars. Depositional environments, interpreted from detailed facies analyses, are overlain on the stratigraphy. Four allomembers (A1-A4) are recognized in the Potsdam Group (see text for more detail).

Allomember 4: Nepean Member of Keeseville Formation (proposed): Lower Ordovician: consists of basal terrestrial and overlying marginal marine and tide-dominated shallow marine quartz arenite that forms the uppermost Potsdam. Allomember 3 is locally conformably but abruptly overlain (Wilson, 1946; Brand and Rust, 1977; Selleck, 1993) or unconformably overlain (Salad-Hersi et al., 2002; Dix et al., 2004) by the mixed carbonate and siliciclastic Theresa Formation. Existing and new ages of the basal Theresa Formation indicate that the switch from pure siliciclastic (Potsdam) to mixed siliciclastic-carbonate (Theresa) was diachronous, younging from the southwest to the northeast (Figure 3).

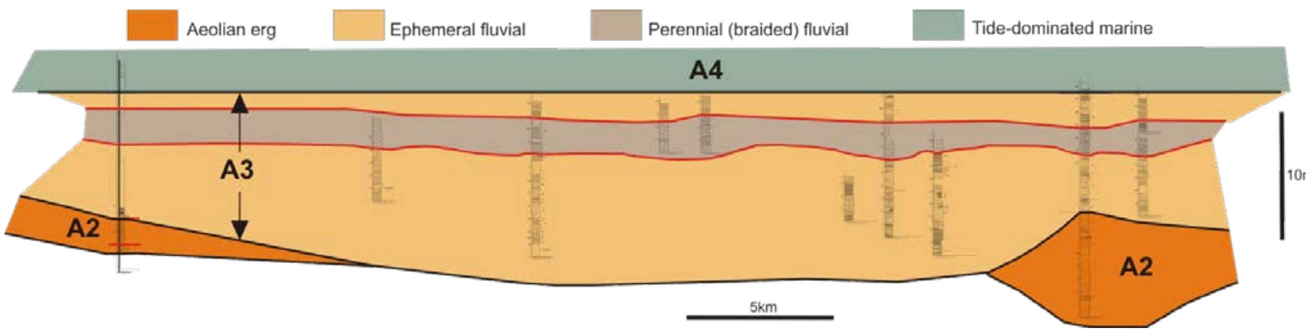

Figure 4. Cross-sectional correlation Potsdam allomembers (A2-A4) and facies associations in the Southwestern Ottawa Embayment (the exact location of this correlation is given in Figure 2). Allomember 3 makes up most of the Potsdam in this area, and is dominated by sheet-like ephemeral fluvial facies.

DEPOSITIONAL FACIES ASSOCIATIONS

Four Depositional facies associations, each recoding deposition by unique depositional environments and depositional processes, are recognised in this part of the Potsdam Group. These include: aeolian erg, ephemeral fluvial, perennial (braded) fluvial and tide-dominated marine (Figure 4). Of these, aeolian erg and tide-dominated marine are well described from previous work in the Potsdam (Bjerstedt and Erickson, 1989; Selleck, 1993; MacNaughton et al., 2002; Hagadorn et al., 2008, 2011), and do not make up a large part of the Potsdam succession in this area, so they are not summarized in detail here. Ephemeral and perennial fluvial deposits make up the bulk of the Potsdam Group in this area (Figure 4) and have not previously been described in detail. Also, these facies associations are present at most of the stops today. The following is a summary of facies analysis and criteria for the recognition of these depositional environments in the Potsdam Group.

Perennial (braided) fluvial facies association: braided fluvial deposits are recognized by a dominance of coarse-grained trough cross-stratified sandstone, locally with tractional conglomerates, as well as the presence of lateral, downstream and upstream accreting architectural elements and channel elements (Figures 5, 9 – 10, 16a), and a lack of trace fossils. The most common elements are lateral, downstream, and upstream accretion elements, interpreted as the products of solitary and compound mid-channel and point bars formed by sequential and gradual accretion during successive channelized flood events in a braided river setting (Figure 5). Internally, these elements are made up of trough cross-stratified coarse-grained sandstone interpreted to have been deposited by the migration of subaqueous dunes. Other common elements include tractional conglomerates and channel elements (Figure 5). Tractional conglomerates are recognized by imbricated, oriented and sometimes graded conglomerate beds, interpreted as a number of gravel bedforms including chutes and lobes, bed load sheets and clusters forming at mid-channel positions at the base of compound bar deposits or near bar tops. Channel elements (Figure 5) vary in size and are filled either with dune cross-stratified sandstone or draping or concordant bedding. The largest of these are interpreted to form at the base of channel by scouring due to the confluence of channels around mid-channel compound bars, while smaller channel elements are interpreted as bar-top channels (Figures 5, 10 and 16b). A hierarchy of bounding surfaces are present, and the highest order surfaces subdivide braided fluvial strata into channel belts successions, which are differentiated by changes in average paleoflow, grain size and sedimentary character. Good examples of this facies association will be shown at Stops 1A and B.

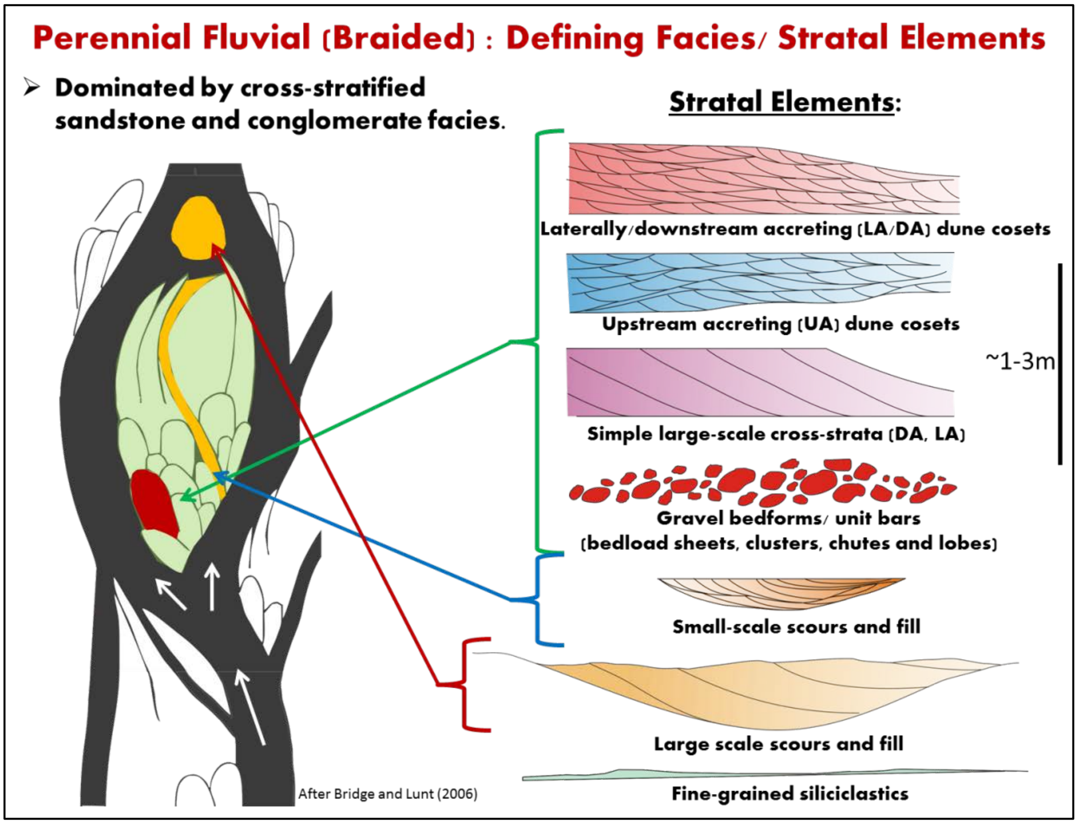

Figure5. Architectural elements and facies typifying braided fluvial systems in the Potsdam Group. The most abundant deposits are of laterally, downstream and upstream accreting dune cross-stratification, formed by the migration and accretion of bars. Channel elements are also recognized. Large Channel elements are interpreted as confluence scours that form in front of large compound bars, and smaller scours are interpreted as bar top channels and their fill.

