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**Lithostratigraphic and allostratigraphic framework of the Cambrian-
Ordovician Potsdam Group and correlations across Early Paleozoic southern
Laurentia**

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Abstract

The Potsdam Group is a Cambrian to Lower Ordovician siliciclastic unit that crops out along the southeastern margins of the Ottawa graben. From its base upward the Potsdam consists of the Ausable, Hannawa Falls and Keeseville formations. In addition, the Potsdam is subdivided into three allounits: Allounit 1 comprises the Ausable and Hannawa Falls, and allounits 2 and 3, respectively, the lower and upper parts of the Keeseville. Allounit 1 records Early to Middle Cambrian syn-rift arkosic fluvial sedimentation (Ausable Formation) with interfingering mudstone, arkose and dolostone of the marine Altona Member recording transgression of the easternmost part of the Ottawa graben. Rift sedimentation was followed by a middle Cambrian climate change resulting in local quartzose aeolian sedimentation (Hannawa Falls Formation). Allounit 1 sedimentation termination coincided with latest(?) Middle Cambrian tectonic reactivation of parts of the Ottawa graben. Allounit 2 (lower Keeseville) records mainly Upper Cambrian quartzose fluvial sedimentation, with transgression of the northern Ottawa graben resulting in deposition of mixed carbonate-siliciclastic strata of the marine Riviere Aux Outardes Member. Sedimentation was then terminated by an earliest Ordovician regression and unconformity development. Allounit 3 (upper Keeseville) records diachronous transgression across the Ottawa graben that by the Arenigian culminated in mixed carbonate-siliciclastic, shallow marine sedimentation (Theresa Formation). The contact separating the Potsdam Group and Theresa Formation is conformable, except locally in parts of the northern Ottawa graben where the presence of localized islands and/or coastal salients resulted in subaerial exposure and erosion of the uppermost Potsdam strata, and accordingly unconformity development.

Keywords: Potsdam Group, Ottawa graben, Stratigraphy, Laurentia, Early Paleozoic.

Introduction

In east-central North America siliciclastic sedimentary rocks of the Cambro-Ordovician Potsdam Group unconformably overlie rocks of the 1 – 1.5 Ga Grenville Orogen and crop out locally along the margins of the fault-bounded Ottawa Embayment and Quebec Basin at the southeastern end of the Ottawa graben and in the adjacent St. Lawrence lowlands (Fig. 1). The Potsdam Group is one of the oldest named rock units in North America (Emmons, 1838) and for almost 200 years has been studied locally in New York State, Ontario and Quebec (Logan, 1863; Alling, 1919; Chadwick, 1920; Wilson, 1946; Clark, 1966; 1972; Otvos, 1966; Fisher, 1968; Greggs and Bond, 1971, 1972; Brand and Rust, 1977; Selleck 1978a & b; Wolf and Dalrymple, 1984; Globensky, 1987; Salad Hersi et al. 2002a; Dix et al. 2004; Landing et al. 2009; Sanford, 2007; see also Sanford and Arnott, 2010 for summary of past work). Nevertheless, there is still little consistency or consensus regarding the lithological correlations, depositional environments or stratigraphic nomenclature of the Potsdam in the Ottawa Embayment – Quebec Basin due to the fact that few studies extend beyond provincial or international borders (however, see Sanford 2007; Sanford and Arnott, 2010). Furthermore, complex isopach and lithofacies distributions and the general lack of age-diagnostic fossils, ash beds or easily correlated stratal surfaces in a compositionally monotonous, mostly continental siliciclastic succession have confounded depositional age determinations and stratigraphic correlations. Disentangling the existing inconsistencies and complexities of Potsdam Group stratigraphy and lithofacies remains important for gaining a better understanding of the Early Paleozoic history of North America and also for providing context to studies of the paleoecology of Early Paleozoic microbial and metazoan life (Clark and Usher, 1948; Bjerstedt and Erickson 1989; MacNaughton et al. 2002;

Hagadorn and Belt 2008; Collette and Hagadorn 2010; Hagadorn et al. 2011). Furthermore, regional correlations between the Potsdam Group and Lower Palaeozoic strata across eastern North America are uncertain, but are needed to better constrain the eustatic fluctuations, climate change events and tectonic events that affected Early Paleozoic Laurentia (e.g. Lavoie, 2008; Landing et al., 2003, 2009; Salad Hersi and Dix, 2006; Cherns et al., 2013; Lowe and Arnott, 2016).

The purpose of this paper, therefore, is to evaluate previous depositional and stratigraphic frameworks and to clarify details of the Potsdam stratal succession. We do so by independently undertaking systematic and detailed lithofacies analysis and litho- and allostratigraphic correlations of the Potsdam Group based on study of 296 outcrop locations¹ and 12 fully-cored wellbores (Table 1). Furthermore, we provide new age control using conodont biostratigraphy to better constrain stratigraphic correlations. Finally, we consider regional correlations with coeval strata in northeastern North America in order to disentangle the eustatic, climatic and tectonic controls on sedimentation of the Potsdam Group and on the Early Paleozoic paleo-southern Laurentian margin and craton.

Paleogeographic and tectonic setting

The Ottawa Embayment and Quebec Basin are semi-connected basins filled by Lower Paleozoic strata and located at the southeastern end of a rift structure termed the Ottawa graben (a.k.a., the Ottawa-Bonnechere graben; Kay, 1942; Fig. 2). The Ottawa graben originated in the Latest Neoproterozoic (ca. 590 Ma) during rifting and breakup of the supercontinent Rodinia

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¹ See supplementary data file 1

(Kumerapeli, 1985, 1993; Kamo et al., 1995; Allen et al., 2010; Burton and Southworth, 2010; Bleeker et al., 2011). During the Cambrian and Early Ordovician Potsdam sedimentation occurred in and along the margins of the eastern (paleo-southern) part of this pre-existing rift, which at that time was located at ca. 10° – 30° south latitude and ca. 200 – 400 km inboard of the Quebec Re-entrant portion of the south-facing passive Laurentian margin (Torsvik et al. 1996; Landing, 2007; Landing et al., 2009; McCausland et al. 2007, 2011; Lavoie, 2008; Allen et al., 2009; Fig. 2). Numerous authors, including Lewis (1971), Salad Hersi and Dix (2006), Landing et al. (2009) and Sanford and Arnott (2010), suggest that intra-plate tectonism played an active role in Potsdam sedimentation, however the connection between tectonic reactivation of the Ottawa graben and Potsdam sedimentation, if true, remains poorly resolved. Furthermore, Potsdam sedimentation was coeval with siliciclastic and carbonate sedimentation across the passive Laurentian shelf and slope (Lavoie et al., 2003; Landing, 2007; Lavoie, 2008), all of which was influenced by a high-order sea level rise across Laurentia that began in the Early Cambrian and eventually covered the Laurentian margin and craton with a shallow epeiric sea by the end of the Early Ordovician. This transgressive event is termed the cratonic Sauk Megasequence, which in turn is divided into smaller divisions representing lower order transgressive-regressive cycles (Sauk I, II and III, among others; Sloss, 1963; James et al., 1987).

Depositional environments

In this study, detailed facies analysis recognizes six terrestrial to shallow marine environments, which are: braided fluvial (FA1), ephemeral fluvial (FA2), aeolian erg (FA3), coastal sabkha (FA4), tidal marine (FA5) and open-coast tidal flat (FA6). These are summarized

in Table 2 and their distribution within the Potsdam sedimentary pile is given in the next section and in Figures 3 and 4. For more detail regarding these facies associations see Lowe (2016) and Lowe and Arnott (2016).

Lithostratigraphy of the Potsdam Group

The Potsdam Group encompasses siliciclastic and rare carbonate strata that unconformably overlie metamorphic and igneous rocks of the Proterozoic Grenville zone and underlie mixed carbonate and siliciclastic strata of the Theresa Formation. The Potsdam Group has a highly uneven isopach, which in large part reflects changes across intrabasinal faults (Figs. 1, 4; Sanford, 2007; Sanford and Arnott, 2010). Accordingly, it is thickest in the southwestern Ottawa Embayment and southern Quebec Basin where it reaches a maximum thickness of at least 630 m thick (Figs. 1, 4), but then thins continuously to the northwest and abruptly to the west across a series of faults to only ~10 – 40 m thick throughout the western Ottawa Embayment.

In this work the Potsdam comprises three formations, which stratigraphically upward are: Ausable, Hannawa Falls and Keeseville (Fig. 3, Table 3). It has long been understood that units of the Potsdam Group in Canada (Covey Hill, Nepean and Cairnside formations) are equivalent to the units in New York State (e.g. Wilson, 1946; Kirwan, 1963; Otvos, 1966; Lewis, 1971; Brand and Rust, 1977; Bjerstedt and Erickson, 1989; Salad Hersi et al., 2002a; Dix et al., 2004; Sanford, 2007; Landing et al., 2009; Sanford and Arnott, 2010; Hagadorn et al., 2011; Lowe and Arnott, 2016), and this work supports that. Therefore, the names of units from Canada are here abandoned and replaced everywhere by the names of equivalent units in New York State, which

significantly predate the Canadian formation names (originally from Emmons (1841) and Alling (1919)). This abandonment is in accordance with the North American Stratigraphic Code (Article 7(e) from NACSN, 2005) and is intended to mitigate uncertainty regarding unit equivalence across borders. Besides this, the main changes made here from the lithostratigraphic frameworks of Landing et al. (2009), Salad Hersi et al. (2002a) and Sanford and Arnott (2010) are:

- a. modification of the rank of the Altona Formation to Altona Member, due to its intertonguing relationship with the Ausable Formation;
- b. use of feldspar as a diagnostic criterion for the Ausable Formation (e.g. Lewis, 1971; Landing et al., 2009), and documentation of the contacts between the arkosic Ausable and overlying quartz arenitic Hannawa Falls and Keeseville Formations;
- c. elevation of the Hannawa Falls from member to formation status;
- d. reassignment of mainly quartz arenite strata, previously correlated to the upper Covey Hill or Ausable formations, to the lower Keeseville Formation, including strata of the Chippewa Bay, Edwardsville and Riviere Aux Outardes members;
- e. abandonment of the Chippewa Bay and Edwardsville members, and;
- f. recognition that the Keeseville Formation is separated by an unconformity into two units over much of the study area, here informally termed the lower Keeseville Formation and upper Keeseville Formation,

The existing age diagnostic fossil data, including new fossil ages presented here, suggest that the Potsdam Group ranges in age from late Early Cambrian to Early Ordovician (Fig. 3).

Descriptions and interpretations of taxa used for age determinations are provided in appendices A and B.

Ausable Formation

The Ausable Formation comprises mostly grey to red, coarse- to very coarse-grained and pebbly cross-stratified braided fluvial arkose, and pebble to cobble conglomerate with arkose matrix, with rare boulder – cobble colluvium and thin (≤ 7 cm) muddy fine-grained sandstone and siltstone layers (Fig. 5; Lowe and Arnott, 2016). It includes strata formerly assigned to the Ausable Member in New York (Alling, 1919; Fisher 1968; and revised by Sanford and Arnott, 2010), the Nicholville and Allens Falls Conglomerate in northeastern New York (Chadwick, 1920; Reed, 1934; Postel et al., 1959; Fisher, 1968), and the arkosic parts of the Covey Hill Formation in Quebec and Ontario (Clark, 1966, 1972; Sanford and Arnott, 2010). The Ausable Formation covers an expansive area of the Ottawa Embayment and Quebec Basin ($\sim 15,000 - 16,000$ km²) and exhibits a highly uneven isopach and distribution closely tied to regional faults (Fig. 4), occurring mainly in fault-bounded grabens in the northern and eastern parts of the Ottawa Embayment and western Quebec Basin (i.e. on the hanging wall sides of the Gloucester, Russell-Rigaud, Ste. Justine and Chateauguay faults, Figs. 1, 4). Strata are thickest (≥ 450 m) immediately south of the Ste. Justine fault, approximately ~ 40 km southwest of the island of Montreal, and remain thick (typically $\sim 300 - 400$ m thick) south- and northwards along the western Quebec Basin and axis of the Oka-Beauharnois Arch. In the northern Ottawa Embayment, Ausable strata thin continuously eastward to ~ 8 m in the hanging wall trough of the Gloucester Fault (Figs. 1, 4). In the southwest Ottawa Embayment, the Ausable is generally

absent except for isolated, ~0.5 – 25 m thick accumulations along the northern Adirondacks and locally adjacent to faults in the Frontenac Arch. Based on biostratigraphic control from strata in the intertonguing Altona Member near its base in the southern Quebec Basin (Landing et al., 2009; summarized below), and also in the overlying Keeseville Formation (Walcott, 1891; Fisher, 1955; Flower, 1964), a late Early to Middle Cambrian depositional age is proposed for the Ausable Formation. Multiple possible stratotypes exist for the Ausable Formation, and are summarized in Table 3. The section exposed on Ile Perrot in Quebec (outcrop location 194 in supplementary data file 1), consisting of ~15 m of mainly coarse-grained, cross-stratified arkose (e.g. Fig 5), is not the thickest or most extensive exposure of the Ausable Formation, but nonetheless is the most readily accessible section and is representative of Ausable lithology and facies. Therefore this is the type section for the Ausable Formation proposed here.

Altona Member

The Altona Member (revised from the Altona Formation of Landing et al., 2009) is an intertonguing unit near the base of the Ausable Formation in the eastern Ottawa Embayment and western Quebec Basin, consisting mostly of red to light grey arkose, mudstone, siltstone and rare carbonate interbeds deposited on an open-coast tidal flat (Tables 2, 3; Figs. 1, 3, 4, 6, 7, 8; Lowe, 2016). Correlation of Altona strata from its type locality near West Chazy NY~60 km to the north near Laval, QC (Quonto-International St. Vincent De Paul No. 1) reveals that the Altona is a northward-thinning (~80.5 – 20 m) and eastward-pinching tongue of coastal marine strata underlain, overlain and intercalated with coarse-grained fluvial arkose of the Ausable Formation (Fig. 6) – it is these stratal relationships that form the primary justification for modifying its

status to member of the Ausable Formation (Article 25(b) from NACSN, 2005). The depositional age of the Altona is constrained by trilobite occurrences in the southern Quebec Basin, where the Altona is exposed on a number of fault blocks along the northeastern margin of the Adirondack Dome (Landing et al., 2009).

The base of the Altona Member, although not exposed in outcrop, is captured in the Quonto-International core where it is marked by the first occurrence of FA3 mudstone and siltstone above coarse-grained, cross-stratified braided fluvial arkose (Fig. 7a). The lower ~11 m of the Altona succession in the Quonto-International core is dominated by sparsely bioturbated, tidal flat mudstone and siltstone facies with rare arkose strata (Figs. 7a – c). Most of the arkose occurs as relatively thin (generally < 4 cm), normally-graded and structureless beds interpreted to be the deposits of either unconfined, coastal fluvial sheetfloods or storm/wave-generated currents across the tidal flat (Figs. 7b – c; Table 2; Lowe, 2016). Most notable is a ~12 cm thick, scour-based cross-stratified arkose bed near the base of the Altona succession that most likely records the interfingering of tidal flat and braided fluvial sedimentary systems (Fig. 7a). Above the lower ~11 m of the Altona succession in the Quonto-International core is a ~1 m thick interval of low-angle cross-stratified, locally dolomitic arkose beds (Figs. 7d). Similar strata are exposed in outcrop at several localities in New York State (Fig. 8a) and here are interpreted to be hummocky and swaley cross-strata (HCS/SCS) representing storm-related deposition on the lower intertidal zone (e.g. Yang et al., 2006; see also Table 2 and Lowe, 2016). Stratigraphically upward, these strata are overlain by a ~5 m section comprising ~5 – 10 cm thick, normally-graded, very coarse- to coarse-grained arkose beds recording high-energy fluvial sheetflood or storm/wave driven coastal sedimentation events interbedded with ~0.2 – 1 m thick planar and ripple cross-stratified fine-grained sandstone and silty mudstone (e.g. Fig. 7e). The upper ~4 m

of the succession in Quonto-International is mostly missing but what is present consists generally of sparsely bioturbated mudstone and siltstone, similar to the basal ~11 m of the section. The upper contact of the Altona Member is obscured in core by a ~0.5 m thick mafic sill of probable Mesozoic age.