Ephemeral fluvial facies association: Ephemeral fluvial systems are distinguished from perennial fluvial systems in that they are characterized by a very different set of conditions- specifically, deposition during catastrophic and episodic high discharge events that are prompted by uncharacteristically high precipitation rates in a semi-arid climate. Such discharge overwhelms existing dry channel networks (if present), resulting un-channelized very high energy and shallow sheet flood conditions. Deposits of ephemeral fluvial systems are common in this part of the Potsdam and are interpreted to have formed a north-facing fan system. They are recognized by a predominance of planar stratification formed by upper stage plane bed, with less common but highly diagnostic cross-stratification formed by supercritical bedforms (antidunes, chutes and pools and cyclic steps), and occasional wave and current ripples, erosionally-based subaqueous dune cross-stratified cosets, desiccation cracks, adhesion structures and stratification and minor aeolian strata (Figure 6). Architectural elements are mostly simple and sheet-like (upper flow regime (UFR) bars, Figure 6), and are interpreted to have formed by rapid aggradation during high energy and short-lived sheet floods (perhaps as short as a day, e.g. Stear 1984). Packages bound by high-order bounding surfaces are interpreted as the deposits of depositional lobes in a distributary fan type of system, rather than channel belts as in perennial (braided) fluvial systems (e.g. Hampton and Horton, 2007; Figure 7).

The most diagnostic sedimentary structures are antidunes, chutes and pools and cyclic steps, and are primarily recognized by low- to moderate-angle cross-stratification with dips generally opposing that of associated dune cross-stratification; all of which form under supercritical flows (Froude # >1) with higher velocities and shallower (< 20 cm) depths than the subaqueous dunes that characterize perennial fluvial deposits. Although poorly recognized in the sedimentary record and relatively rare due to rare due to the conditions required for their deposition, their recognition in fluvial outcrops has been highlighted in a review paper by Fielding (2006) and their depositional constraints and mechanisms have been outlined recently by experimental studies by Cartigny et al. (2013).

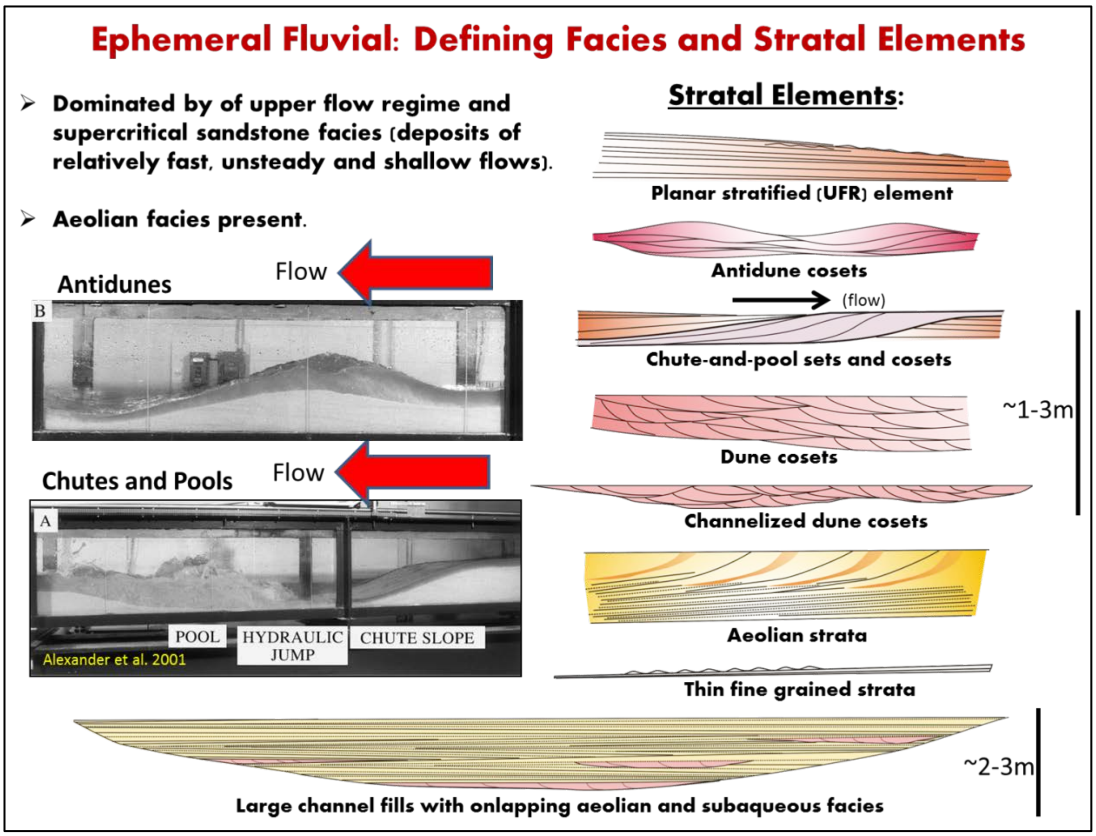

Figure 6. Architectural elements and facies typifying ephemeral fluvial depositional systems in the Potsdam Group. The most common element is low angle to horizontal upper flow regime (UFR) elements, dominated by upper stage plane bed. However, the most diagnostic elements are those formed by supercritical bedforms, typifying very fast and violently energetic relatively shallow sheet flood conditions (antidunes and chutes and pools, but also cyclic steps (see Figure 8)).

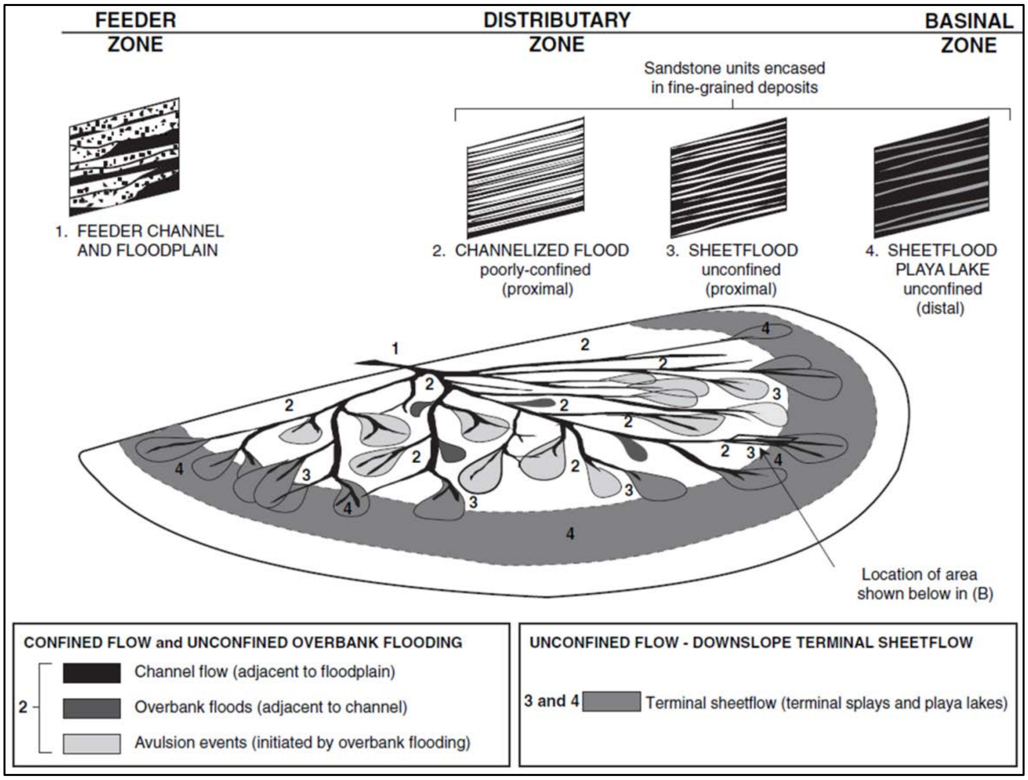

Figure 7. Schematic depositional model of a sheetflood-dominated ephemeral fluvial distributary fan system, from the Eocene-Oligocene Potoco Formation in the Altiplano plateau of Bolivia (from Hampton and Horton, 2007). The sheet-like ephemeral fluvial exposures we will view today are interpreted to have been part of a similar system in a north-facing distributary fan, probably deposited in the unconfined and proximal sheetflood environment (#3).

Antidunes are recognized by thin (2 – 15 cm) lenticular sets of low angle ($\leq 20^{o}$) cross-laminated lower medium to upper coarse grained sandstone bounded by low-angle ($5 – 15^{o}$) concave-upward scours (troughs), with occasional low angle ($10 – 15^{o}$) convex-upwards symmetrical formsets (Figures 8 and 14). These form under shallow supercritical flows (Froude number >1) in which upstream-migrating surface waves are in-phase with the bed (Figure 8). The breaking of surface waves causes the erosion of antidune crests and the deposition of backsets into antidune troughs, which is the most common type of stratification preserved. The preservation of convex-upwards antidune formsets (as at Stop 4) indicates higher rates of aggradation and therefore high sediment concentrations (Cartigny et al., 2013).

Chute and pool stratification is recognized by upstream-dipping scours filled by upstream-dipping sigmoidal cross-stratification (Figures 6, 8, 15b-c, 16b). These are formed
under flows with even higher Froude numbers (and therefore higher velocities and/or shallower depths) than antidunes in which upstream-migrating surges and hydraulic jumps form (turbulent rapid flow expansions from supercritical to subcritical conditions). Low angle backsets at the base characterize the upstream migration of the surge, while overlying, higher angle backsets formed during the development of a stationary hydraulic jump, and relatively planar laminations at the top formed after the hydraulic jump subsided and shallow, supercritical sheet flow conditions resumed (Figure 8). Chutes and pools are not stable bedforms, but instead represent deposits of the transition between more stable antidunes and cyclic steps (Cartigny et al., 2013). Their presence

therefore probably records highly unstable flow conditions, during either the waning or waxing stage of supercritical flows.

Cyclic steps are recognized by thin to thick (15 cm - 1.2 m) low to high angle (10 – 35^o) boundary-conform backsets (Figures 8, 16b and 17a). They form at higher Froude numbers than antidunes and chutes and pools, and under the highest velocities for a given flow depth of any known bedform. Essentially, they are upstream-migrating bedforms in which the lee-side is erosional and the stoss-side is depositional, due to the presence of regularly-spaced hydraulic jumps in their troughs and flow acceleration over their crests (Figure 8).

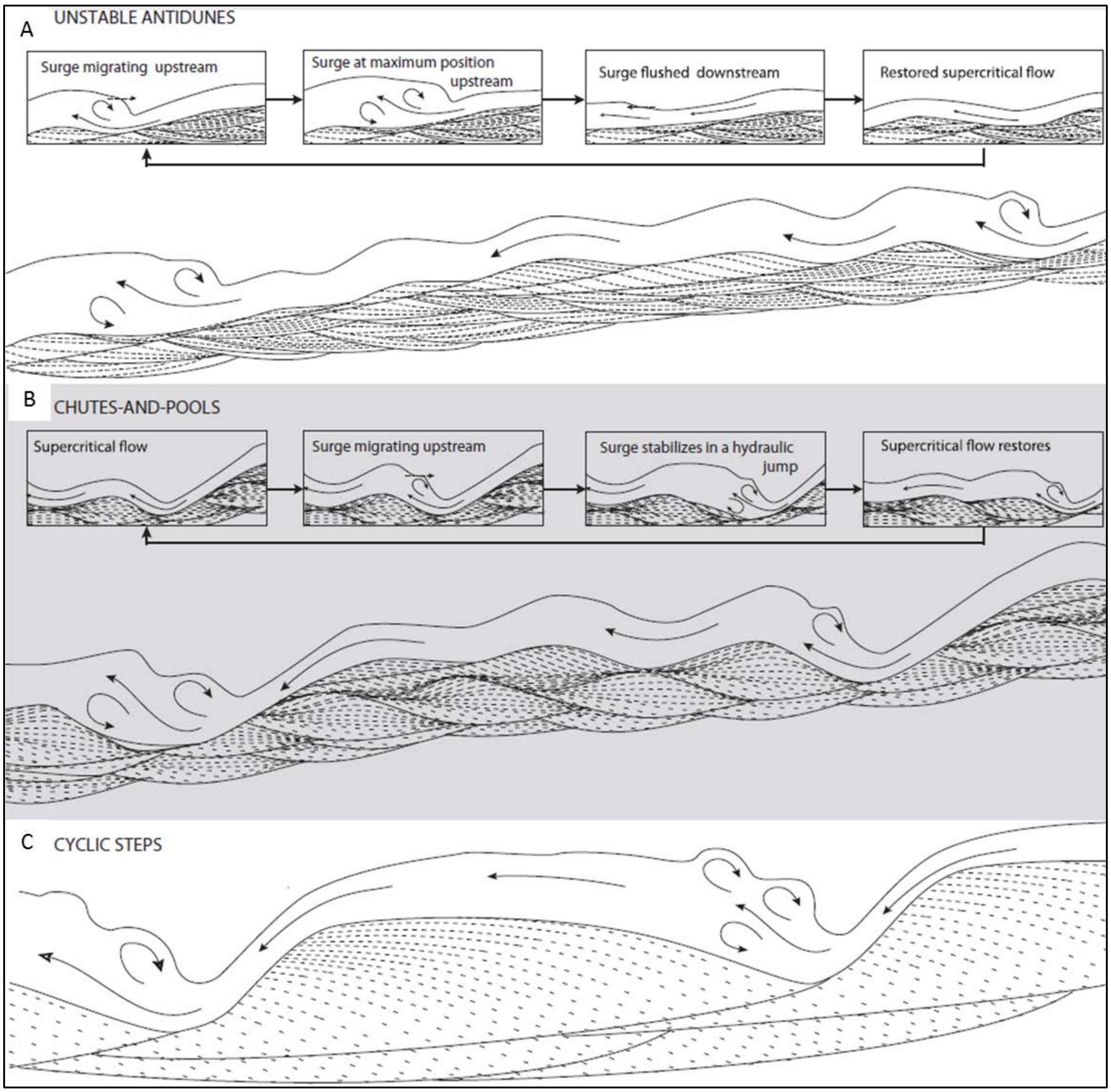

Figure 8. Schematic summary of the depositional processes and products of supercritical flows in which surface waves, surges and hydraulic jumps interact with the bed, from Cartigny et al., 2013. The bedforms resulting from such flows (antidunes, chutes-and-pools, cyclic steps) migrate in the upstream direction and the preserved cross-laminations dip in the opposite direction of the paleoflow direction.

FIELD TRIP STOPS

Stop 1A: Braided fluvial architecture, interactions with active basement topography and an Early Ordovician marine transgression**.** *Wellesley Island Route 191 (44.31640 N; -76.00551 W).* This section consists of perennial fluvial deposits of allomember 3 (Chippewa Bay Mb of the Keesville Fm) overlain by tide-dominated marine strata of Early Ordovician allomember 4 (the Nepean Mb of the Keeseville Fm). This section contains good braided fluvial architectures, interesting stratigraphy and evidence of interaction with the adjacent basement ridge directly to the south (Figure 9).