The composite type section of Altona exposed in outcrop in northeastern New York State, previously described in detail by Landing et al. (2009), is similar to the succession in the Quonto-International core with the exception of its greater thickness (~80 m) (Landing et al., 2009; Brink, 2015). In addition, unlike the cored succession in Quebec, strata in the uppermost part of the Altona in New York State are well exposed and include rare dolomicrite beds with common cryptic microbial laminites, shrinkage and injection features, rare silt laminae, burrows and fossil fragments (Landing et al., 2009; Brink, 2015; Fig. 5.7b – c). The latter beds are interpreted as peritidal dolomicrite that most likely accumulated in low energy parts of the tidal flat landward of the wave maximum and also away from sediment-laden river mouths. Here sedimentation rates were low and evaporation, tidal pumping and/or meteoric-seawater mixing promoted the precipitation of penecontemporaneous dolomite (e.g. Folk and Land, 1975; Mount, 1984; Carballo et al., 1987; Purser et al., 1994, Pratt, 2010, Lowe, 2016; Table 2). Overlying the uppermost dolostone bed is ~12 m of intertidal mudstone and siltstone interbedded with ~5 – 23 cm thick beds composed of normally-graded, coarse- to very coarse-grained arkosic river-mouth-splay deposits, signaling the re-introduction of terminal fluvial systems that locally and only temporally interrupted tidal flat sedimentation (Fig. 8d). In outcrop, the upper contact of the Altona Member is marked by the uppermost occurrence of tidal flat facies, conformably overlain by ~400 – 450 m of coarse-grained, cross-stratified braided fluvial arkose (e.g. Landing et al., 2009; Brink, 2015).

Ausable – Hannawa Falls contact

The Ausable Formation is conformably overlain by quartz arenite aeolian erg strata of the Hannawa Falls Formation in the western and southwest Ottawa Embayment. The contact between these units is marked by a ~0.3 – 1.9 m thick unit of ephemeral fluvial deposits that separates braided fluvial strata of the Ausable from aeolian strata of the Hannawa Falls (Fig. 9). This ephemeral fluvial unit consists of massive, cobble-pebble conglomerate lags interbedded with upper medium- to coarse-grained planar stratified sandstone consisting of inversely-graded wind ripple strata, illuviated matrix and common coarse- and very coarse sandstone deflation lags (Fig. 9). Clasts in the conglomerate exhibit pitted and grooved surfaces suggesting aeolian abrasion (Fig. 9b). Feldspar content decreases across this interval from ~30% in the Ausable to ≤ 5% (visual estimation in thin section). This conformable transition from braided fluvial to aeolian strata is interpreted to record reworking and local deflation and armoring of upper Ausable braided fluvial strata by ephemeral sheet floods and wind as a result of a progressive but major shift in climate from humid to arid conditions.

Ausable – Keeseville contact

In the eastern Ottawa Embayment and Quebec Basin the Hannawa Falls Formation is absent, and here the Ausable Formation is separated from overlying quartz arenites of the lower Keeseville Formation by a previously unrecognized cryptic unconformity (Fig. 10). Here, the top of the Ausable is a low-relief undulating erosional surface with ~10 – 25 cm of relief and capped by a ~4 – 10 cm thick massive pebble and granule conglomerate with a matrix of coarse- to

medium-grained sandstone (Fig. 10). Distinctively the conglomerate is preferentially cemented by pore-filling silica that preserves anomalously high intergranular volume ($\sim 22 - 26\%$, compared to $\sim 5 - 15\%$ for most silica-cemented Potsdam Group beds) and contains rare illuviated matrix (Fig. 11a-b). Additionally, detrital feldspar grains in the uppermost $\sim 1.5 - 2$ m of the Ausable are preferentially degraded and pseudomatrix and illuviated matrix become better developed upward (Fig. 11). Collectively, these features suggest the development of an initial lag, probably by aeolian deflation, followed by development of a silcrete paleosol with an upper duricrust and underlying illuvial horizon (e.g. Thiry, 1999). Silica was probably sourced from the breakdown of detrital feldspars beneath the silcrete, and was mobilized by upward-migrating groundwater driven by surface evaporitic pumping. Evaporation also served to concentrate the dissolved silica, which upon reaction with atmospheric CO_2 , reduced the pH of the silica-bearing groundwater and promoted silica precipitation (e.g. Selleck, 1978b).

Hannawa Falls Formation

The Hannawa Falls Formation is defined mainly by large-scale cross-stratified aeolian erg (FA3) and rare ephemeral fluvial (FA2) quartz arenite, commonly with a pervasive red coloration owing to grain-rimming hematite cements (Fig. 12). The Hannawa Falls Formation is a revision of Sanford and Arnott's (2010) Hannawa Falls Member and typified by the well-known large-scale cross-stratified red bed exposures along the Raquette River south of the town of Potsdam, New York (Fig. 12a), first described by Emmons (1838) and historically deemed the type section of the "Potsdam Sandstone: and here considered the type section of the Hannawa Falls Formation. Upgrading the Hannawa Falls to formation status is based on its wide areal

distribution (correlated over 19,600 km²) and recognizable lithologic features (see below; Fig. 10). Sanford and Arnott (2010) used red coloration as a primary criterion for defining their Hannawa Falls Member. However, color is probably a questionable primary attribute for lithostratigraphic correlation given that its presence or absence may or may not be reflective of depositional origin (e.g. Chan et al., 2000; and Beitler et al., 2005), and is probably why color ranks below features like mineralogical composition and texture as criteria for lithostratigraphic definition (Article 24(c) from NACSN, 2005). Accordingly, the Hannawa Falls Formation is defined here on the basis of four diagnostic criteria, which in order of importance are: (a) quartz arenite composition, (b) recognizable unconformable contact with the overlying Keeseville Formation, (d) well-sorted medium sand size, (c) aeolian sedimentary fabrics including inversely-graded laminae and large-scale cross-stratification, and (d) common pervasive red color (Fig. 10). Strata of the Hannawa Falls Formation range from ~ 2 – 25 m thick and crop out mainly in stratigraphic outliers throughout the Frontenac Arch/Adirondack Lowlands in eastern Ontario and northern New York, but also are present in the subsurface of the northwestern Ottawa Embayment on the eastern side of the Gloucester Fault (Figs. 1, 4). The Hannawa Falls Formation is undated, but most likely is middle or upper Middle Cambrian based on its conformable relationship with the underlying Middle Cambrian Ausable Formation and the rare occurrence of *Protichnites* and *Diplichnites* (e.g. MacNaughton et al. 2002). In the western Ottawa Embayment, an unconformity separates the Hannawa Falls Formation from the Keeseville Formation. In most places it is expressed as an erosional disconformity (Fig. 13), but locally an angular unconformity where Hannawa Falls strata are structurally tilted (Fig. 14; e.g. Sanford, 2007; Sanford and Arnott, 2010). Locally, a ~15 – 25 cm thick, massive and anomalously coarse-grained (pebble-cobble) regolithic conglomerate is present (Fig. 13c).

Evidence of structural deformation of Hannawa Falls strata was described by Sanford and Arnott (2010) and included broad localized synclines, half-synclines, low- to high-angle normal faults, rare thrust faults and otherwise massive and/or convolute stratification most likely related to extension oriented sub-parallel or oblique to the trend of the Ottawa Embayment. (e.g. Fig. 14). In addition to erosion and structural deformation, the upper $\sim 0.3 - 2$ m of the Hannawa Falls Formation is exceptionally red (Fig. 13a -b). The intensity of the red color increases abruptly upward towards the unconformity (Fig. 13b), and is related to increasing intergranular hematite and fibrous, void-filling illite cements that preserve higher than normal primary intergranular volumes ($\sim 26 - 28\%$; Fig. 15). In addition, angular clasts eroded from this horizon are common in the lower $\sim 1 - 2$ m of the overlying Keeseville Formation, suggesting that near-surface hematite and clay cementation predated deposition of the overlying Keeseville (Figs. 13, 14). Therefore, this upward-reddening, hematite- and illite-cemented horizon is interpreted to have formed as an early (pre-burial) near-surface paleosol horizon. Specifically, it is interpreted as a ferric oxisol (classification of Mack et al., 1993), or laterite, and reflects extensive groundwater leaching of alkali elements and silica and near-surface precipitation of residual hematite and kaolinite (Singer, 1975; Mack et al., 1993). Kaolinite, however, was later recrystallized to illite during burial diagenesis. Requisite Fe and Al for lateritization was most likely sourced from leached clay grain coatings, rare detrital feldspar grains, and/or perhaps the nearby basement.

Keeseville Formation

The Keeseville Formation is the uppermost lithostratigraphic unit of the Potsdam Group, and consists of buff to white, generally silica-cemented quartz arenite and rare quartzite-clast

cobble-boulder conglomerate, dolomitic sandstone and dolostone (Fig. 16). The Keeseville Formation (from Sanford and Arnott, 2010) replaces the Keeseville Member in New York (from Emmons, 1841; Fisher 1968) and its stratigraphic equivalents named the Nepean Formation (Wilson, 1946) and Cairnside Formation (Clark, 1966; 1972) in Ontario and Quebec, respectively. The Keeseville Formation is the most areally expansive unit in the Potsdam Group, cropping out across the entire Ottawa Embayment and Quebec Basin – an area of at least 26,000 km². Like the Ausable Formation, it has an uneven regional isopach, ranging in thickness from only ~8 m to 180 m. However unlike the Ausable it consists of a complexly interstratified and regionally-variable assemblage of depositional facies (Figs. 3, 4, 16; Table 3). Due to its wide extent and lithofacies variability many localities could be considered as representative (Table 3). The most complete and easily-accessed sections of the Keeseville Formation crop out along Highway 12 in northern New York State, between Alexandria Bay and Blind Bay (e.g., 86, 87, 100, 104, 112; Fig. 16d). Together these closely-spaced outcrops should be considered a composite stratotype of the Keeseville Formation, as they expose the entire Keeseville Formation in this area, most of its constituent lithofacies, and its lower and upper contacts (Selleck 1975, 1978, 1993; Bjerstedt and Erickson, 1989; Lowe, 2014). Throughout much of the Ottawa Embayment and Quebec Basin the Keeseville Formation is subdivided into the upper Keeseville Formation and upper Keeseville Formation that in most places is separated by an unconformity (Figs. 3, 17).

Lower Keeseville Formation

The lower Keeseville Formation consists of the upper Middle to Upper Cambrian lower part of the Keeseville Formation. The best exposed, but also most geographically-isolated exposures of the lower Keeseville occur in Ausable Chasm in the southernmost part of the Quebec Basin. Here a ~140 m thick section exposes mostly supratidal sabkha deposits with microbial surface features and rare epifaunal traces (*Protichnites*, *Diplichnites*, and *Climacticnites*) and scyphomedusae impressions (e.g. Hagadorn and Belt, 2008). Locally these strata are intercalated with erosionally-based, low-angle symmetrical sets and cosets interpreted as antidune stratification (e.g. Lowe and Arnott, 2016), suggesting an intimate association of marginal marine and high-energy sheetflood-dominated ephemeral fluvial systems. An uppermost Middle Cambrian *Crepicephalus* Zone trilobite assemblage has been described in the lower Chasm section (Walcott, 1891; Flower, 1964; Lochman, 1968; Landing et al., 2009), whereas the middle and upper parts of the section are most probably Upper Cambrian (e.g. Hagadorn and Belt, 2008).

About ~45 – 60 km north of Ausable Chasm, the lower Keeseville is well-exposed over a ~2000 km² area that straddles the New York -- Quebec border north of the Adirondack highlands, east of the Chateauguay Fault and south of the Ste. Justine Fault in the southeastern Ottawa Embayment and southern Quebec Basin (Fig. 1). An Upper Cambrian age for the majority of all unit 2 strata in this area is supported, in part, by Upper Cambrian trilobites (Fisher, 1968), and comparison of paleomagnetic poles with other documented Late Cambrian North American paleopoles (Seguin et al., 1981). In this area, the Keeseville is made up of ~50 – 100 m of ephemeral and minor braided fluvial strata (Lowe and Arnott, 2016). The fluvial systems that formed in this area likely transported sediment to the supratidal environments

farther south (mentioned above), and occasionally may have been inundated by coastal flooding based on the rare occurrence of *Proticnites*, *Diplichnites*, *Climacticnites* and rare trilobite fauna.

In the southwestern Ottawa Embayment and along the margins of the Frontenac Arch, allounit 2 consists of ~4 – 22 m succession of ephemeral and local braided fluvial strata (Chippawa Bay Member of Sanford and Arnott, 2010; and Potsdam I of Kirchgasser and Theokritoff, 1971; Selleck, 1975, 1978, 1993; Lowe and Arnott, 2016). In places the braided fluvial strata contain cobble traction-transport conglomerate interstratified with cobble-boulder talus that mantle the margins of fault-bounded basement highs. This suggests that fault-bounded basement topography inherited from earlier episodes of tectonic activity exerted an influence on fluvial sedimentation in allounit 2 (e.g. Lowe and Arnott, 2016).

In the northern Ottawa Embayment and Quebec Basin, allounit 2 strata thin westward from 90 – 15 m thick, and comprise an ~4.5 – 60 m thick succession of ephemeral and braided fluvial strata (Lowe and Arnott, 2016) capped locally by a ~2 – 33 m thick tide-dominated marine unit with rare peritidal dolostone interbeds, here called the Riviere Aux Outardes Member (from Clark, 1966; Globensky, 1982; Salad Hersi and Lavoie, 2000a).

Riviere Aux Outardes Member

The Riviere Aux Outardes Member was defined by Clark (1966) as a locally calcareous marine unit that capped the Covey Hill Formation (here abandoned and equivalent to the Ausable Formation). However, neither Clark (1966, 1972) nor later researchers in Quebec (Globensky 1982, 1986; Salad Hersi and Lavoie 2000a&b) recognized the importance of detrital feldspar in defining the Ausable, and as a result did not find the cryptic unconformity between the Ausable

and Keeseville formations documented here (see “Top Ausable”). Based on the recognition of this contact, correlations presented here suggest that the Riviere Aux Outardes caps the lower Keeseville Formation, and extends across the northern Ottawa Embayment and Quebec Basin (e.g., Salad Hersi and Lavoie 2000a). New conodont data from a dolostone bed in the Riviere Aux Outardes Member, located ~90 cm below the intra-Keeseville disconformity at an outcrop in Rockland, ON (outcrop locality 2, see supplementary data file 1), support an earliest Ordovician depositional age for upper part of allounit 2 (Fig. 17; Appendix A; Nowlan, 2013). This bed yielded numerous *Variabiloconus bassleri* specimens and a single *Cordylodus(?)* specimen, in addition to fragments of phosphatic inarticulate brachiopods, indicating an upper Skullrockian (i.e. early Tremadocian) age.