Perennial fluvial deposits of allomember 3 are present at the base of the outcrop. On the west side of the road, 2 - 3 channel belt successions are present, and are differentiated by abrupt grain size and paleoflow direction changes and by sharp bounding contacts. The lower channel belt (Figure 9A) consists mainly of tractional conglomerate facies and was a ~WNW paleoflow. This is overlain by a sharp contact and a 1 – 1.5 m thick lateral accretion bar deposit at the base of the second channel belt succession (Figure 9A). Boulder debris increases upward and these thin debrites thin to the north. Clasts are presumably derived directly from the ridge to the south (Figure 9B). A laterally-discontinuous boulder debrite characterizes the base of the third channel belt, underlain by a sharp, angular erosional contact (Figure 9C). This “progradation” of boulder debris in the upper part of the second channel belt succession and base of the third is interpreted to represent the presence (possibly active) of the basement ridge directly to the south during deposition of allomember 3 (Figure 9B).

The contact between Allomember 3 and 4 is best viewed some 50 m north, and is present on both sides of the road. Early silcrete nodules of probable groundwater origin are present 1 – 1.5 m from the top of Allomember 3. The base of Allomember 4 is marked by an erosional contact overlain by coarse-tail graded conglomerate. Approximately 1 m above this are gutter casts (visible on the west side of the road) above which fully marine strata onlaps underlying transgressive lag deposits (this onlap is very low angle and is best viewed at the next stop).

Stop 1B: *Wellesley Island, I-81 (44.31725, -76.01024)*: **SAFETY NOTE**: This section gives a broader view of the previous section, and is located only ~200 m to the west. The best view is from the west side of the I-81, looking east across the I-81.

The Allomember 3-4 contact is well displayed here (Figure 10a). The base of Allomember 3 is a north-dipping erosional contact overlain by a ~50 – 75 cm thick conglomerate. The conglomerate is onlapped by tabular-bedded tide-dominated marine strata of Allomember 4. The lower contact and conglomerate are interpreted as a transgressive surface of erosion and transgressive lag, respectively (Figure 10A). Although marine strata appear to onlap the lag deposit here relatively passively, this contact was accompanied by erosional gutter casts at the previous stop, suggesting local erosion by waves and tides.

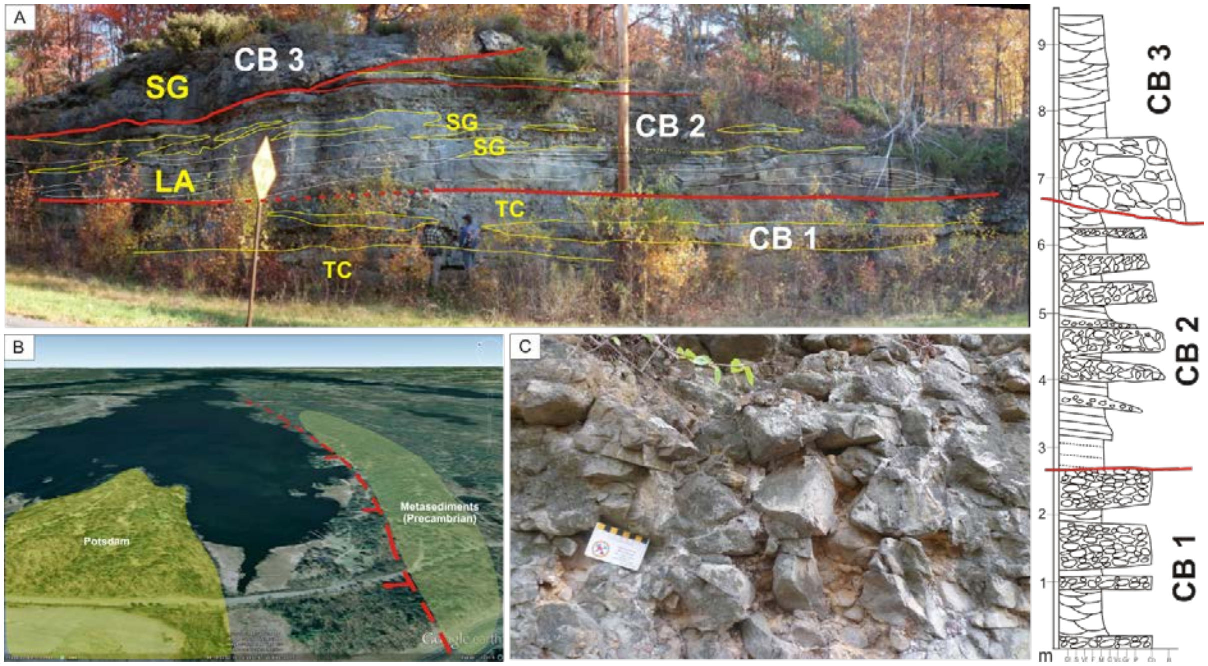

Figure 9. Fluvial architecture and progradation of boulder debris at Stop 1A. A: 3 channel belts are identified here, separated by high order bounding surfaces (CB 1-3). TC= tractional conglomerate, SG= Sediment gravity flow (debrite), LA= lateral accretion element. B: This section is located adjacent to a normal fault and basement ridge. The increasing progradation of debris flow (A and C) indicates that this ridge was present during sedimentation.

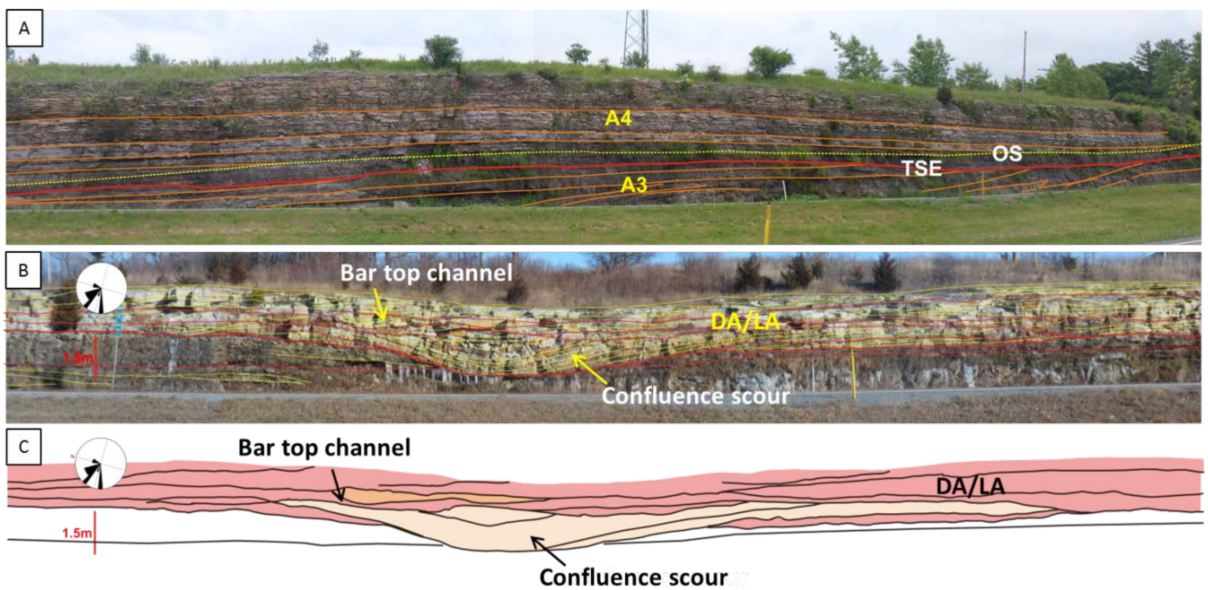

Figure 10. Stop 1B: A: contact between allomembers 3 and 4 (A3, A4). A3 is overlain by a transgressive surface of erosion (TSE) and a conglomerate lag. Marine strata of A4 onlaps the lap (OS= onlap surface). B, C: braided fluvial architectures in A3, exposed farther to the north along I-81. Paleoflow is to the NW.