Lower – Upper Keeseville Formation contact

In the northern Ottawa Embayment and Quebec Basin the unconformity that truncates the upper part of the lower Tremadocian Riviere Aux Outardes Member exhibits local erosional relief of ~5 – 10 cm (Fig. 17). Rip-up clasts of peritidal dolostone and dolomite-cemented marine sandstone of the Riviere Aux Outardes Member occur in the basal ~0.1 – 1.1 m of the overlying upper Keeseville Formation, suggesting early carbonate cementation and subsequent cannibalization of parts of the upper Riviere Aux Outardes Member (Fig. 17b).

In the southwestern Ottawa Embayment and along the margins of the Frontenac Arch, the unconformity capping fluvial strata of the lower Keeseville is sharp with local 10 – 50 cm deep scours (Fig. 18). Additionally, in most parts of the southwest Ottawa Embayment strata in the uppermost ~1.5 m of the lower Keeseville show evidence of paleosol development. Specifically,

chloritic and/or Fe-rich clays coat sand grains and inhibit the ubiquitous silica cement present in over- and underlying strata. Furthermore, primary sedimentary stratification is absent in these illuvial horizons (Fig. 18b). The presence of clay coats and disruption of stratification in strata beneath the unconformity suggests intense near-surface illuviation, and more specifically, the formation of an argillisol (e.g. Gile and Grossman, 1968; Mack et al., 1993). In contrast, sections located in the south-westernmost Ottawa Embayment directly south of the St. Lawrence River and on the north side of the Black Lake fault (Fig. 1) expose a 0.3 – 1.2 m thick nodular or massive preferentially silicified horizon, with localized brecciation, in the uppermost part of these fluvial strata (Fig. 19). Parts of this horizon were described earlier by Selleck (1978), who interpreted it as a silcrete paleosol.

Unlike elsewhere, no unconformity could be identified in Keeseville strata in the southeastern Ottawa Embayment and Quebec Basin, in the area bounded by the Ste. Justine and Chateauguay fault. This suggests that fluvial sedimentation continued uninterrupted here during the latest Cambrian and earliest Ordovician while erosion and pedogenesis occurred elsewhere.

Upper Keeseville Formation

The Lower Ordovician upper Keeseville Formation generally consists of fluvial strata succeeded upward by marginal- and/or fully-marine strata. The minimum age of the upper Keeseville is everywhere constrained by conodont biostratigraphy at the base of the overlying Theresa Formation, and suggest that the upper Keeseville youngs from the southeast to the northwest. In the southeast Ottawa Embayment and adjacent southern Quebec Basin, ephemeral fluvial and rare aeolian strata, with rare occurrences of *Proticnites* (Hagadorn et al., 2011), are

capped everywhere by sabkha facies (~1 – 40 m thick) and overlain by tide-dominated marine strata (~9 – 17 m thick) (Figs. 3, 4). The upward transition from terrestrial to marine is gradational and particularly well-exposed in the upper part of Ducharme Quarry in southern Quebec (Fig. 20). Here, ephemeral fluvial strata are separated from younger tide-dominated marine strata by a ~1.8 m thick transitional section (Fig 20) consisting mostly of coastal sabkha sandstone facies intercalated with several cm-thick pebble conglomerate beds (Fig. 20c-d), each generally capped by a thin (≤ 1 cm) drape of bioturbated silty mudstone with a low diversity *Cruziana* ichnofacies (Fig. 20b). Each pebble conglomerate and bioturbated mud drape is interpreted to record an episodic transgression, marked first by transgressive erosion (conglomerate) followed by deeper marine conditions (bioturbated mud drape). Thus the repetitive occurrence of these transgressive strata within coastal sabkha facies records repetitive episodes of shoreline retrogradation followed by reestablishment of coastal conditions. This transitional interval is then overlain by tide-dominated marine strata, which record the final coastal retrogradation in this part of the basin.

In the southwestern Ottawa Embayment and cropping out along the margins of the Frontenac Arch, upper Keeseville strata consist of a ~3.5 – 10 m thick, bioturbated tide-dominated marine succession. The abrupt base of the unit is mantled locally by a ~5 – 15 cm thick massive pebble/cobble transgressive lag (Figs. 18, 21), which then is commonly onlapped at a shallow angle ($\leq 5^\circ$; Figs. 18b, 21) by marine strata.

In the northern Ottawa Embayment and Quebec Basin the upper Keeseville consists of 3.5 – 30 m of braided fluvial (FA1) and/or ephemeral fluvial (FA2) strata capped abruptly by ~6 – 72 m of sabkha deposits (FA4). In most places the latter is overlain by a by ~1 – 5 cm thick pebble lag capped by ~3 – 42 m of tide-dominated marine strata (FA5), except on the footwall

side of regional normal faults near Montreal (Ste. Justine fault) and Ottawa (the Gloucester and Hazeldean faults; Figs. 1, 4).

Keeseville – Theresa contact and depositional age of the upper Keeseville

The upper Keeseville Formation is everywhere overlain by marine, mixed carbonate and siliciclastic strata of the Theresa Formation. The general consensus is that the Theresa Formation (and equivalent March Formation, now abandoned, see Dix et al., 2004) follows the original definition of Cushing (1908) to consist of a generally bioturbated, “grey calcareous [dolomitic] sandstone and interbedded clean, white quartz sandstone of marine origin” (Cushing, 1908; Wilson, 1946; Fisher, 1968; Brand and Rust, 1977; Globensky, 1982; Selleck, 1984; Salad Hersi et al., 2002a, 2003; Dix et al., 2004; Sanford and Arnott, 2010). The nature of the Theresa – Potsdam is poorly resolved, and had been variably documented as unconformable (e.g., Greggs and Bond, 1972; Salad Hersi et al., 2002a; Dix et al., 2004), or conformable and diachronous (Cushing, 1908; Wilson, 1946; Otvos, 1966; Clark, 1972; Brand and Rust, 1977; Sanford and Arnott, 2010). The majority of authors agree that the base of the Theresa Formation should be placed at the base of the lowest dolomitic sandstone bed (Cushing, 1908; Wilson, 1946; Greggs and Bond, 1972; Brand and Rust, 1977; Globensky, 1982, 1986; Selleck, 1978a, 1993; Williams and Wolf, 1984; Bernstein, 1992), although other authors including Clark (1966, 1972), Salad Hersi and Lavoie (2000b) and Sanford and Arnott (2010) propose that the base of the Theresa should correspond to the top of the highest clean quartz arenite bed above which the lithofacies is “subordinate or absent”. These criteria are vague, and it is unclear what thickness of layer constitutes a “bed” or what specifically is meant by “subordinate”. Furthermore, the latter

definition for the base of the Theresa at the highest clean quartz arenite contradicts the lithologic makeup of the Theresa Formation itself, which according to all previous authors consists of significant amounts of clean, silica-cemented quartz arenite lithofacies, and therein similar to the Keeseville Formation (Cushing, 1908; Wilson, 1946; Clark, 1966, 1972; Fisher, 1968; Greggs and Bond, 1972; Brand and Rust, 1977; Globensky, 1982, 1986; Selleck, 1978a, 1993; Williams and Wolf, 1984; Bjerstedt and Erickson, 1989; Bernstein, 1992; Salad Hersi et al., 2002a, 2003; Dix et al., 2004). For that reason we follow the most commonly and reliably used criterion for locating the Keeseville – Theresa contact: the base of lowermost pervasively carbonate-cemented dolomitic sandstone bed. Although the term “bed”, as defined by McKee and Weir (1953), is defined to be any layer thicker than 1 cm, it is considered here to be a layer at least 4 cm thick, and therefore distinct from mm- to a few cm-thick, discontinuous lenses of carbonate cemented sandstone that are common in the upper part of the Keeseville Formation. This is an objective and easily-recognizable criterion for locating the contact in outcrop and core, and moreover records the initiation of mixed carbonate and siliciclastic sedimentation of the Theresa Formation.

Based on this definition, the nature of the Keeseville – Theresa contact depends on its location relative to regional faults, the thickness of the underlying Keeseville and the facies association above and below the contact. For example, in the southeastern Ottawa embayment and Quebec Basin, in the area south of the St. Justine fault and east of the Chateauguay fault (Fig. 1), the uppermost allounit 3 consists of inter/subtidal marine facies and the Keeseville – Theresa contact is conformable and gradational. In these areas the change to strata dominated by carbonate cement is marked by a progressive increase in the abundance and thickness of carbonate-cemented beds above the contact (Fig. 22). This suggests continuous sedimentation

during an episode of gradual flooding on the hanging wall sides of these regional normal faults. In contrast, on the footwall side of regional normal faults in the northwest Ottawa Embayment near Ottawa (Gloucester Fault) or the northern Quebec Basin near Montreal (Fig. 1), the contact truncates coastal sabkha or locally aeolian facies of allounit 3 and is defined by a sharp and erosional contact (Figs. 23c-d, 24) typically with minor relief (~5 – 10 cm) and evidence of pedogenic alteration including locally concentrated illuvial matrix and rare void-filling spheriolic chalcidony (e.g. Salad Hersi et al, 2002a). This contact is likely an intra-Early Ordovician disconformity of unknown duration, consistent with the observations of Salad Hersi et al. (2002a) and Dix et al. (2004), and records a period of non-deposition, minor erosion and pedogenesis followed by marine flooding. Finally, in parts of the southwest Ottawa Embayment, allounit 3 strata are comparatively much thinner and the contact with the Theresa Formation is marked by an abrupt change from silica- to carbonate-cemented strata (e.g. Greggs and Bond; Selleck, 1978a, 1993; Bjerrestedt and Erickson, 1989; Sanford and Arnott, 2010; Fig 23a). Here too the uppermost ~5 – 12 cm of the Keeseville is locally to pervasively cemented by dolomite (increasing toward the contact) and robust vertical trace fossils filled with sediment sourced from above the contact, and therefore quite possibly representative of a firmground *Glossifungites* ichnofacies, are observed (Fig. 23b). Collectively these features suggest a hiatus in sedimentation, but without subaerial erosion or pedogenesis, recording a rise of relative sea level that temporarily overwhelmed local sediment supply.

The age of the uppermost part of the Keeseville Formation can be constrained regionally by conodont biostratigraphy (Fig. 25) previously reported from the lowermost part of the Theresa Formation (Greggs and Bond, 1971; Brand and Rust, 1977; Salad Hersi et al., 2002a, 2003; Dix et al., 2004), and a newly collected sample from the southwestern Quebec Basin (near Ste.

Clotilde, QC; GSC- 450797), ~15 – 30 m above the base of the Theresa where the Potsdam-Theresa contact is conformable and gradational. This latter sample yielded over 100 conodont specimens including many *Drepanoistous gracilis* and *Colaptoconus quadriplicatus* (Appendix B, McCracken, 2014) suggesting a large probable age range of lower Stairsian to mid Blackhillsian stages (see Ross et al., 1997), or Upper Tremadocian to Lower Arenigian, overlapping with the age of the Theresa Formation throughout most of the Ottawa Embayment and Western Quebec Basin (Greggs and Bond, 1972; Brand and Rust, 1977; Salad Hersi et al., 2002a&b, 2003; Dix et al., 2004). Though the precision of the biostratigraphic data is low, the collective age determinations from at or near the base of the Theresa Formation suggest that the basal part of the Theresa is diachronous (e.g. Salad Hersi et al., 2003) and youngs slightly from the southeast to the southwest from as old as Early-Middle Tremadocian in the southeastern Quebec Basin and southeastern Ottawa Embayment (Salad Hersi et al., 2003; Salad Hersi and Dix, 2006) to as young as Early Arenigian in the northwestern Ottawa Embayment (Brand and Rust, 1977; Dix et al., 2004) (Fig. 25).

Allostratigraphic evolution and regional correlation of the Potsdam Group

The lithostratigraphic framework described above forms the basis for unambiguous correlation of lithostratigraphic units across the Ottawa Embayment and Quebec Basin. Additionally, the combination of lithofacies and biostratigraphic data provides details of sedimentary environments and timing of deposition. However, this combined stratigraphic framework does not account for the mechanisms (e.g. climate, eustacy, and/or tectonics) driving the development of stratal discontinuities nor the temporal or spatial changes in sedimentary

environments that occurred during Potsdam deposition. Additionally, it cannot be used to make regional correlations with coeval but lithologically different stratal successions of the Laurentian margin and craton in order to identify the controls that influenced Potsdam sedimentation (Fig. 26). Instead, allostratigraphy is used to facilitate correlation of regionally extensive discontinuity-bound units, termed allounits, which like sequences in sequence stratigraphy, are based on the assumption that geological processes, like sea level change or tectonism, affect deposition over large areas in spite of differences in lithofacies (Bhattacharya, 1993; Bhattacharya, 2011). Moreover, allostratigraphy is preferred because it is comparatively generic and lacks the rigid sea level change terminology of sequence stratigraphy, and thereby has greater flexibility for describing and interpreting the various controls that influence sedimentation (e.g. Bhattacharya, 1993; Bhattacharya and Willis, 2001; Hu and Plint, 2009; Bhattacharya, 2011). This is particularly important for stratigraphic analyses in the Potsdam Group because it is a mostly terrestrial, cratonic unit where deposition would have been principally controlled by upstream influences including climate, basin physiography and tectonics, rather than more basinward eustatic changes (e.g. Holbrook et al., 2006). Three allounits are recognized here, each considered to record discrete episodes of sedimentation in the eastern Ottawa Graben (here termed the EOG for brevity).

Allounit 1

Allounit 1 consists of the Ausable Formation and conformably overlying Hannawa Falls Formation. Accordingly it records late Early to Middle Cambrian arkosic braided fluvial and tidal flat sedimentation (Ausable Formation and Altona Member, respectively) followed by

Middle Cambrian quartz arenitic aeolian sedimentation (Hannawa Falls Formation). The fault-bounded isopach and mineralogical immaturity of the locally thick (≥ 450 m) Ausable succession, which contains $\sim 10 - 40\%$ euhedral, unaltered feldspar grains (Lewis, 1971), suggests syn-rift sedimentation and derivation from rapidly exhumed and minimally transported cratonic granites and gneisses (e.g. the “basement uplift” field of Dickenson and Suczek, 1979; also see Dickenson et al., 1983; Cox and Lowe, 1995). Near the base of the mostly braided fluvial Ausable Formation records a latest Early Cambrian westward (paleo-northward) marine transgression into the EOG. The marine Altona Member, therefore, most likely represents a late Early Cambrian rift-subsidence driven incursion of the Humber Seaway into the EOG, with mud and sand on the Altona tidal flats sourced from fluvial discharge of coeval Ausable braided rivers. Lithofacies similar to the Altona were deposited on the nearby shelf; $\sim 80 - 150$ km to the paleo-southwest, recorded by arkosic and rare carbonate tide-dominated sedimentation of the Monkton Formation (Speyer, 1983; Goldberg and Mehrtens, 1998). The Monkton probably represents a basinward extension of the Ausable and Altona, with tide-dominated, mainly arkosic shelf environments fed by Ausable Rivers.

Evidence of syn-rift sedimentation during Ausable time is not limited to the EOG. In fact, the initiation of Ausable braided fluvial sedimentation in the EOG is coeval with faulting and subsidence in the Franklin Basin, $\sim 80 - 90$ km to the paleo-south of the EOG where shallow marine strata are abruptly overlain by debris flow deposits and dysoxic deep marine mudstones of the Parker Formation (Cady, 1945; Shaw, 1958; Landing 2007; Landing et al., 2009). Of note also is evidence of potentially coeval (late Early – Middle(?) Cambrian) cratonic rifting and syn-rift sedimentation throughout eastern and central North America, including in the Midcontinent and East Continent Rifts, the Mississippi Valley and Rough Creek grabens and Rome Trough

(Woodward, 1961; Thomas, 1991; Drahovzal, 1995, 1996, 1997; Harris and Drahovzal, 1996). Accordingly, Sanford and Arnott (2010) have suggested that the lithologically-similar but undated syn-rift Middle Run and Jacobsville formations in the fault-bounded East Continent and Midcontinent rift systems (Brown et al, 1982; Shrake, 1991; Shrake et al., 1991; Drahovzal, 1997; Baranoski et al., 2009) are fully or partly correlative to the syn-rift Ausable Formation in the EOG. Although these units have previously been interpreted to be Proterozoic Grenville foreland basin strata (Santos et al., 2002; Baranoski et al., 2009), or the fills of even earlier rift basins (Brown et al., 1982), a recent combined geochronological, stratigraphic and paleomagnetic by Malone et al. (2016) suggest that the Jacobsville and related strata in the Midcontinent rift was very likely deposited following the Cryogenian, supporting the correlation of Sanford and Arnott (2010). Nevertheless, it is clear that intracratonic rifting was widespread in paleo-Southern Laurentia during the Early and Middle Cambrian, broadly coeval with rifting and syn-rift sedimentation in the EOG.

Later, during the mid to late Middle Cambrian, climate change from humid to arid conditions resulted in the cessation of Ausable braided fluvial sedimentation, local deflation and aridisol development and aeolian erg sedimentation of the Hannawa Falls Formation. Hannawa Falls strata mainly accumulated in southwest parts of the EOG suggesting the dispersal of windblown sediment from the paleo-southeast, consistent the likely paleo-southeasterly prevailing wind direction at the sub-equatorial location of the EOG. Moreover, the mineralogical change from arkose to quartz arenite most probably reflects from the loss of labile feldspar during highly corrasive windblown transport. Coeval Middle Cambrian strata on the Laurentian shelf record sedimentation on relatively narrow (<200 km wide), high-energy carbonate platforms (e.g. the Winooski and March Point formations; Cady, 1945; James et al., 1987;

Knight, 1991; Knight and Boyce, 1991; Landing, 2007) and slow sedimentation of thin intervals of black mudstone, calcitubidites and local glauconitic sandstone on the Laurentian slope (i.e. the Orignal/Ste. Roche, Lauzon and Hatch Hill formations, Fig. 26; Landing, 1993, 2007; Landing et al., 2002; Lavoie et al., 2003; Lavoie, 2008). These siliciclastic-poor depositional conditions are consistent with arid climate conditions recorded by the Hannawa Falls Formation, which would have significantly reduced the occurrence and discharge of fluvial systems and thus delivery of siliciclastic sediment to the continental shelf and beyond.

Allounit 1 – Allounit 2 unconformity

Although sparse, the available geochronological control and stratigraphic relationships suggest that the unconformity at the base of allounit 2 is a diachronous surface that incorporates much of the late Middle Cambrian (~1 – 5 Myr) in the southeastern EOG (i.e. in the vicinity of Ausable Chasm) to possibly as much as ~4 – 10 Myr, and therefore the Middle – Late Cambrian, throughout most of the EOG. Paleosol horizons commonly cap eroded allounit 1 strata, and Sanford and Arnott (2010) documented structural deformation of allounit strata interpreted to record reactivation of faults coincident with or following formation of the allounit 1-2 unconformity. Notably, Lavoie (1997, 1998) and Lavoie et al. (2003) document the presence of coarse Paleozoic and Precambrian debris deposited on the nearby Laurentian slope (Ste. Damase Formation, Fig. 26), which is interpreted to record abrupt unroofing of the Saguenay graben.

The allounit 1 – 2 unconformity is also coeval with a late Middle to early Late Cambrian regression across southern Laurentia (Palmer, 1983; James et al., 1987; Chow and James, 1987;

Lavoie et al., 2003). On the nearby Laurentian shelf and craton interior this regression is recorded by a Middle Cambrian unconformity overlain by latest Middle Cambrian to earliest Late Cambrian terrestrial, coastal and marine quartz arenites (the Danby, “Potsdam”, and Mount Simon formations, Fig. 26; Cady, 1945; Catacosinos, 1973; Dott et al., 1986; Mehrtens and Butler, 1989; Sharke et al, 1991; Landing, 2007; Medina and Rupp, 2012). Meanwhile, in the nearby and more distal parts of the coeval Laurentian continental slope, ~100 – 1600 km to the paleo-south and southeast, this regression resulted in the progradation of shelf carbonates and/or the local occurrence of regressive slope conglomerates containing shelf carbonate platform clasts recording erosion and/or collapse of the shelf-slope break (e.g. Mill River and Ste. Damase formations and Downes Point Member; James and Stevens, 1986; James et al., 1987; Chow and James, 1987; Lavoie et al., 2003; Landing, 2007; Lavoie, 2008). Notably, this regression is not recorded in coeval strata on the northern Laurentian margin (James et al., 1987), suggesting that it was more likely the result of tectonic uplift of the southern Laurentian margin rather than a eustatic fall, which is consistent with evidence for tectonic reactivation of the Neoproterozoic Ottawa and Saguenay grabens. However, the cause of uplift and coeval tectonic reactivation of Neoproterozoic grabens is currently unknown.

Allouit 2

Quartzose coastal sabkha sedimentation of allouit 2 began during the latest Middle Cambrian in the southeastern EOG, followed by more widespread early – middle Late Cambrian fluvial and local aeolian sedimentation throughout the EOG. In the northern EOG fluvial sediments were transgressed in the latest Cambrian resulting in deposition of tide-dominated

marine strata of the Riviere Aux Outardes Member. The record of widespread quartzose sedimentation followed by local marine drowning recorded by allounit 2 strata is well represented by strata in the coeval Laurentian Shelf and cratonic basin successions (Fig 26), recording a Late Cambrian to earliest Ordovician(?) marine transgression and highstand event that drowned siliciclastic hinterlands and initiated widespread carbonate sedimentation (e.g. Landing, 2007; Fig. 26). For example, in the Mohawk and southern Champlain valleys this sedimentation history is recorded by a conformable succession consisting of the basal “Potsdam Formation” – a quartz arenite that is likely Keeseville Formation equivalent, plus the overlying Galway (lithologically similar but not correlated with the Theresa Formation) and Little Falls formations (Fig. 26; Landing et al., 2003; Landing, 2007). In Vermont these events are recorded by the Danby Formation sandstone and overlying Little Falls Formation carbonate (Fig. 26; Landing, 2007). In the adjacent parts of the Appalachian and Michigan basins two cycles of quartzose sedimentation followed by marine transgression and carbonate sedimentation occurred in the Late Cambrian (Catacosinos, 1973; Clayton and Attig, 1990; Medina and Rupp, 2012). At the base of the second cycle, the Wonowoc Formation coincides with the top of the Sauk II sequence (Fig. 26), and additionally the top of “Grand Cycle B”, both recording sea level fall throughout the St. Lawrence Promontory shelf (~1500 – 1600 km to the paleo-southeast of the EOG) (James et al., 1987; Lavoie, 2008). Interestingly, these two cycles, in addition to the top boundary of the Sauk II sequence that separates them, are not recorded in allounit 2 of the Ottawa graben or in the nearby New York Promontory or Quebec Re-entrant shelf successions, the reasons for which are currently unknown, but may be related to higher rates of subsidence in these latter areas.

Allounit 2 – Allounit 3 contact

The contact separating allounits 2 and 3 is a Late Cambrian to earliest Ordovician unconformity throughout most of the EOG, except for the southeast EOG where it is a correlative conformity recording a continuous history of fluvial sedimentation through the Late Cambrian and Early Ordovician. Regardless of its local manifestation, this contact correlates to a well-documented eustatic fall that resulted in an extensive unconformity that truncates Upper Cambrian strata in successions deposited on the nearby Laurentian shelf and the Appalachian, Michigan and Illinois basins (Fig. 26; James et al., 1987; Chow and James, 1987; Landing, 1993; Salad-Hersi et al., 2002b; Landing et al., 2003). On the Laurentian shelf the eustatic fall is interpreted to be constrained to a minimum age of latest Cambrian based on the Late Cambrian age of erosionally-truncated strata beneath the unconformity (Landing, 1993; Salad Hersi et al., 2002b; Landing et al., 2003). Nevertheless, strata overlying the unconformity are Tremadocian (Salad Hersi et al 2002b) and thus regression and erosion may have occurred at any time between the Latest Cambrian and Early Tremadocian.

On the coeval Laurentian slope, the Uppermost Cambrian – Lower Ordovician Kamouraska Formation in the Rivière-Boyer Nappe consists of quartz arenitic turbidites quite possibly sourced from eroded quartzose Keeseville and/or Hannawa Falls strata (Fig. 26; Lavoie et al., 2003; Lavoie, 2008; Malhame and Hesse, 2015). This interpretation is supported not only by compositional similarities between the Kamouraska and Keeseville/Hannawa Falls but also by surface texture analysis of grains in the Kamouraska that strongly suggests inherited windblown transport (Malhame and Hesse, 2015), consistent with cannibalization of aeolian and ephemeral fluvial strata of the Hannawa Falls and Keeseville formations. This relationship, if

true, suggests transport of recycled Potsdam sediment from the EOG across the Laurentian shelf during and following eustatic fall in the latest Cambrian and earliest Ordovician.

Allounit 3

Allounit 3 records the final phase of siliciclastic sedimentation in the Potsdam Group, recorded by the upper Keeseville Formation, during an Early Ordovician (Tremadocian – earliest Arenigian) marine transgression culminating in the widespread deposition of mixed siliciclastic-carbonate marine strata of the Theresa Formation. This transgression was more regionally extensive than earlier transgressive events (Altona or Riviere Aux Outardes), and correlates with a Lower Ordovician (Tremadocian) eustatic rise (James et al., 1987; Lavoie et al., 2003; Landing et al., 2003; Landing, 2007; Lavoie, 2008).

However, unlike most areas in Laurentia where transgression was rapid and almost isochronous, transgression of the EOG initiated in the mid-Tremadocian and was slow and diachronous toward the paleo-northeast, culminating in the latest Tremadocian or earliest Arenigian (Fig. 26). Structural and stratigraphic evidence suggest that the protracted and diachronous nature of this transgression may have been due to variations in accommodation space related to topography associated with faults that were active before or during sedimentation. In the southeast EOG, low-lying fault-bounded topography resulted in a relatively deep, high accommodation setting and thus gradual flooding (e.g. Figs. 20 and 22). In the western EOG, on the other hand, abrupt Late Tremadocian flooding occurred over shallow marine environments with low accommodation, temporarily overwhelming the local sediment supply and resulting in a sharp, but conformable Keeseville –Theresa contact (Figure 23 a–b).

Finally, areas on the footwall sides of major faults in the northern EOG were subaerially exposed, essentially existing as fault-bounded islands during most of the Tremadocian eustatic transgression, resulting in the disconformity between the Keeseville and Theresa documented here and by others (e.g. Salad Hersi et al., 2002a; Dix et al., 2004; Figs. 23c–d, 24). Whether these faults were active during transgression or were instead the topographic remnants of earlier faulting is unknown, however syn-transgressive movements on these faults could explain how these areas remained subaerially exposed and were locally eroded while most of the Laurentian shelf, cratonic basins and nearby areas of the southern Ottawa Graben were being flooded.

Summary and Conclusions

With minor nomenclatural modification, this work largely confirms conclusions of the earlier basin-scale investigations of Sanford (2007) and Sanford and Arnott (2010) inasmuch as the Potsdam Group is a complex composite Cambrian and Upper Ordovician siliciclastic unit dissected by at least one, and probably two major unconformities. From the base upward the Potsdam sedimentary pile consists of the arkosic Ausable Formation, which in the eastern part of the study area intertongues with the Altona Member, conformably succeeded by the red, quartz arenitic Hannawa Falls Formation. These, then, are unconformably overlain by the quartz arenitic Keeseville Formation, which locally is intercalated with the Riviere Aux Outardes Member.

In addition to these proposed lithostratigraphic revisions, the Potsdam Group is also subdivided into three discontinuity-bounded allounits recording distinct episodes of regional sedimentation. Allounit 1 comprises the Ausable and Hannawa Falls Formations. The Ausable

records the onset of Early Cambrian rifting and syn-rift sedimentation of arkosic braided fluvial strata into fault-bounded sub-basins of the EOG. Of note, this syn-rift sedimentation event coincided with rifting and syn-rift sedimentation reported elsewhere, including in the Franklin Basin, Rome Trough, Rough Creek graben and rift basins underlying parts of the Michigan and Appalachian basins and intervening arches. In the nearby Laurentian shelf succession the coeval Monkton Formation records coeval arkosic tide-dominated marine sedimentation, while in the deep marine Franklin Basin the Parker Formation records deep marine siliciclastic sedimentation of sand-rich turbidites. The Altona Member, a tidal flat succession intertonguing locally with the Ausable Formation in the Ottawa graben, records late Early Cambrian transgression into the eastern EOG driven by localized rift-generated accommodation.

Later in the Middle Cambrian, climate change from humid to arid conditions resulted in the cessation of fluvial drainage and sedimentation in the EOG and development of an aeolian erg system (Hannawa Falls Formation) that accumulated mainly in the western EOG under prevailing paleo-southeasterly winds. These windblown sediments also marked a shift in the detrital composition from arkose to quartz arenite due to a combination of sedimentary recycling and corrasion of feldspars during windblown transport. Coeval shelf sedimentation was carbonate-dominated (e.g. the Winooski, March Point formations) and slope sediments consisted of thin intervals of slowly accumulated black mudstone, calcitubidites and local glauconitic sandstone (i.e. the Orignal/Ste. Roche, Lauzon and Hatch Hill formations), consistent with a climate-driven shutdown of fluvial sediment delivery systems to the continental shelf.

Erg sedimentation of the Hannawa Falls was followed by the development of a subaerial unconformity by the latest Middle Cambrian to earliest Late Cambrian. At the same time, or soon after, local structural deformation affected Allouit 1 strata, recording localized tectonic

reactivation of the EOG. Coeval with these events in the EOG is the deposition of polymict conglomerate of the Ste. Damase Formation on the Laurentian slope, itself considered to record reactivation and unroofing of the Saguenay graben. Furthermore, a non-eustatic regression is recorded by strata deposited across the Southern Laurentian margin, suggesting possible tectonic uplift of the southern Laurentia at this time.

Allounit 2 consists of the uppermost Middle Cambrian to lowermost Ordovician lower Keeseville Formation and records Upper Cambrian quartzose fluvial sedimentation followed by eustatic transgression in the paleo-eastern Ottawa graben (Riviere Aux Outardes Member), followed by earliest Ordovician regression and subaerial erosion across most of the Ottawa graben. The transgression and regression recorded by allounit 2 strata is well-represented by coeval strata deposited on the Laurentian shelf, all of which record an upward decrease in siliciclastic sedimentation due to Late Cambrian eustatic rise and are capped by a regressive Cambrian – Ordovician stage boundary unconformity (e.g. the “Potsdam”-Galway-Little Falls formations in central New York, Danby-Little Falls formations in Vermont and Rock River-Strites Pond formations in Quebec).

Allounit 3 records a protracted and diachronous northwestward (paleo-northeastward) eustatic rise across the southern Ottawa graben that eventually culminated in widespread mixed carbonate-siliciclastic, shallow marine sedimentation (Theresa Formation). This early Ordovician transgression occurred rapidly over most of Southern Laurentia, resulting in the widespread development of epeiric seas. The comparatively protracted eustatic rise over the Ottawa graben was due to the persistence of fault-bounded topographic topography that locally counteracted the effect of rising sea level.

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References

Allen, J.S., Thomas, W.A., and Lavoie, D. 2009. Stratigraphy and structure of the Laurentian rifted margin in the Northern Appalachians; a low-angle detachment rift system. *Geology* (Boulder), **37**: 335-338.