Some instructive braided fluvial architectures can be seen farther north that demonstrate the initiation of a new channel belt succession and subsequent bar migration (Figure 10b, c). Again, we should be looking east across the I-81. The paleoflow here is to the NW to the N, generally coming out of the outcrop. A broad but very obvious confluence scour marks the base of the second channel belt succession from the previous stop (Figure 10b-c). Low to moderate angle dune cross-stratified laterally to downstream accreting elements (DA/LA on Figure 10b-c), interpreted as the deposits of bars- are built up into a compound bar deposit. A smaller scour element is present near the top of this compound bar succession, and is interpreted as the deposit of a cross-bar channel.

Stop 2: Ephemeral and perennial fluvial contact. *Route 26, south of Alexandria Bay (44.32148, -75.90305):* This stop shows the contact between ephemeral fluvial and perennial fluvial systems in Allomember 3 (Chippewa Bay Mb of the Keeseville Fm). The ephemeral fluvial section is best viewed in the northern part of this section (stop 2A), and the ephemeral –perennial contact is exposed just 100 m to the north (Stop 2B).

Stop 2A: Ephemeral fluvial strata are exposed here, and diagnostic architectural elements include UFR bars and antidune cosets. These architectures are better exposed at later stops (stops 4, 5 and 6).

Stop 2B: The contact between ephemeral and perennial fluvial systems is exposed here, 100 m to the south of 2A along route 26 (Figure 11). The contact is sharp and horizontal (with minor, cm-scale incision). The lower ephemeral fluvial deposits are characterized by their tabular bedding, whereas the overlying perennial fluvial deposits are clearly trough cross-stratified, dominated by dune-cross stratification with mean paleoflow to the north. This contact is correlated elsewhere (Figures 4, 16a and 18c) and is interpreted to record a change in climate from semi-arid to humid.

Figure 11. Ephemeral – perennial fluvial contact exposed at Stop 2B. Minimal incision is present along this contact, in contrast to the same contact exposed at stop 6.

Stop 3: Allomember 2-3 contact: *Near Millsite Lake on Cottage Hill Road, east of Redwood, NY (44.29374, -75.79057).* Precambrian basement as well as Allomembers 2, 3 and 4 are exposed here (Hannawa Falls Mb of the Ausable Fm; and the Chippewa Bay and Nepean Mbs of the Keeseville Fm, respectively). All of these are exposed on the south side of the road, uphill from the Millsite Lake access parking. Grenville basement and the Precambrian unconformity are visible from the road. A ~50 cm regolith is present just above the basement.

Overlying that is a 2 m section of aeolian red beds of the early Late Cambrian Allomember 2 (Hannawa Falls Mb of the Ausable Fm). An excellent exposure of the allomembers 2 – 3 unconformity is exposed on a small ridge just a small way (~10 m) south over the ditch and into the wooded area. The unconformity is erosional and lithified rip-up clasts of allomember 2 are present in the lower few cm of Allomember 3 (Figure 12a-b). Lithification of allomember 3 is characterized by hematite rims and kaolinite cementation (Figure 13), interpreted to have formed pedogenically by the formation of a laterite paleosol. This contact is correlated to others in the Ottawa-Embayment and Quebec Basin, and represents a long period of time (possibly ca. 10 Myr) and significant changes in provenance, depositional setting and paleogeography (from basin –wide correlations, detrital zircon analysis and regional paleoflow analysis).

Allomember 2 (Latest Cambrian – Earliest Ordovician Chippewa Bay Mb of the Keeseville Fm) is relatively thick (~10 m) and consists mainly of ephemeral fluvial facies. Specific architectures and divisions of facies associations into ephemeral and perennial fluvial deposits are not differentiated here due to poor exposure of the section.

Allomember 3 (Early Ordovician Nepean Mb of the Keeseville Fm) is exposed in the upper ~2.5 m of the section (near the top of the hill) and consists of medium-scale tabular dune and ripple cross stratification that is locally bioturbated by a filter-feeding *Skolithos* ichnofacies (including *Skolithos*, *Diplocraterion*, and *Arenicolites*).

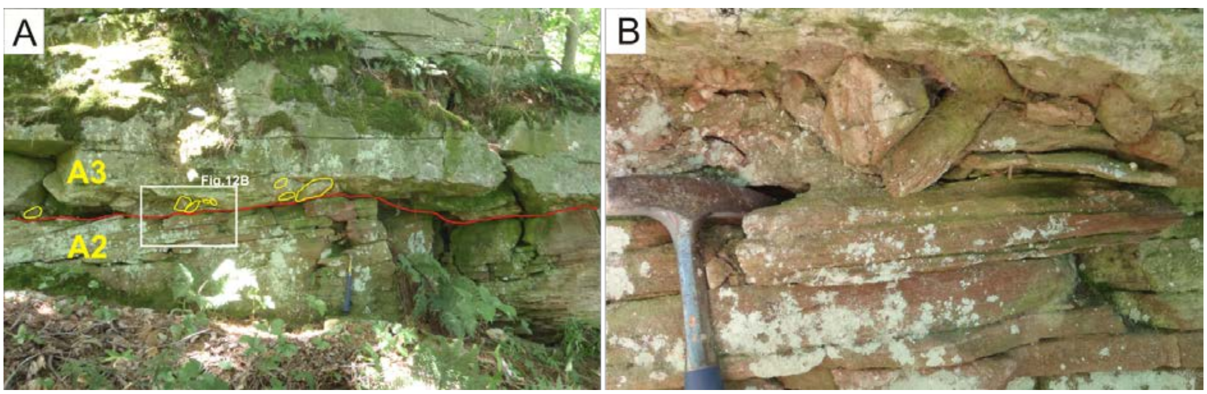

Figure 12. Allomembers 2-3 (A2-A3) contact exposed at Stop 3. A: the contact is sharp and erosional with undulating relief and several cm. A-B: lithified clasts of A2 are present at the base of A3, suggesting that A3 was lithified before deposition of A3. This contact is correlated to outcrops to the south Theresa (~10 km to the south), as far north as Perth, ON (~70 km to the north) and east as Pope Mills (~30 km).

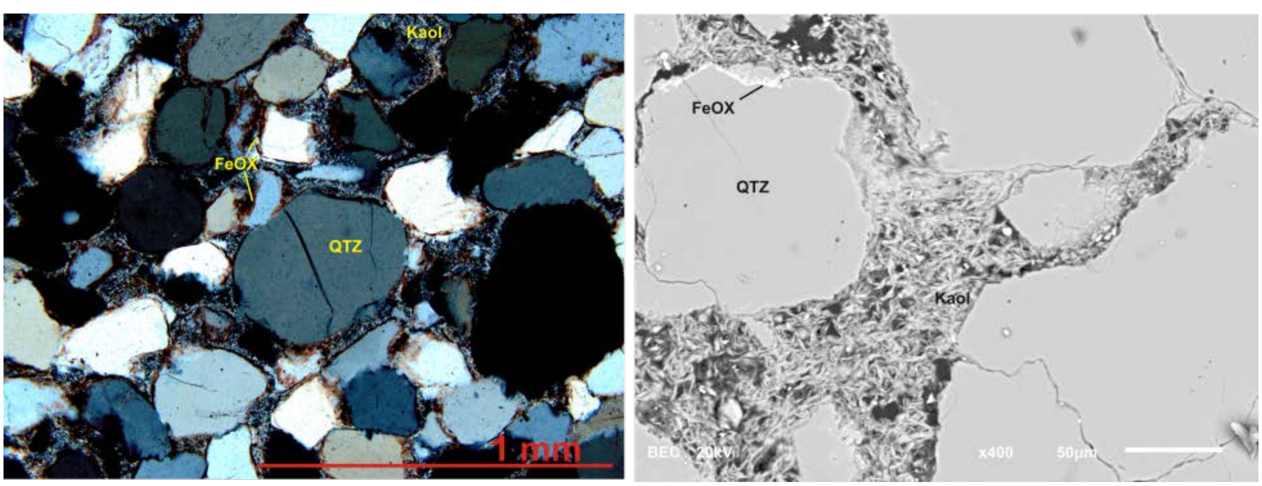

Figure 13. Photomicrograph and backscattered SEM image of A2 at Stop 3. Detrital quartz grains (QTZ) are rimmed by hematite (FeOX) and cemented by pore-filling kaolinite (Kaol).