Allen, J.S., Thomas, W.A., and Lavoie, D. 2010. The Laurentian margin of northeastern North America. *In* From Rodinia to Pangea: The Lithotectonic Record of the Appalachian Region. *Edited by* Tollo, R.P., Bartholomew, M.J., Hibbard, J.P., and Karabinos, P.M. Memoir - Geological Society of America 206. Boulder, Colorado, U.S.A. pp. 71-90.

Alling, H.L. 1919. Geology of the Lake Clear region (parts of Saint Regis and Saranac quadrangles). *In* New York State Museum and Science Service Bulletin 207, the New York State Education Department, Albany, New York. pp.111-145.

Baranoski, M.T., Dean, S.L., Wicks, J.L., and Brown, V.M. 2009. Unconformity-bounded seismic reflection sequences define Grenville-age rift system and foreland basins beneath the Phanerozoic in Ohio. *Geosphere*, **5**: 140-151.

Beitler, B., Parry, W.T., and Chan, M.A. 2005. Fingerprints of fluid flow; chemical diagenetic history of the Jurassic Navajo Sandstone, southern Utah, U.S.A. *Journal of Sedimentary Research*, **75**: 547-561.

Bhattacharya, J.P., and Willis, B.J. Lowstand deltas in the Frontier Formation, Powder River Basin, Wyoming: implications for sequence stratigraphic models, USA. *The American Association of Petroleum Geologists Bulletin*, **85**: 261-294.

Bhattacharya, J.P. 1993. The expression and interpretation of marine flooding surfaces and erosional surfaces in core; examples from the Upper Cretaceous Dunvegan Formation in the Alberta foreland basin. *In* Sequence Stratigraphy and Facies Associations, *Edited by* Summerhayes, C.P., and Posamentier, H.W. International Association of Sedimentology Special Publication 18, pp. 125-160.

Bhattacharya, J.P. 2011. Practical problems in the application of the sequence stratigraphic method and key surfaces: integrating observations from ancient fluvial–deltaic wedges with Quaternary and modelling studies. *Sedimentology*, **58**: 120-169.

Bjerstedt, T.W., and Erickson, J.M. 1989. Trace fossils and bioturbation in peritidal facies of the Potsdam-Theresa formations (Cambrian-Ordovician), Northwest Adirondacks. *Palaios*, **4**: 203-224.

Bleeker, W., Dix, G.R., Davidson, A., and LeCheminant, A. 2011. Tectonic Evolution and Sedimentary Record of the Ottawa-Bonnechere Graben: Examining the Precambrian and Phanerozoic History of Magmatic Activity, Faulting and Sedimentation. *In* Geological Association of Canada - Mineralogical Association of Canada - Society of Economic Geologists - Society for Geology Applied to Mineral Deposits Joint Annual Meeting, Ottawa, Canada, Guidebook to Fieldtrip 1A, 98 p.

Brand, U., and Rust, B.R. 1977. The age and upper boundary of the Nepean Formation in its type section near Ottawa, Ontario. *Canadian Journal of Earth Sciences*, **14**: 2002-2006.

Brink, R.A. 2015. Sedimentologic Comparison Of The Late/lower Early Middle Cambrian Altona Formation And The Lower Cambrian Monkton Formation. MSc thesis, Department of Geology, University of Vermont, Burlington, Vermont.

Brown, L., Jensen, L., Oliver, J., Kaufman, S., and Steiner, D. 1982. Rift structure beneath the Michigan Basin from COCORP profiling (USA). *Geology*, **10**: 645-649.

Burton, W.C., and Southworth, S. 2010. A model for Iapetan rifting of Laurentia based on Neoproterozoic dikes and related rocks. *In* From Rodinia to Pangea: The Lithotectonic Record of the Appalachian Region. *Edited by* Tollo, R.P., Bartholomew, M.J., Hibbard, J.P., and Karabinos, P.M. Memoir - Geological Society of America 206. Boulder, Colorado, U.S.A. pp. 455-476.

Cady, W.M. 1945. Stratigraphy and structure of west-central Vermont. Bulletin of the Geological Society of America, **56**: 515-587.

Carballo, J., D., Land, L.S., and Miser, D.E. 1987. Holocene dolomitization of supratidal sediments by active tidal pumping, Sugarloaf Key, Florida. Journal of Sedimentary Petrology, **57**: 153-165.

Catacosinos, P.A. 1973. Cambrian Lithostratigraphy of Michigan Basin. The American Association of Petroleum Geologists Bulletin, **57**: 2404-2418.

Chadwick, G.H. 1920. The Paleozoic rocks of the Canton Quadrangle. New York State Museum Bulletin 217-218. University of the State of New York, Albany, New York.

Chan, M.A., Parry, W.T., and Bowman, J.R. 2000. Diagenetic hematite and manganese oxides and fault-related fluid flow in Jurassic sandstones, Southeastern Utah. American Association of Petroleum Geologists Bulletin, **84**: 1281-1310.

Cherns, L., Wheeley, J.R., Popov, L.E., Ghobadi Pour, M., Owens, R.M., and Hemsley, A.R. 2013. Long-period orbital climate forcing in the early Palaeozoic? Journal of the Geological Society, **170**: 707-710.

Chow, N., and James, N.P. 1987. Cambrian grand cycles; a Northern Appalachian perspective. *Geological Society of America Bulletin*, **98**: 418-429.

Clark, T.H. 1966. Châteauguay Area; Châteauguay, Huntingdon, Beauharnois, Napierville and St. Jean counties. 122, Québec Department of Natural Resources Geological Report 122, Québec Department of Natural Resources, Québec, Québec.

Clark, T.H. 1972. Region de Montreal--Montreal area. Québec Geological Exploration Service Geological Report 122, Québec Department of Natural Resources, Québec, Québec.

Clark, T.H., and Usher, J.L. 1948. The sense of Climactichnites. *American Journal of Science*, **246**: 251-253.

Clayton, L., and Attig, J.W. 1990. Geology of Sauk County, Wisconsin. Wisconsin Geological and Natural History Survey, Information Circular 67.

Collette, J.H., and Hagadorn, J.W. 2010. Three-dimensionally preserved arthropods from Cambrian Lagerstaetten of Quebec and Wisconsin. *Journal of Paleontology*, **84**: 646-667.

Cox, R., and Lowe, D.R. 1995. Compositional evolution of coarse clastic sediments in the Southwestern United States from 1.8 to 0.2 Ga and implications for relationships between the development of crustal blocks and their sedimentary cover. *Journal of Sedimentary Research*, **65**: 477-494.

Cushing, H.P. 1908. Lower portion of the Paleozoic section in northwestern New York. *Bulletin of the Geological Society of America*, **19**: 155-176.

Dickinson, W.R., and Suczek, C.A. 1979. Plate tectonics and sandstone compositions. The American Association of Petroleum Geologists Bulletin, **63**: 2164-2182.

Dickinson, W.R., Beard, L.S., Brakenridge, G.R., Erjavec, J.L., Ferguson, R.C., Inman, K.F., Knepp, R.A., Lindberg, F.A., and Ryberg, P.T. 1983. Provenance of North American Phanerozoic sandstones in relation to tectonic setting. Geological Society of America Bulletin, **94**: 222-235.

Dix, G.R., Salad Hersi, O., and Nowlan, G.S. 2004. The Potsdam-Beekmantown Group boundary, Nepean Formation type section (Ottawa, Ontario): A cryptic sequence boundary, not a conformable transition. Canadian Journal of Earth Sciences, **41**: 897-902.

Dott, R.H., Jr., Byers, C.W., Fielder, G.W., Stenzel, S.R., and Winfree, K.E. 1986. Aeolian to marine transition in Cambro-Ordovician cratonic sheet sandstones of the northern Mississippi Valley, U.S.A. Sedimentology, **33**: 345-367.

Drahovzal, J.A. 1995. Exploration strategies and possible submarine fan complexes in the Rough Creek Graben, western Kentucky. The American Association of Petroleum Geologists Bulletin, **79**: 1412.

Drahovzal, J.A. 1996. Cambrian and Precambrian rifting in central and western Kentucky; evidence from reflection-seismic data. The American Association of Petroleum Geologists Bulletin, **80**, 1522-1523.

Drahovzal, J.A. 1997. Proterozoic sequences and their implications for Precambrian and Cambrian geologic evolution of western Kentucky; evidence from seismic-reflection data. *Seismological Research Letters*, **68**: 553-566.

Emmons, E. 1838. Report of the second geological district of the State of New York. New York Geological Survey Annual Report 2, New York Geological Survey, Albany, New York, p. 185-252.

Emmons, E. 1841. Proposed Keeseville Sandstone for parts of Potsdam: Fifth annual report of the survey of the second geological district of New York. New York Geological Survey Annual Report 5, New York Geological Survey, Albany, New York, p. 113-136.

Fisher, D.W. 1955. Time span of the Theresa and Potsdam formations in the region peripheral to the Adirondack Mountains, New York. *Bulletin of the Geological Society of America*, **66**: 1558-1559.

Fisher, D.W. 1968. Geology of the Plattsburgh and Rouses Point, New York–Vermont, quadrangles. Special Bulletin no.1, Vermont Geological Survey, Burlington, Vermont.

Flower, R.H. 1964. The nautiloid order Ellesmeroceratida (Cephalopoda). New Mexico Bureau of Mines and Mineral Resources Memoir 12, Socorro, New Mexico.

Folk, R.L., and Land, L.S. 1975. Mg/Ca Ratio and Salinity; Two Controls over Crystallization of Dolomite. *The American Association of Petroleum Geologists Bulletin*, **59**: 60-68.

Gile, L.H., and Grossman, R.B. 1968. Morphology of the argillic horizon in desert soils of southern New Mexico. *Soil Science*, **106**: 6-15.

Globensky, Y. 1982. Lachute region; Region de Lachute. Rapport Geologique - Ministere de l'Energie et des Ressources 200, Ministere de l'Energie et des Ressources, Quebec, Québec.

Globensky, Y. 1986. Geology of the Saint-Charles and Lachine region (south); Geologie de la region de Saint-Charles et de Lachine (sud). MM 84-02, Ministere de l'Energie et des Ressources, Québec, Québec.

Globensky, Y. 1987. Geology of the Saint Lawrence Lowlands; Geologie des basses-terres du Saint-Laurent. MM 85-02, Ministere de l'Energie et des Ressources, Québec, Québec.

Goldberg, J., and Mehrtens, C. 1998. Depositional environment and sequence stratigraphy interpretation of the lower Middle Cambrian Monkton quartzite, Vermont. *Northeastern Geology and Environmental Sciences*, **20**: 11-27.

Greggs, R.G., and Bond, I.J. 1971. Conodonts from the March and Oxford formations in the Brockville area, Ontario. *Canadian Journal of Earth Sciences*, **8**: 1455-1471.

Greggs, R.G., and Bond, I.J. 1972. A Principal Reference Section Proposed for the Nepean Formation of Probable Tremadocian Age Near Ottawa, Ontario. *Canadian Journal of Earth Sciences*, **9**: 933-941.

Hagadorn, J.W., and Belt, E.S. 2008. Stranded in upstate New York; Cambrian scyphomedusae from the Potsdam Sandstone. *Palaaios*, **23**: 424-441.

Hagadorn, J.W., Collette, J.H., and Belt, E.S. 2011. Eolian-aquatic deposits and faunas of the Middle Cambrian Potsdam Group. *Palaaios*, **26**: 314-334.

Haq, B.U. and Schutter, S.R., 2008. A chronology of paleozoic sea-level changes. *Science*, **322**: 64-68.

Harris, D.C, and Drahovzal, J.A. 1996. Cambrian potential indicated in Kentucky Rome Trough. *Oil & Gas Journal*, **94**: 52-57.

Holbrook, J., Scott, R.W., and Oboh-Ikuenobe, F.E. 2006. Base-level buffers and buttresses: a model for upstream versus downstream control on fluvial geometry and architecture within sequences. *Journal of Sedimentary Research*, **76**: 162-174.

Hu, G., and Plint, A.G. 2009. An allostratigraphic correlation of a mudstone-dominated, syn-tectonic wedge: the Puskwaskau Formation (Santonian-Campanian) in outcrop and subsurface, Western Canada Foreland Basin. *Bulletin of Canadian Petroleum Geology*, **57**: 1-33.

James, N.P., and Stevens, R.K. 1986. Stratigraphy and correlation of the Cambro-Ordovician Cow Head Group, western Newfoundland. *Bulletin - Geological Survey of Canada* 366. Geological Survey of Canada, Ottawa, Ontario.

James, N.P., Botsford, J.W., and Williams, S.H. 1987. Allochthonous slope sequence at Lobster Cove Head; evidence for a complex Middle Ordovician platform margin in western Newfoundland. *Canadian Journal of Earth Sciences*, **24**: 1199-1211.

Kamo, S.L., Krogh, T.E., and Kumarapeli, P.S. 1995. Age of the Grenville dyke swarm, Ontario - Quebec: implications for the timing of Iapetan rifting. *Canadian Journal of Earth Sciences*, **32**: 273-280.

Kay, G.M. 1942. Ottawa-Bonnechere graben and Lake Ontario homocline. Bulletin of the Geological Society of America, **53**: 585-646.

Kirwan, J.L. 1963. The age of the Nepean (Potsdam) Sandstone in eastern Ontario. American Journal of Science, **261**: 108-110.

Knight, I., and Boyce, W.D. 1991. Deformed Lower Paleozoic Platform Carbonates, Goose Arm - Old Man's Pond. Current Research, Report 91-1, Newfoundland Department of Mines and Energy, Geological Survey Branch, St. John's, Newfoundland.

Knight, I. 1991. Geology of Cambro-Ordovician rocks in the Port Saunders (NTS 12I/11), Castors River (NTS 12I/15), St. John Island (NTS 12I/14) and Torrent River (NTS 12I/10) map areas. Geological Survey, Department of Mines and Energy, Geoscience Publications and Information Section, St John's, Newfoundland.

Kumarapeli, P.S. 1985. Vestiges of Iapetan rifting in the craton west of the Northern Appalachians. Geoscience Canada, **12**: 54-59.

Kumarapeli, P.S. 1993. A plume-generated segment of the rifted margin of Laurentia, southern Canadian Appalachians, seen through a completed Wilson Cycle. Tectonophysics, **219**: 47-55.

Landing, E. 1993. Cambrian-Ordovician boundary in the Taconic allochthon, eastern New York, and its interregional correlation. Journal of Paleontology, **67**: 1-19.

Landing, E. 2007. Ediacaran-Ordovician of east Laurentia; geologic setting and controls on deposition along the New York Promontory region. *In* Ediacaran-Ordovician of east Laurentia,

Edited by Landing, E. Bulletin - New York State Museum 510, The New York State Education Department, Albany, New York. pp.5-24.

Landing, E., Westrop, S.R., and van, A.H. 2003. Uppermost Cambrian-Lower Ordovician faunas and Laurentian Platform sequence stratigraphy, eastern New York and Vermont. *Journal of Paleontology*, **77**: 78-98.

Landing, E., Amati, L., and Franzi, D.A. 2009. Epeirogenic transgression near a triple junction; the oldest (latest Early-Middle Cambrian) marine onlap of cratonic New York and Quebec. *Geological Magazine*, **146**: 552-566.

Lavoie, D. 1997. Cambrian–Ordovician slope conglomerates in the Humber Zone, Québec Reentrant, Québec. *In* Current research 1997-D, Geological Survey of Canada, Ottawa, Ontario. pp. 9-20.