Stop 4: Antidune cross-stratification: *North ledge outcrop on the north side of Highway 37: between Redwood and Hammond, NY (44.38048, -75.75508).* This is a relatively small outcrop of ephemeral fluvial strata from Allomember 3 (Chippewa Bay Mb of the Keeseville Fm). Here one of the most diagnostic elements indicating sustained deposition by supercritical flows is present: antidune cosets and convex-up formsets (Figure 14). This is interbedded with UFR bar form elements, dominated by upper flow regime plane bed indicative of fast-moving and probably shallow unidirectional flows (Figure 14).

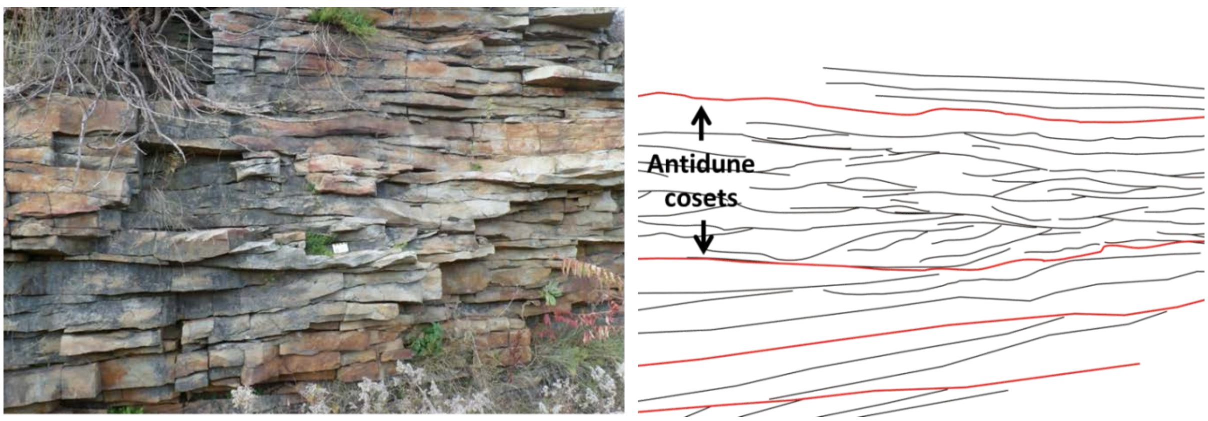

Figure 14. Antidune cross-stratification exposed at Stop 4. The small card is 10 cm across.

Stop 5: Aeolian and chute-and-pool stratification in an ephemeral fluvial setting: *North and south of Highway 37, between Redwood and Hammond, NY (44.38696, -75.74568).* This is another exposure of Allomember 3 (Chippewa Bay Mb of the Keeseville Fm) that highlights some aeolian and upper flow regime facies of the ephemeral fluvial facies association. On the north side of the road is a small outcrop that contains the remains of an aeolian dune, complete with lee-side grain flow deposits and "pinstripe" wind ripple stratification (Figure 15a). On the south side of the road is a natural pavement, with rib-and furrow structures formed by the intersection of 3D dune cross-strata, showing a paleoflow of 355^{o} (~N). Past this and down a steep slope of rubble (beware of broken glass here! – proceed with caution) is an outcrop exposing the same interval as at the last stop. This outcrop exposes some of the best examples of up-flow dipping chute and pool and cyclic step stratification (Figure 15b-c) recoding the deposition from extremely fast-moving highly-concentrated supercritical flows.

Stop 6: Perennial-Ephemeral fluvial contact (again!) and cyclic steps: *North and south of Highway 37 and on Cemetery Road, near Hammond (44.40248692, -75.72873119).* This is another exposure of the ephemeral – perennial fluvial contact within allomember 3 (Chippewa Bay Mb of the Keeseville Mb) and one that also showcases some thick cyclic step supercritical bedform stratification. On the north and south of Highway 37, the ephemeral fluvial deposits with moderate angle upper flow regime macroforms are incised by dune cross-stratified channel elements of perennial fluvial deposits (Figure 16a). On the east branch of Cemetery Road, south of Highway 37, a ~N-S oriented section reveals the "macroforms" actually consist of thick, up flow-dipping cyclic step stratification (Figure 16b). Incredibly, cross-stratification formed by dunes is preserved on the stoss-side of cyclic steps, climbing and dipping in the opposite direction of the upflow-dipping chute and pool backsets (Figure 16b). On the south part of this exposure, antidune cross-stratification and formsets are present (Figure 16b).

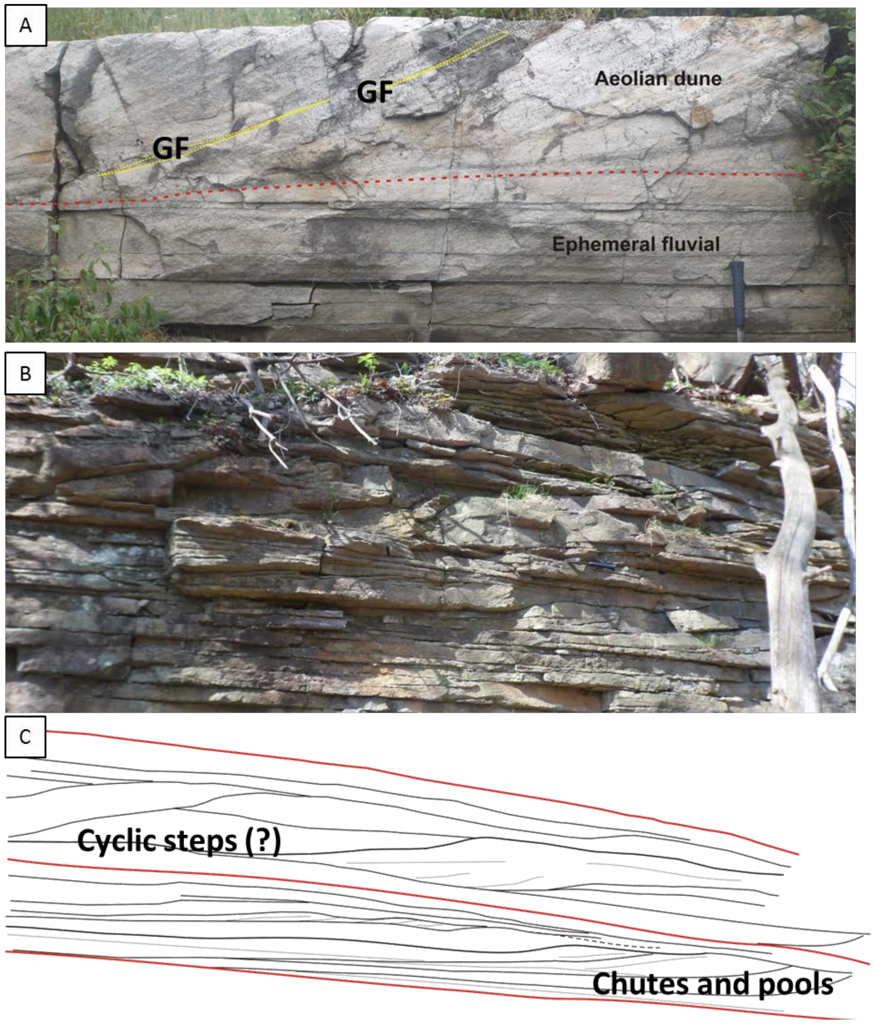

Figure 15. Stop 5: A: aeolian dune cross-stratification is exposed on a small outcrop on the north side of the road. B, C: in the wooded area south of Route 37 is a ledge that exposes some upstream-dipping cyclic step and chute-and-pool cross-stratification. This exposure is at roughly the same stratigraphic position as the antidunes exposed at Stop 4. Fig 15C is a traced sketch of Fig 15B.