Lavoie, D. 1998. Along strike Upper Cambrian – Lower Ordovician stratigraphic nomenclature and framework for the external Humber Zone, from Québec City to Gaspé. *In* Current research 1998-D, Geological Survey of Canada, Ottawa, Canada. pp. 11-18.

Lavoie, D. 2008. Appalachian foreland basin of Canada. *In* The sedimentary basins of the United States and Canada. *Edited by* Miall, A.D. Sedimentary Basins of the World, Vol. 5, Elsevier, The Netherlands. pp. 65-103.

Lavoie, D., Burden, E., and Lebel, D. 2003. Stratigraphic framework for the Cambrian-Ordovician rift and passive margin successions from southern Quebec to western Newfoundland. *Canadian Journal of Earth Sciences*, **40**: 177-205.

Lewis, D.W. 1971. Qualitative petrographic interpretation of Potsdam sandstone (Cambrian), southwestern Quebec. *Canadian Journal of Earth Sciences*, **8**: 853-882.

Lochman, C. 1968. *Crepicephalus* faunule from the Bonnetterre Dolomite (Upper Cambrian) of Missouri. *Journal of Paleontology*, **42**: 1153-1162.

Logan, W.E. 1863. *Geology of Canada*. Geological Survey of Canada Report of Progress from Commencement to 1863, Dawson Brothers, Montreal, Quebec.

Lowe, D.G. 2016. Sedimentology, Stratigraphic Evolution and Provenance of the Cambrian – Early Ordovician Potsdam Group in the Ottawa Embayment and Quebec Basin. Ph.D. thesis, Department of Earth Sciences, University of Ottawa, Ontario.

Lowe, D.G. 2014. Stratigraphy and Terrestrial to Shallow Marine Environments of the Potsdam Group in the Southwestern Ottawa Embayment. *In* *Geology of the Northwestern Adirondacks and St. Lawrence River Valley*, New York State Geological Association 86th annual meeting guidebook, pp.183 – 203.

Lowe, D.G., and Arnott, R.W.C. 2016. Composition and architecture of braided and sheetflood-dominated ephemeral fluvial strata in the Cambrian-Ordovician Potsdam group: A case example of the morphodynamics of early Phanerozoic fluvial systems and climate change. *Journal of Sedimentary Research*, **86**: 587-612.

Mack, G.H., James, W.C., and Monger, H.C. 1993. Classification of Paleosols. *Geological Society of America Bulletin*, **105**: 129-136.

MacNaughton, R.B., Cole, J.M., Dalrymple, R.W., Braddy, S.J., Briggs, D.E.G., and Lukie, T.D. 2002. First steps on land; arthropod trackways in Cambrian-Ordovician eolian sandstone, southeastern Ontario, Canada. *Geology*, **30**: 391-394.

Malhame, P., and Hesse, R. 2015. Quartz arenites of the Cambro-Ordovician Kamouraska formation, Quebec Appalachians, Canada: II. Eolian sands in deep-sea sedimentary gravity-flow deposits. *Canadian Journal of Earth Sciences*, **52**: 261-277.

Malone, D.H., Stein, C.A., Craddock, J.P., Kley, J., Stein, S., and Malone, J.E. 2016. Maximum depositional age of the Neoproterozoic Jacobsville Sandstone, Michigan: Implications for the evolution of the Midcontinent Rift. *Geosphere*, **12**: 1271-1282.

McCausland, P.J.A., Van, d.V., and Hall, C.M. 2007. Circum-Iapetus paleogeography of the Precambrian-Cambrian transition with a new paleomagnetic constraint from Laurentia. *Precambrian Research*, **156**: 125-152.

McCausland, P.J.A., Hankard, F., Van, d.V., and Hall, C.M. 2011. Ediacaran paleogeography of Laurentia: Paleomagnetism and ^{40}Ar - ^{39}Ar geochronology of the 583Ma Baie des Moutons syenite, Quebec. *Precambrian Research*, **187**: 58-78.

McCracken, A.D., 2014. Report on 2 Early Ordovician conodont samples from the Potsdam Group near Saint-Chrysostome, southwestern Quebec submitted by David Lowe and Bill Arnott (University of Ottawa). Geological Survey of Canada Paleontological Report 2-ADM-2014, Geological Survey of Canada, Calgary, Alberta.

McKee, E.D., and Weir, G.W. 1953. Terminology for stratification and cross-stratification in sedimentary rocks. *Geological Society of America Bulletin*, **64**: 381-389.

Medina, C.R., and Rupp, J.A. 2012. Reservoir characterization and lithostratigraphic division of the Mount Simon Sandstone (Cambrian); implications for estimations of geologic sequestration storage capacity. *Environmental Geosciences*, **19**: 1-15.

Mehrtens, C.J., and Butler, R.J. 1989. Sedimentology of the Upper Cambrian Danby Formation, western Vermont: an example of mixed siliciclastic and carbonate sedimentation. *Northeastern Geology*, **11**: 84-97.

Mount, J.F. 1984. Mixing of siliciclastic and carbonate sediments in shallow shelf environments. *Geology*, **12**: 432-435.

NACSN (the North American Commission on Stratigraphic Nomenclature), 2005. North American Stratigraphic Code. *American Association of Petroleum Geologists Bulletin*, **89**: 1547-1591.

Nowlan, G.S., 2013. Report on two samples from Lower Ordovician strata in the vicinity of Rockland in eastern Ontario submitted for conodont analysis by David Lowe and Bill Arnott (University of Ottawa). Geological Survey of Canada, Paleontological Report 004-GSN-2013, Geological Survey of Canada, Calgary, Alberta.

Otvos, J., E.G. 1966. Sedimentary structures and depositional environments, Potsdam Formation, Upper Cambrian. *American Association of Petroleum Geologists Bulletin*, **50**: 159-165.

Palmer, A.R., and James, N.P. 1980. The Hawke Bay Event; a circum-Iapetus regression near the lower Middle Cambrian boundary. *In* The Caledonides in the U.S.A., Proceedings. *Edited by* Wones, D.R. Memoir 1, Virginia Polytechnic Institute and State University Department of Geological Sciences, Blacksburg, Virginia. pp. 15-18.

Postel, A.W., Nelson, A.E., and Wiesnet, D.R. 1959. Geologic map of the Nicholasville quadrangle, New York. Map GQ-123, United States Geological Survey, Reston, Virginia.

Pratt, B.R. 2010. Peritidal Carbonates. *In* Facies Models 4. *Edited by* N.P. James and R.W. Dalrymple. Geological Association of Canada, St. John's, Newfoundland. pp. 401-420.

Purser, B., Tucker, M., and Zenger, D. 1994. Dolomites; a volume in honour of Dolomieu. International Association of Sedimentologists Special Publication 21, Blackwell, Oxford, UK.

Reed, J.C. 1934. Geology of the Potsdam Quadrangle. *In* New York State Museum Bulletin 297, State Department of Education, Albany, NY, United States. pp. 5-65.

Ross Jr., R.J., Hintze, L.F., Ethington, R.L., Miller, J.F., Taylor, M.E., Repetski, J.E., Sprinkle, J., and Guensburg, T.E. 1997. The Ibexian, lowermost series in the North American Ordovician. *In* Early Paleozoic Biochronology of the Great Basin, Western United States. U.S. Geological Survey Professional Paper 1579, United States Government Printing Office, Washington D.C. pp. 1-50.

Salad Hersi, O., Lavoie, D., and Nowlan, G.S. 2003. Reappraisal of the Beekmantown Group sedimentology and stratigraphy, Montreal area, southwestern Quebec; implications for

understanding the depositional evolution of the Lower-Middle Ordovician Laurentian passive margin of Eastern Canada. *Canadian Journal of Earth Sciences*, **40**: 149-176.

Salad Hersi, O., Lavoie, D., Hilowle Mohamed, A., and Nowlan, G.S. 2002a. Subaerial unconformity at the Potsdam–Beekmantown contact in the Quebec Reentrant: regional significance for the Laurentian continental margin history. *Bulletin and Canadian Petroleum Geology*, **50**: 419-440.

Salad Hersi, O., Lavoie, D., and Nowlan, G.S. 2002b. Stratigraphy and sedimentology of the Upper Cambrian Strites Pond Formation, Philipsburg Group, southern Quebec, and implications for the Cambrian platform in eastern Canada. *Bulletin and Canadian Petroleum Geology*, **50**: 542-565.

Salad Hersi, O., and Dix, G.R. 2006. Precambrian fault systems as control on regional differences in relative sea level along the Early Ordovician platform of eastern North America. *Journal of Sedimentary Research*, **76**: 700-716.

Salad Hersi, O., and Lavoie, D. 2000a. Pre-Cairnside Formation carbonate-rich sandstone: evidence for a Cambrian carbonate platform in southwestern Quebec? *Current Research 2000-D3*, Geological Survey of Canada, Ottawa, ON, Canada.

Salad Hersi, O., and Lavoie, D. 2000b. Lithostratigraphic revision of the Upper Cambrian Cairnside Formation, upper Potsdam Group, southwestern Quebec. *Current Research 2000-D4*, Geological Survey of Canada, Ottawa, ON, Canada.

Sanford, B.V. 2007. Stratigraphic and structural framework of the Potsdam Group in eastern Ontario, western Quebec and northern New York State. Ph.D. thesis, Department of Earth Sciences, University of Ottawa, Ontario.

Sanford, B.V., and Arnott, R.W.C. 2010. Stratigraphic and Structural Framework of the Potsdam Group in eastern Ontario, western Quebec and northern New York State. Geological Survey of Canada Bulletin 5907, Geological Survey of Canada, Ottawa, Ontario.

Santos, J.O.S., Hartmann, L.A., McNaughton, N.J., Easton, R.M., Rea, R.G., and Potter, P.E. 2002. Sensitive high resolution ion microprobe (SHRIMP) detrital zircon geochronology provides new evidence for a hidden Neoproterozoic foreland basin to the Grenville Orogen in the eastern Midwest, U.S.A. Canadian Journal of Earth Sciences, **39**: 1505-1515.

Seguin, M.K., Rao, K.V., and Arnal, P. 1981. Paleomagnetic study of Cambrian Potsdam Group sandstones, St. Lawrence Lowlands, Quebec. Earth and Planetary Science Letters, **55**: 433-449.

Selleck, B.W. 1978. Syndepositional brecciation in the Potsdam Sandstone of northern New York State. Journal of Sedimentary Petrology, **48**: 1177-1184.

Selleck, B.W. 1975. Paleoenvironments and petrography of the Potsdam Sandstone, Theresa Formation and Ogdensburg Dolomite (U. Camb. - L. Ord.) of the southwestern St. Lawrence Valley, New York. Ph.D. thesis, Department of Geology, University of Rochester, Rochester, New York.

Selleck, B.W. 1978. Paleoenvironments of the Potsdam Sandstone and Theresa Formation of the southwestern St. Lawrence Lowlands. *In* Field Trip Guidebook - New York State Geological Association, 50th Annual Meeting, Syracuse, New York. pp.173-188.

Selleck, B.W. 1993. Sedimentology and diagenesis of the Potsdam Sandstone and Theresa Formation, southwestern St. Lawrence Valley. *In* Field Trip Guidebook - New York State Geological Association, 65th Annual Meeting, Canton, New York. pp. 219-228.

Shaw, A.B. 1958. Stratigraphy and structure of the Saint Albans area, northwestern Vermont. *Bulletin of the Geological Society of America*, **69**: 519-567.

Shrake, D.L. 1991. The Middle Run Formation; a subsurface stratigraphic unit in southwestern Ohio. *The Ohio Journal of Science*, **91**: 49-55.

Shrake, D.L., Carlton, R.W., Wickstrom, L.H., Potter, P.E., Richard, B.H., Wolfe, P.J., and Sitler, G.M. 1991. Pre-Mount Simon basin under the Cincinnati Arch. *Geology*, **19**: 139-142.

Singer, A. 1975. A Cretaceous laterite in the Negev Desert, southern Israel. *Geological Magazine*, **112**: 151-162.

Sloss, L.L. 1963. Sequences in the cratonic interior of North America. *Geological Society of America Bulletin*, **74**: 93-113.

Speyer, S.E. 1983. Subtidal and intertidal clastic sedimentation in a Lower Cambrian sequence-Monkton Quartzite, northwestern Vermont. *Northeastern Geology*, **5**: 29-39.

Thiry, M. 1999. Diversity of continental silicification features; examples from the Cenozoic deposits in the Paris Basin and neighbouring basement. *In* Palaeoweathering, palaeosurfaces and related continental deposits, *Edited by* Thiry, M., Simon-Coincon, R. Special Publication of the International Association of Sedimentologists 27, International Association of Sedimentologists, Ghent, Belgium. pp. 87-127.

Thomas, W.A. 1991. The Appalachian-Ouachita rifted margin of southeastern North America. *Geological Society of America Bulletin*, **103**: 415-431.

Thomas, W.A. 2006. Tectonic inheritance at a continental margin: *GSA Today*, **16**: 4-11.

Torsvik, T.H., Smethurst, M.A., Meert, J.G., and Van, D.V. 1996. Continental break-up and collision in the Neoproterozoic and Palaeozoic - A tale of Baltica and Laurentia. *Earth Science Reviews*, **40**: 229-229.

van Staal, C.R., Whalen, J.B., McNicoll, V.J., Pehrsson, S., Lissenberg, C.J., Zagorevski, A., van Breemen, O., and Jenner, G.A. 2007. The Notre Dame Arc and the Taconic Orogeny in Newfoundland. *In* 4-D Framework of Continental Crust, *Edited by* Hatcher, R.D., Jr., Carlson, M.P., McBride, J.H., and Martínez Catalán, J.R. *Geological Society of America Memoir* 200, Geological Society of America, Boulder Colorado. pp. 511-552.

Walcott, C.D. 1891. Correlation papers, Cambrian. *U.S. Geological Survey Bulletin* 81, U.S. Geological Survey, Reston, VA, United States.

Waldron, J.W.F., and van Staal, C.R. 2001. Taconian Orogeny and the accretion of the Dashwoods Block; a peri-Laurentian microcontinent in the Iapetus Ocean. *Geology*, **29**: 811-814.

Williams, D.A., and Wolf, R.R. 1984. Paleozoic geology of the Westport area, southern Ontario. Ontario Geological Survey Map P.2723, Ontario Geological Survey, Sudbury, Ontario.

Williams, D.A., Rae, A.M., and Wolf, R.R. 1984. Paleozoic geology of the Ottawa area, southern Ontario. Ontario Geological Survey Map P.2716, Ontario Geological Survey, Sudbury, Ontario.

Wilson, A.E. 1946. Geology of Ottawa–St. Lawrence lowland, Ontario and Quebec. Geological Survey of Canada Memoir 241, Geological Survey of Canada, Ottawa, Ontario.

Wolf, R.R., and Dalrymple, R.W. 1984. Sedimentology of the Cambro-Ordovician sandstones of eastern Ontario. *In* Geoscience Research Grant Program Summary of Research 1983 – 1984. *Edited by* Milne, V.G. Ontario Geological Survey Miscellaneous Paper 121, Ontario Geological Survey, Sudbury, Ontario. pp. 240-252.

Woodward, H.P. 1961. Preliminary subsurface study of southeastern Appalachian Interior Plateau. *Bulletin of the American Association of Petroleum Geologists*, **45**: 1634-1655.

Yang, B.C., Dalrymple, R.W., Chun, S.S., and Lee, H.J. 2006. Transgressive sedimentation and stratigraphic evolution of a wave-dominated macrotidal coast, western Korea. *Marine Geology*, **235**: 35-48.