Stop 7: Potsdam-Theresa contact: *Highway 12, just north of Pleasant Valley Road (44.46609, -75.76102).* This is a classic stop, showing the Potsdam—Theresa contact. The uppermost Potsdam is the typical tide-dominated marine facies association characterizing Allomember 4 in the area. The contact at this location is interpreted as a probable conformable but drastic facies change, into deeper water, storm- and tide- dominated shelf setting. The Theresa here is largely characterized by dolomite cemented fine- to medium-grained sandstone (locally coarse) with normally-graded beds, 2 -15 cm thick, consisting of sharp to diffuse upper plane bed laminations overlain by wave and/or combined flow ripples and bioturbated fine argillaceous sandstone. These beds are interpreted as tempestites (e.g. Selleck, 1993). Hummocky cross-stratification (HCS) in the Theresa is probably largely inhibited due to a relatively strong unidirectional flow component caused by reinforcing ebb tides. Experiential work has shown that only small unidirectional velocities mixed with strong oscillatory wave-generated currents are needed to inhibit HCS (Dumas et al., 2005).

Stop 8: Marine flooding and a groundwater silcrete linked to the Black Lake Fault. *Highway 12 near Chippewa Bay (44.44787, -75.74829).* This stop consists of two small outcrops on either side of Highway 12. These outcrops show the contact between Allomembers 3 and 4, characterized here by a sharp erosional discontinuity and a flooding surface separating ephemeral fluvial strata below from marine strata above. A massive silcrete horizon is present here at the very top of allomember 3, with conical intraclast breccias, originally described by Selleck (1978). A recent honours study focusing the genesis of this silcrete was undertaken by Ed DeSantis at the University of Ottawa. Ed's findings were that: (a) the silcrete is of groundwater origin, rather than pedogentic origin due to the preservation of primary sedimentary structures, occurrence of nodules and lack illuviation features; (b) multiple generations of silica overgrowths are present, indicating multiple precipitation-dissolution events; (c) the silica was likely derived from feldspars in basement rocks, given that the underlying Potsdam contains no evidence of feldspar dissolution; and (d) movement of fluids along, and movement of the Black Lake fault itself contributed silica and also stresses that generated the conical breccias in these relatively well-indurated horizons. The close spatial relationship between the distribution of the pervasive silica horizon, the conical breccias and the Black Lake fault provide good evidence for this relationship (DeSantis, 2014). The stratigraphic location of the silcrete (at the top of allomember 3) although suggestive of a pedogentic origin, is interpreted to have resulted from transgressive erosion down to the well-indurated and erosionally-resistant horizon.

Stop 9: Stratigraphy, sedimentology and diagenesis- this stop has it all! *Highway 12 just south of Schermerhorn Landing (44.41019, -75.78736).* Allomembers 2, 3 and 4 are all exposed in this section. Allomember 2 is present at the westernmost part of this exposure, where it is at least ~8 m in thickness (the base is not exposed, Figure 4), which contrasts with the thin preservation of this unit at Stop 3 and lack of preservation elsewhere, and attests to the variable preservation of allomember 2 in this area. Here it consists of large-scale cross-stratification formed by the migration of aeolian dunes. Inversely graded grain flow avalanche cross-strata are present, and can be found on the south side of the highway. Allomember 2 also has a blocky structural fabric, which appears to be truncated by the allomember 2-3 contact (Figure 17A).

Allomember 2 (~10 m thick) consists of planar-tabular stratified ephemeral fluvial deposits, with a few ~west dipping cyclic step deposits towards the top of the unit, and some ~NE-dipping subaqueous dune cosets as well as aeolian sand sheet deposits. The massive silcrete at the top of allomember 3 is well-developed here. It is coincident with bedding in the western part of the exposure, but towards the east it cuts across the bedding at a low angle, dipping east (Figure 17B). Minor conical autoclastic breccias are present here within the silcrete, and appear to be spatially associated with vertical fractures in the underlying sandstone.

At the very easternmost part of this outcrop and on the south side of the road, the eastward-dipping silcrete horizon is onlapped by marine strata of allomember 4 (Figure 17B). Elsewhere, allomember 4 has been eroded, which shows that the silcrete horizon is currently more resistant to erosion as it probably was in the Latest Cambrian- Earliest Ordovician.

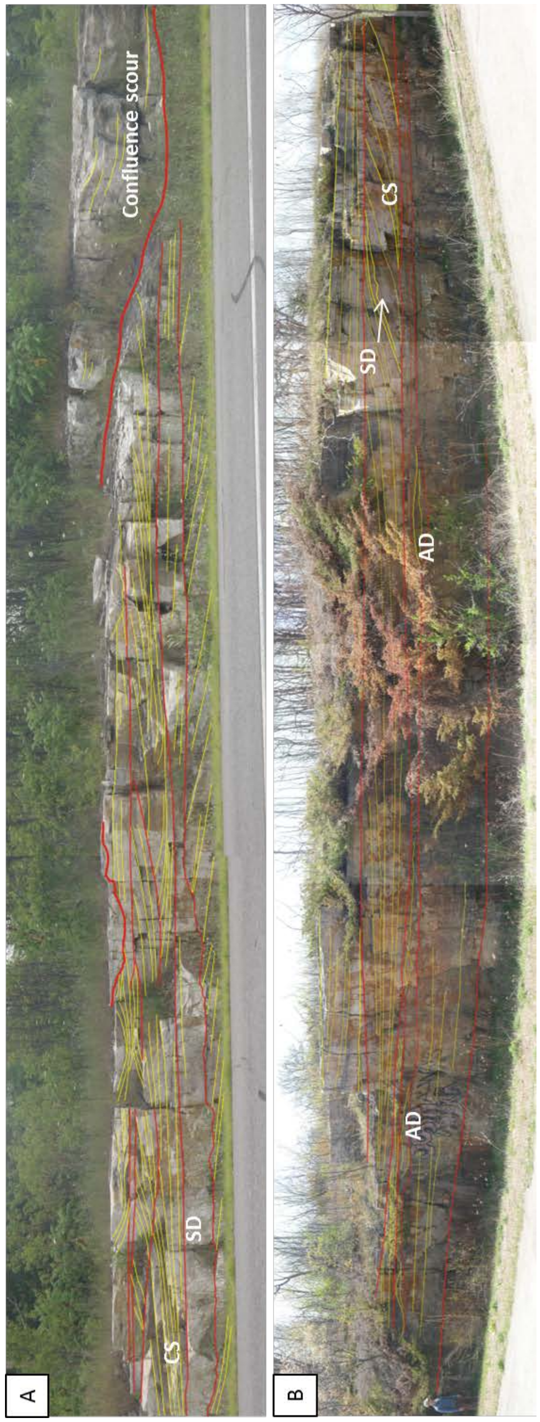

Figure 16: Ephemeral and perennial fluvial architectures and facies preserved at Stop 6. A: outcrop on the south side of Route 37 showing high and low angle upper flow regime elements such as cyclic steps (CS) and channelized subaqueous dune cross-stratification (SD). Overlying braided fluvial deposits deeply incise the ephemeral deposits to the west, where they form a confluence scour. B: Same outcrop viewed from Cemetery road. Cyclic steps (CS) are present at the northern part of the section and are draped by subaqueous dune cross-strata (SD) and sheet-like upper flow regime elements. Antidunes (AD) occur in an underlying bed.