Well name	UTM location
Lanark County No.1	408825E; 4973929N
Lanark County No.2	411137E; 4974141N
AMEC MW-301 monitoring well	424622N; 5023046N
GSC Dominion Observatory No.1	443950E; 5026500N
GSC LeBreton No. 1	445500E; 5028100N
GSC Russell No.1	469150E; 5017450N
Consumers Gas No. 12023	468919E; 5011842N
GSC McCrimmon No. 1	520250E; 5030200N
Gastem Dundee No.1	544391E; 4989999N
St. Lawrence River No.1*	577025E; 5013642N
Quonto-International St. Vincent de Paul No.1	604418E; 5055374N
Quonto-International Mascouche No.1	600900E; 5066250N

Table 1: Boreholes used in this study and their coordinates. Lithological data for core St. Lawrence River No. 1 is from Sanford (2007) and Sanford and Arnott (2010).

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Facies Association	Description	Interpretation
FA1	Mostly upper medium- / coarse-grained, trough cross-stratified sandstone; sets are ~5 – 70 cm thick (a). Rare 0.5 – 1.6 m thick tabular cross-stratified sandstone sets (b), and rare high-relief scours filled by boundary-conformable cross-stratified sandstone (c). Most cross-stratified sandstone forms a downcurrent-accreting compound architecture (d). Also rare are pebble to cobble conglomerate with imbricated or aligned fabric (e), and thin (≤ 7 cm) fine-grained, normally-graded, matrix-rich sandstone beds.	Braided fluvial: deposition of coarse-grained bedload under steady flow conditions by the migration of dunes (a), rare unit bars (b) and tractional gravel (e). Downcurrent accreting architecture (d) records the buildup and migration of downstream-accreting compound braid bars, rare scours (c) record confluence scouring, and thin fine-grained sandstone beds (f) record overbank sedimentation.
FA2	Mainly medium-grained, planar-stratified sandstone consisting of common inversely-graded laminae (a), structureless planar laminae with common irregularly textured bedding planes (b), normally-graded laminae (c), and symmetrical (d) and asymmetric (e) ripples. Rare low- to high-angle, coarse-grained cross-strata with ~3 cm – 1.2 m thick sets. Cross-stratification dips opposite to other kinds of angular cross-strata and fills dm- to m-scale scours (f), and channel-filling coarse-grained trough cross-stratified sandstone with ~5 – 20 cm thick sets (g).	Ephemeral fluvial: Planar strata records shallow, unconfined terminal sheetflood sedimentation followed by aeolian reworking, resulting in a combination of shallow water (upper plane bed (c), current (e) and wave (d) ripples) and aeolian facies (wind ripple (a) and adhesion (b) stratification). Scour-filling, upstream-migrating supercritical bedform cross-strata (f) record high-energy sheetflood conditions and channelized cross-strata (g) records the erosion and filling of rare distributary channels by sandy dunes.
FA3	Mostly medium-grained sandstone occurring as ~0.5 – 20 m thick trough cross-stratified sets (a), interstratified with lesser ~5 – 40 cm thick planar-stratified beds (b). Cross-strata in large sets (a) are ~0.5 – 6 cm thick and inversely-graded (c), and planar strata in (b) consist of inversely-graded planar laminae (d) and structureless planar laminae with common bumps and crenulations on bedding planes (e).	Aeolian erg: large-scale sets (a) record the migration of aeolian dunes with common grain-flows (c) occurring on their steep leeward side. Interstratified planar beds (b) record interdune sedimentation, mainly the migration and buildup of wind ripples (d) and adhesion strata (e) recording mostly dry but intermittently damp conditions.
FA4	Mostly medium-grained, planar-stratified sandstone (a) with similar shallow water, adhesion and aeolian facies as FA2. Features indicative of evaporate mineralization are common in outcrop, including weathered gypsum and halite pseudomorph impressions (b) and dolomitic nodules and gypsum/anhydrite(?) pseudomorphs (c). Gypsum veins and nodules are present in core. Also present are delicate contorted and tightly-folded sandstone intraclasts (d) and dm- to m- deep channels filled with upper medium- to coarse-grained, cross-stratified sandstone with ~5 – 70 cm thick sets (e). Rare epifaunal and infaunal trace fossils (f).	Coastal Sabkha: Planar stratified sandstone (a) records low energy windblown and shallow water sedimentation on a coastal plain environment. Evaporite pseudomorphs and minerals (b, c) record evaporitic precipitation from seawater, whereas sandstone intraclasts (d) record the consolidation of surficial sand by microbial and/or efflorescent salt encrustation. Channels and their cross-stratified sandstone fill (e) record the channelization of fluvial and/or tidal drainage across the sabkha, followed by their filling with dune cross-stratified coarse sand. Rare trace fossils (f) record a sparse and likely stressed coastal fauna.
FA5	Mainly medium to coarse-grained, trough and tabular cross-stratified sandstone with ~5 – 70 cm thick sets, forming ~0.2 – 3 m thick compound cosets with a downstream-accreting architecture (a). Infaunal burrows (b), mainly <i>Skolithos</i> and <i>Diplocraterion</i> , occur near the tops and bases of compound cosets. These are interstratified with intensely bioturbated tabular beds (c) with rare low-relief symmetrical and asymmetric ripples and	Tidal shelf and estuary: Compound cosets (a) record high energy tidal shelf and nearshore sedimentation by the buildup and migration of compound dunes and compound dune fields. Burrows near the tops and bases of compound dunes (b) record colonization events preceding and following compound dune sedimentation. Intensely bioturbated strata (c) record ambient low-energy tidal shelf sedimentation surrounding

	patchy carbonate cement. Rare cryptically-laminated and sparsely bioturbated dolomicrite beds (e) also occur.	compound dunes. Rare dolomicrite beds (e) are interpreted as peritidal dolomite beds, mediated by microbial mat growth on low energy parts of the tidal shelf.
FA6	Mostly red and locally variegated red and grey, locally dolomitic, massive or laminated silty mudstone (a), interstratified with common erosively- or sharp-based ~0.3 – 2 cm thick layers of siltstone to lower medium-grained sandstone (b), and rare ~3 – 35 cm thick tabular, poorly-sorted, normally-graded, locally erosively based, medium- to very coarse-grained sandstone beds (c). Also present are rare ~0.9 – 2.5 m thick, sharp-based beds composed of well-sorted, fine- to medium-grained, hummocky, swaley and current-ripple cross-stratified sandstone (d), and cryptically-laminated and dolomicrite beds (e). Mudstone, fine sandstone and dolostone strata are sparsely bioturbated with rare vertical and horizontal traces, including <i>Cruziana</i> (f).	Open coast tidal flat: Mudstone (a) and thin sandstone beds (b) record ambient tide- and wave-driven coastal sedimentation, whereas thick coarse-grained sandstone beds (c) record strong fluvial discharge onto the coastal flat, and hummocky- and swaley-cross stratified sandstone beds (d) record strong storm-wave induced sedimentation. Laminated dolomicrite beds (e) are interpreted as peritidal dolomites accumulated in low energy lagoonal intertidal environments landward of the wave maximum and away from river mouths. Sparse trace fossils (f) including <i>Cruziana</i> corroborate a marginal marine setting, and the low diversity and abundance of traces was likely due to salinity variations, common subaerial exposure and high near-bed sediment concentrations.

Table 2: Summary of the six depositional facies associations recognized in the Potsdam Group. For more details please see Lowe (2016) and Lowe and Arnott (2016).

Lithostratigraphic Unit	Description	Lithofacies association(s)	Notable localities/ potential stratotypes*
Ausable Formation	Red to grey coarse-grained arkose and rare conglomerate, mudstone, siltstone and dolostone, occurring at the base of the Potsdam. The Altona Member consists of a conformable intertonguing package of mudstone-dominated strata with rare arkose and dolostone located in the eastern part of the study area near the base of the Ausable Formation.	FA1 (braided fluvial), FA6 (open coast tidal flat – Altona Member only).	Exposures at Lapham Mills NY, Altona Flat Rock State Forest NY, Ile Perrot QC, Franklin QC, Nicholsville NY and at the head of Briton Bay on the Big Rideau Lake, ON (localities 245, 251-253, 194, 176, 246 and 12, respectively*). <i>Altona Member:</i> Crops out on Military Turnpike (rt. 190) and Atwood Farm location, NY. Localities 184 – 186, 232 – 234; see also Landing et al. (2009).
Hannawa Falls Formation	Mostly red to pink, medium-grained quartz arenite conformably overlying the Ausable Formation and unconformably overlain by the Keeseville Formation.	FA3 (aeolian erg), FA2 (ephemeral fluvial).	Exposures in the Raquette River in Hannawa Falls NY (loc. 220), and nearby quarry (192), Sloan Quarry ON (27), Hughes Farm ON (26), Ellisville Quarry (68; basal unit), Exposure near Chippewa Bay NY (86; at base of section).*
Keeseville Formation	Generally buff to grey, medium- to coarse-grained quartz arenite and rare quartzose conglomerate, mudstone and dolostone. Unconformably overlies the Ausable and Hannawa Falls formations. In the northern part of the study area the Riviere Aux Outardes Member forms an intertonguing unit of bioturbated, locally dolomitic sandstone and rare dolostone.	FA1 (braided fluvial), FA2 (ephemeral fluvial), FA3 (aeolian erg), FA4 (coastal sabkha), FA5 (tidal shelf).	Ausable Chasm (locality 190), outcrops in and around the town of Altona NY (e.g. 154, 187), Ducharme Quarry (200, 201, 203), outcrops and quarries near Melocheville QC (e.g. 206, 207, 210), outcrops along Highway 12 near Alexandria Bay, NY (e.g. 86, 87, 100, 104, 112), near Perth ON (e.g. 16, 76), near Gananoque ON (e.g. 22, 68), near Brockville, ON (e.g. 20, 223), in Nepean and Kanata, ON (e.g. 1, 5, 222) and in Gatineau, QC (e.g. 8, 9).*

10 Table 3: Summary of the lithostratigraphic formations that comprise the Potsdam Group.

Figure Captions

Figure 1: Geologic and isopach map of the Potsdam Group in the Ottawa Embayment and Quebec Basin. Isopach thickness is in meters. These two basins are semi-connected but are separated by the Oka-Beauharnois Arch. A second arch, the Frontenac Arch, bounds the southeastern margin of the Ottawa Embayment. A number of normal faults occur within this area and exert a strong control over the Potsdam isopach and lithofacies distributions (see text for more details). Some of these faults are particularly important and are discussed in this paper, and include: the Gloucester fault (GF), Rideau Lakes fault (RLF), Black Lake fault (BLF), Chateauguay Lake fault (CLF), Russel-Rigaud Fault (RRF) and Ste. Justine fault (SJF). Red dots and numbers mark the location and identity (respectively) of wellbores used for isopach interpolation and regional correlation. Stratigraphy and correlation of cores from wellbores are shown in figure 4.

Figure 2: Paleogeographic and tectonic map of Southern Laurentia during the Cambrian and earliest Ordovician with the modern North American coastline overlain for reference compiled using a number of sources (see “Paleogeographic and tectonic setting”), but mainly modified from modified from Thomas (2006) and Allen et al. (2010). Dashed black lines correspond to the presumed margin of Laurentian continental crust, and dashed red lines correspond to major oceanic transform faults. The Ottawa graben (OG) is outlined in red, along with related intracratonic rifts such as the Saguenay graben (SG), Rome trough (RT) and Rough Creek graben (RC). The shaded area indicates the known distribution of the Potsdam Group in the Ottawa Embayment and Quebec Basin, at the paleo-southern end of the Ottawa Graben. The numbers correspond to the locations of the different the cratonic, shelf and slope successions across southern Laurentia stratigraphic shown in figure 26.

Figure 3: Stratigraphic correlation of units and lithofacies across the northern and southern parts of the Ottawa Embayment and Quebec Basin. Locations of biostratigraphic age control are indicated by the red stars. Potsdam allounits, discussed in the latter part of this paper, are labelled as A1 – A3. Sources of these biostratigraphic constrains come from: (a) Landing et al. (2009), (b) Walcott (1891), Flower (1964), Lochman (1968), Landing et al. (2009) (c) Fisher (1968), (d) this study, (e) Greggs and Bond (1971), (f) this study, (g) Brand and Rust (1977) and Dix et al. (2004), and (h) Salad Hersi et al. (2002). See text for more detail regarding the correlation and age of Potsdam strata.

Figure 4: East – West correlation of units and lithofacies associations from cores of the Potsdam Group across the Ottawa Embayment and Quebec Basin. Numbers correspond to those on figure 1, which gives the location of each wellbore. The cores are from: (1) Lanark County No.1, (2)

Lanark County No.2, (3) AMEC MW-301 monitoring well, (4) Dominion Observatory No.1, (5) GSC LeBreton No. 1, (6) GSC Russell No.1 and Consumers No. 12023, (7) GSC McCrimmon No. 1, (8) Gastem Dundee No.1, (9) St. Lawrence River No.1, (10) Quonto-International St. Vincent de Paul No.1, (11) Quonto-International Mascouche No.1. Faults shown here are the Hazeldean fault (HF), Gloucester fault (GF) and Ste. Justine fault (SJF). HF Fm. = Hannawa Falls Formation, RAO mb. = Riviere Aux Outardes Member.

Figure 5: Examples of sections belonging to the Ausable Formation. A) coarse- and very coarse-grained arkose interstratified cobble conglomerate of braided fluvial affinity (FA1); Briton Bay, ON (locality 12). B) Pinkish cross-stratified, pebbly coarse-grained arkose with rare pebble conglomerate and thin silty mudstone beds of braided fluvial affinity (FA1); Flat Rock State Forest, NY (locality 251). Arrow points to person for scale. C) Same lithofacies as above exposed on Ile Perrot, QC (locality 194). Arrow points to hammer for scale. Scale on y-axis of stratigraphic logs is in meters.

Figure 6: Correlation of Altona Member strata from its type locality near Chazy, NY (see Landing et al. (2009) for more details) northward to Quonto St. Vincent de Paul No.1 near Montreal, QC. Datum at the base is the contact with ~1.0 Ga Grenville basement.

Figure 7: Detailed stratigraphic log of the Altona Member from Quonto St. Vincent de Paul No.1, and core photographs illustrating various lithological features. A) Intergradational basal contact of the coastal tidal flat strata (FA6) of the Altona with underlying braided fluvial arkose. Arrow marks the proposed base of the Altona member. B) Red silty mudstone of tidal flat origin interstratified with a thin (≤ 1 cm) erosively-based, normally graded arkose stratum (arrow), possibly deposited by strong wave and/or tidal currents. C) Erosively-based, normally-graded coarse- to medium-grained arkose, interpreted as an event bed deposited rapidly by a high-energy waning current, possibly a fluvial sheetflood onto the tidal flat, or a high-energy storm/wave-driven flood. D) Well-sorted, fine- to medium-grained, low angle cross-stratified arkose, interpreted as hummocky cross-stratification. E) fine- to very-fine grained planar- and ripple cross-stratified arkose. F) Mottled and variegated red and green silty mudstone.

Figure 8: Features of the Altona Member in outcrop, in its type area near West Chazy, NY (see Landing et al., 2009). A) Arrow points to the contact between sparsely bioturbated red silty mudstone (below) and fine-grained hummocky cross-stratified sandstone; located at Stillwater Creek near Jericho, NY (locality 138). B) Blocky and laminated peritidal dolostone exposed at

Atwood Farm near Chazy New York (locality 185). C) Thin section photomicrograph of laminated dolostone. This image is centered on finely alternating laminae of dolomicrite (light pink/brown) and iron-oxide rich clay (opaque) interpreted as the by-product of the growth and decay of successive microbial mats. The red arrow points to a fossil fragment surrounded by a redox halo. D) Massive, coarse-grained normally graded sandstone beds interstratified with red mudstone, near the top of the Altona Member at Atwood Farm (locality 233). The sandstone beds are interpreted to have been deposited quickly from high-energy, high-concentration, rapidly-waning fluvial sheetfloods near the mouth of a nearby braided river. Scale on y-axis of stratigraphic log is in meters.