Stop 10: Cyclic steps and the ephemeral-perennial fluvial contact. *Highway 12, south of Goose Bay (44.35967, -75.85242).* This outcrop exposes a thick (~12 m) section of allomember 3, including a lower section of ephemeral fluvial strata dominated by upper plane bed stratification, with some ~SW dipping cyclic steps and chute and pool stratification, and an upper perennial fluvial section dominated by ~N – NE dipping dune and current ripple cross-stratification with an overall "sheet-like" architecture. Thick (up to 1 m) sets of SW-dipping cyclic step cross-stratified sandstone are exposed at the western part of the outcrop on the south side of the road (Figure 18A). Farther to the east, where the outcrop thins on the south side of the road, low angle and sigmoidal cross-stratification is present, interpreted to have formed by chutes and pools (Figure 18B). Moving east again, the outcrop thickens and exposes a sharp contact between the ephemeral and perennial fluvial deposits (Figure 18C). The large-scale cross-stratification beneath the contact was originally assumed to be from an aeolian dune; however, it lacks the characteristic inversely graded grain flow strata and it shallows to the west, grading into upper flow regime facies. Possible interpretations for this feature include: (a) a large cyclic step deposit, (b) an asymmetric or oblique channel element filled with upper plane bed strata, or (c) it is in fact an aeolian dune that has been onlapped by upper flow regime strata. The contact between the ephemeral and perennial deposits is sharp, but without significant incision. The "sheet-like" nature of the perennial fluvial deposits is interpreted to record deposition and accretion in very wide and shallow channels.

Figure 17: Stop 9: A: Allomember 2-3 (A2-A3) contact. There is a small amount of erosion on this contact, and near-vertical joint fabric is truncated. It is correlated to the A2-A3 unconformity present at Stop 3 and elsewhere (see caption of Figure 12). B: The A3-A4 contact is visible farther east, viewed from the south side of Route 12. The silcrete horizon at the top of A3 dips to the east and is onlapped by marine strata of A4.

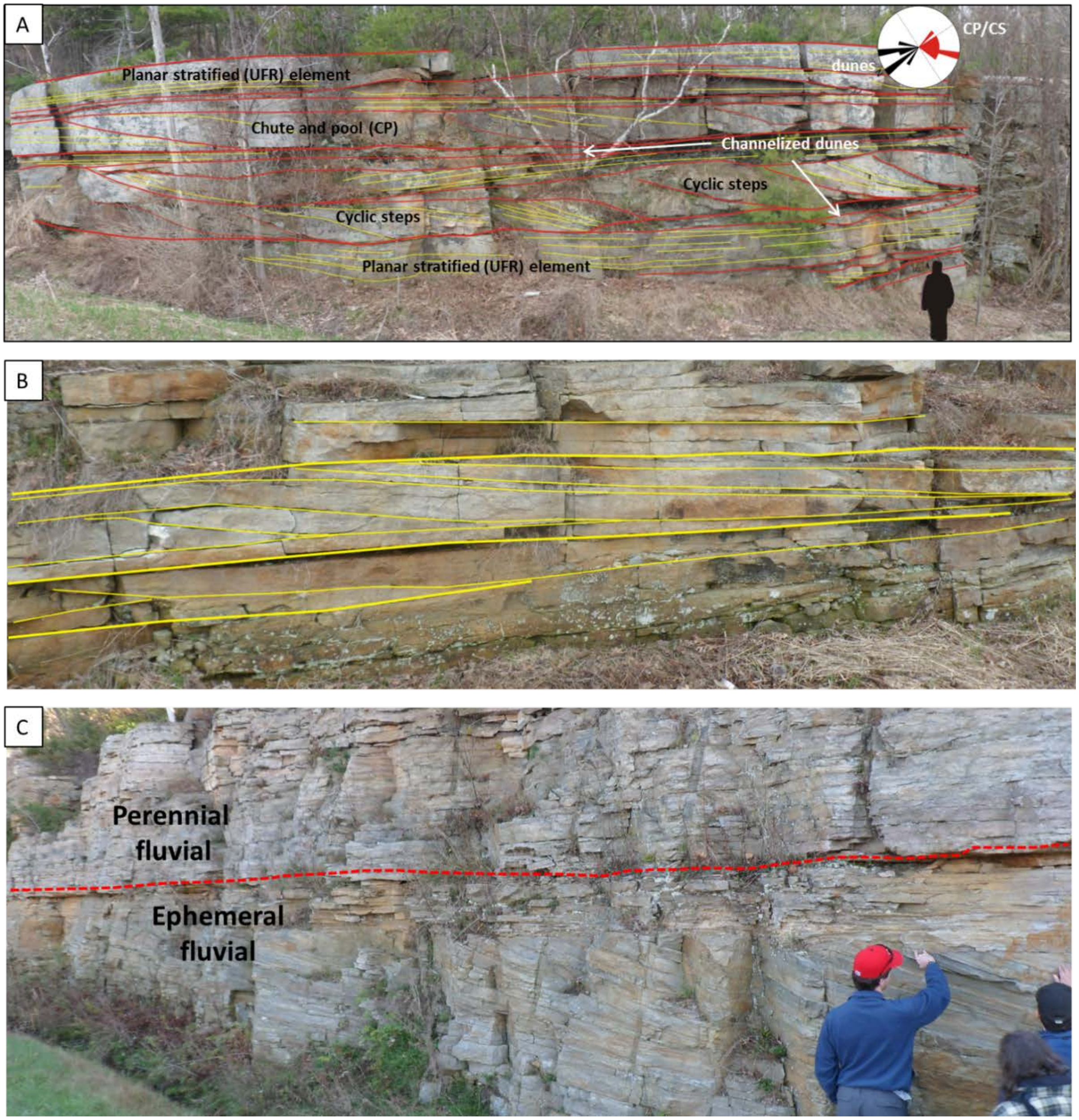

Figure 18: Sedimentary structures and stratigraphy at Stop 10. A: looking south, the westernmost part of this outcrop exposes stacked deposits of ephemeral fluvial origin. Upstream-dipping cyclic step stratification is relatively well-developed here, interbedded with upper flow regime elements and channelized subaqueous dunes. B: farther east is a sigmoidal-cross-stratified feature interpreted as the deposit of a chute-and-pool. C: The ephemeral – perennial fluvial contact of A3 is prominent farther east, defined by a change from upper flow regime- to subaqueous-dune dominated deposition. The origin of the inclined cross-strata at the top of the ephemeral fluvial package is up for debate (see related text).

Stop 11: The Great unconformity and ephemeral fluvial architecture. *Highway 12, east of Alexandria Bay (44.34598, -75.87674).* This is another "classic" Potsdam outcrop, exposing the basal unconformity with Precambrian basement rocks. At this location, all of the Potsdam strata unconformably overlying the Precambrian is correlated to allomember 3, and interpreted as ephemeral fluvial in origin. Allomember 3 appears to onlap a basement knoll at the easternmost part of the outcrop; however, some structural tilting of the lower ~4-6 m of allomember 3 is also vaguely evident above the basement feature. The architecture is sheet-like and dominated by planar laminations with occasional isolated west-dipping cross-beds and scour fills. Sheet-like packages generally 1.5 – 2 m thick are interpreted as discrete deposits of depositional lobes in an ephemeral fluvial setting. The best way to explore this outcrop is to walk from the west to the east, essentially moving up section. Many subtle features can be observed moving up-section; including aeolian wind ripple stratification and lags, isolated aeolian dune cross-stratification, upper flow regime plane bed, minor scour fills, possible cyclic steps and chutes and pools, ripples and adhesion structures and stratification. Near the top of the section is the contact between ephemeral and perennial fluvial facies associations.

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