Figure 9: Contact between arkosic fluvial strata of the Ausable Formation and overlying quartz arenitic and aeolian Hannawa Falls Formation at Jones Falls Locks, ON (locality 53). These formations are separated here by a ~m thick transitional bed consisting of massive boulder lags and planar wind ripple stratified sandstone. A) Contact between the Ausable and the transitional bed (red dashed line). Subangular boulders and cobbles are outlined in black in the transitional bed. B) Close-up of quartzite cobble showing pitted and striated surface texture interpreted to have formed by prolonged windblown abrasion. C) Thin section photomicrograph of wind-ripple stratified sandstone from the transitional bed with abundant interstitial illuvial matrix. Scale on y-axis of stratigraphic log is in meters.

Figure 10: Example of the top of the arkosic Ausable Formation from the eastern Ottawa Embayment and Quebec Basin, near Franklin, QC (locality 176). A) Here the contact is a cryptic unconformity separating arkose of the Ausable and quartz arenite of the lower Keeseville, both of braided fluvial origin (FA1). B) Close-up of the unconformity showing the ~10 – 15 cm thick massive and silicified granule to pebble lag that caps Ausable strata. C) Same contact in core (Gastem Dundee No. 1, southern Quebec; see table 1). Scale on y-axis of stratigraphic log is in meters.

Figure 11: Thin section photomicrographs showing characteristics of the silcrete that caps Ausable strata at the outcrop section in Figure 11 (locality 176). A) & B) are taken from the capping conglomerate, where early pore-filling non-syntaxial silica cements and minor illuvial matrix are present. Qtz= quartz grain, Qtz cem= quartz cement, il= illuvial matrix. C) & D) are photomicrographs of a sample taken ~1.5 m beneath the capping conglomerate. This sample lacks the early silica cements present in the overlying conglomerate, and instead contains abundant illuvial matrix (il) and possible authigenic matrix from degraded feldspars.

Figure 12: Examples of the Hannawa Falls Formation. A) Red, large-scale cross-bedded, well-sorted medium-grained aeolian (FA3) sandstone that characterizes the Hannawa Falls Formation at its type section in the Raquette River at Hannawa Falls, NY (locality 220). B) Thin section photomicrograph of sample taken from the same section. The pervasive red coloration is due to early iron-oxide rims on quartz grains. Fox= iron oxide, Qtz = quartz grain; il= illuvial matrix. C) Large-scale aeolian dune cross-stratification at Sloan Quarry, ON (locality 27).

Figure 13: Examples of the erosional unconformity separating the Hannawa Falls (HF) and lower Keeseville (KV). A) Erosional unconformity (red dashed line) with minor (≤ 10 cm) erosional relief near Millsite Lake, Redwood, NY (locality 124). B) Same unconformity exposed at Sloan Quarry, ON (locality 27). Here the unconformity is mostly a flat erosional surface with progressive upward-reddening of the underlying Hannawa Falls (left side of photo). However a channel feature (Ch) in basal ephemeral fluvial strata of the Keeseville locally incises Hannawa Falls strata. C) & D) show close-ups of the unconformity from A) and B), location shown in inset yellow boxes. C) At Millsite Lake, a ~5 – 10 cm thick regolithic lag caps the Hannawa Falls, and includes clasts of the red Hannawa Falls sandstone (outlined in white) and quartzite (Qtz). D) At Sloan Quarry abundant clasts of finely-laminated Hannawa Falls material are present at the base of the Keeseville channel feature (outlined in white).

Figure 14: Example of the angular unconformity between the Hannawa Falls (HF) and lower Keeseville (KV) exposed along route 42 east of Phillipsville, ON (locality 41). A) View of the section from the roadside, here Hannawa Falls strata exhibit minor folding and/or slumping and brittle faulting that contrasts the flat-lying, comparatively undeformed strata of the overlying Keeseville. Red circle shows rock hammer for scale. B) Close-up of the angular unconformity at the same location, location given in the inset yellow box in figure 16a. Here, fractured and folded Hannawa Falls strata are truncated erosively by relatively unaffected Keeseville strata. The basal Keeseville here is channelized like locally at Sloan Quarry (figure 15 b), and clasts of eroded Hannawa Falls strata (HF, in red) and quartzite clasts (Qtz) are mixed at the base of the Keeseville Formation.

Figure 15: Photomicrographs of Hannawa Falls strata immediately beneath the allounit 1–2 unconformity at Millsite Lake (locality 124, see figure 13a). A) & B) thin section photomicrographs in plane-polarized (A) and cross-polarized (B) light. Quartz grains (Qtz) are rimmed with iron oxide cement (Feox), and surrounded by intergranular illite (ilt) and disseminated iron oxide cement. B) & C) are scanning electron microscopic images of the same horizon, showing the fibrous nature of the authigenic illite (ilt) cement.

155

156 Figure 16: Outcrop examples of the Keeseville Formation from across the study area. A) Mostly
157 planar-stratified coastal plain ephemeral fluvial strata (FA2) exposed in the Great Chazy River in
158 Woods Falls, NY (locality 148). Arrows demarcate the top and base of a coset of antidune
159 stratification. B) Aeolian dune cross-stratification (FA3) exposed in the Rainbow Quarry, Near
160 Malone, NY (locality 188). C) Planar- and cross-stratified coastal sabkha (FA4) strata exposed in
161 the Melocheville Quarry, near Melocheville, QC (locality 275). D) Ephemeral fluvial strata
162 (FA2) exposed along highway 12 near Alexandria Bay, NY (locality 100). The high-angle set at
163 the base is interpreted as a high-angle, upstream-dipping cyclic step set (see Lowe and Arnott,
164 2016). E) Gravelly braided fluvial strata (FA1) at Charleston Lake Provincial Park, ON (locality
165 57). F) Bioturbated, mostly dune cross-stratified, high-energy tide-dominated marine strata
166 (FA5) exposed along highway 15 southwest of Smiths Falls, ON (locality 16).

167

168 Figure 17: Unconformity (red line) between the lower and upper Keeseville Formation at
169 Rockland, ON (locality 2). Here conodonts occur in rare dolostone interbeds in tide-dominated
170 marine (FA5) strata ~0.9 m beneath the unconformity, and indicate an earliest Ordovician
171 depositional age (see text and appendix A for details). A) The unconformity is erosional with ~5
172 – 10 cm of local relief. Immediately above the unconformity is a ~30 cm thick, massive,
173 regolithic conglomerate overlain by braided fluvial strata (FA1) of the upper Keeseville. B)
174 Close-up of the unconformity showing clasts in the regolithic conglomerate layer. Most consist
175 of quartzite, but near the contact dolomitic sandstone clasts sourced the underlying lower
176 Keeseville (outlined in yellow) are common. Scale on y-axis of stratigraphic log is in meters.

177

178 Figure 18: Examples of the unconformity separating the fluvial lower Keeseville and marine
179 upper Keeseville Formation in the western Ottawa Embayment. A) Localized, high-relief
180 undulations characterize the erosive basal transgressive surface of erosion of the tide-dominate
181 marine upper Keeseville, exposed on Wellesley Island, NY (locality 117). These are interpreted
182 as gutter casts. B) Contact exposed along highway 15, southwest of Smiths Falls, ON. Here,
183 fluvial strata with obscured sedimentary fabric are erosively overlain by a transgressive surface
184 of erosion (TSE) capped by a transgressive cobble conglomerate lag (TL) overlain by tide-
185 dominated marine strata (FA5).

186

187 Figure 19: Examples of the silicified horizon that locally caps the lower Keeseville in the
188 southwest Ottawa Embayment, along the southern Frontenac Arch (see text for details). A)
189 Massive silicified horizon with its base outlined by a yellow dashed line. Hammer for scale.
190 Exposed along highway 12 in Chippewa Bay, NY (locality 86). B) Bedding plane of round

191 silicified nodules exposed in strata of the uppermost lower Keeseville Formation, on Wellesley
192 Island, NY (locality 118).

193
194 Figure 20: Coastal ephemeral fluvial (FA2) to tide-dominated marine (FA5) transition in upper
195 Keeseville strata exposed in the upper part of Ducharme Quarry in Quebec (locality 201). The
196 section below 4 m is dominated by coastal ephemeral fluvial strata (FA2) shown in more detail
197 in A: exposed here are low relief antidune cosets (AD), including rare convex-up formsets (white
198 arrow). Also present in planar strata are low angle climbing wind ripple laminae (WRS) and
199 diffuse adhesion lamination (AH). The base of the ~1.8 m transitional layer occurs at ~4.6 m
200 (lower FS). This layer contains six thin, massive pebble conglomerate layers, each interpreted as
201 a transgressive lag. B) Each lag is capped by a thin (≤ 1 cm) bioturbated (simple *Cruziana*
202 ichnofacies) silty mudstone interpreted to record deposit feeders in flooded, sediment-starved
203 conditions (bedding plane surface). Arrows indicate *Cruziana* trace fossils. C) & D) close-up of a
204 pebble lag and its capping mudstone; bedding plane and cross section views, respectively. In D)
205 the yellow dashed lines outline the capping mudstone. E) Intervening strata is mostly medium- to
206 lower coarse-grained coastal sabkha (FA4) strata, and record the reestablishment of intertidal and
207 supratidal conditions following each flooding event. Voids (arrows) are interpreted to be
208 weathered evaporite nodules. F) Vertical filter feeder forms of the *Skolithos* ichnofacies in tide-
209 dominated marine (FA5) strata exposed above the transitional section. Trace fossils include
210 *Diplocraterion* (Dp) and *Skolithos* (Sk). Also shown on the stratigraphic log is the conformable
211 Keeseville – Theresa contact, which here is defined by the lowest carbonate cemented bed ≥ 4
212 cm thick. Scale on y-axis of stratigraphic log is in meters.

213
214 Figure 21: Contacts between the fluvial lower Keeseville, marine upper Keeseville and Theresa
215 formations, exposed along interstate 81 on Wellesley Island, NY (locality 236). Here, strata of
216 the lower Keeseville (allounit 2) are erosively truncated by an erosional surface capped by a
217 massive cobble conglomerate. This surface is interpreted as a transgressive surface of erosion
218 (TSE), and the overlying conglomerate a transgressive lag. The lag is overlain by a subtle onlap
219 surface, over which tide-dominated marine strata of the upper Keeseville (allounit 3) onlap at a
220 very low angle ($\leq 5^\circ$). The base of the Theresa is defined by the lowest carbonate cemented bed
221 ≥ 4 cm thick, and here conformably overlies the upper Keeseville.

222
223 Figure 22: Nature of the Keeseville-Theresa contact from Quonto Gastem No.1 in southern
224 Quebec. (a) and (d) on the core photo demarcate the base and the top of the section shown on the
225 right. Here, quartz arenitic sabkha (FA4) strata are overlain by a flooding surface (FS, bm (b))
226 and ~2.5 m of bioturbated marine quartz arenite (FA5) before the first carbonate-cemented bed $\geq$
227 4 cm thick, which defines the base of the Theresa Formation (bT (c)). Here the Keeseville –

Theresa contact is conformable, and lithofacies above the contact are similar to those below except for the occurrence of pervasively carbonate-cemented arenite beds.

Figure 23: Examples of the Keeseville-Theresa contact from the western Ottawa Embayment. A) and B) are from the outcrop along the Thousands Island Parkway originally described by Greggs and Bond (1971) (locality 223). Here the contact is interpreted to be a sharp flooding surface underlain by locally well-developed *Glossifunghites* ichnofacies (as in B; Sk= *Skolithos*, Dp= *Diplocraterion*). C) Sharp, subtle erosional unconformity developed locally between aeolian dune strata of the upper Keeseville (below) and pervasively-dolomitized arenite of the Theresa Formation (above), exposed along Hawthorne Road, south of Ottawa, immediately on the footwall side of the Gloucester fault (locality 3). D) Cryptic paraconformity between sabkha facies of the upper Keeseville (allounit 3, below) and locally bioturbated tide-dominated marine strata of Theresa Formation (above) at the type locality of the “Nepean Formation” along highway 417 in Ottawa (locality 222). Following Dix et al. (2004) the base of the Theresa is defined by the lowest dolomite-cemented bed. Slight preferential weathering of the uppermost ~20 cm of the Keeseville is attributed to more abundant interstitial illuvial matrix that inhibited silica or dolomite cementation.

Figure 24: Stratigraphic log of the “Nepean Formation” (here abandoned) type section along highway 417 in Ottawa (locality 222, see figure 27d). Red dashed line marks the paraconformity between the upper Keeseville (allounit 3) and the Theresa Formation. A- F show the approximate locations of samples used for conodont biostratigraphy by Dix et al. (2004) (A-C) and by Brand and Rust (1977) (D-F). Scale on y-axis of stratigraphic logs is in meters.

Figure 25: New and previously published biostratigraphic age control in the basal and medial parts of the Theresa Formation. (1) Nowlan (2003) and Salad Hersi and Dix (2006), basal Theresa; (2) Brand and Rust (1977), basal Theresa; (3) Dix et al. (2004), basal Theresa; (4) Greggs and Bond (1971), basal Theresa; (5) Salad Hersi et al. (2002); basal and medial Theresa; (6) this study, medial Theresa; (7) Salad Hersi et al. (2003), basal Theresa. Stages of the Ordovician Period are given as well as stages of the Ibexian conodont series from Ross et al. (1997). Sk. = Skullrockian. Numbers on the left y-axis are millions of years ago.

Figure 26: Correlation of Potsdam strata to coeval strata deposited across Southern Laurentia. (1) Michigan and northern Appalachian basins; (2) Mohawk Valley and southern Lake Champlain Valley in New York State; (3) Potsdam Group in the Ottawa Embayment and Quebec Basin,

263 with allounits 1 – 3 indicated by A1, A2, A3; (4) Laurentian shelf succession in western Vermont
264 and southeastern New York State.; (5) Franklin Basin succession in northern Vermont and
265 Quebec; (6) Laurentian shelf succession of the Phillipsburg slice in southern Quebec and northern
266 Vermont; (7) Laurentian slope succession of the allochthons in southwestern Vermont and
267 eastern New York State; (8) Laurentian slope succession of the Bacchus nappe in southeastern
268 Quebec; (9) Laurentian slope succession of the Riviere-Boyer Nappe in southeastern Quebec;
269 (10) Laurentian shelf succession of the St. Lawrence Promontory, western Newfoundland; (11)
270 Laurentian slope succession of the St. Lawrence Promontory, western Newfoundland. See text
271 for detailed discussion, proposed stratigraphic correlations and references. Alt. = Altona
272 Member, HF = Hannawa Falls Formation, RAO = Riviere aux Outardes Member, SI = Stearing
273 Island Member, FC = Factory Cove Member, SP = Saint Pauls Member. A1 – A3 label the
274 allounits of the Potsdam discussed in the text.

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Figure 1: Geologic and isopach map of the Potsdam Group in the Ottawa Embayment and Quebec Basin. Isopach thickness is in meters. These two basins are semi-connected but are separated by the Oka-Beauharnois Arch. A second arch, the Frontenac Arch, bounds the southeastern margin of the Ottawa Embayment. A number of normal faults occur within this area and exert a strong control over the Potsdam isopach and lithofacies distributions (see text for more details). Some of these faults are particularly important and are discussed in this paper, and include: the Gloucester fault (GF), Rideau Lakes fault (RLF), Black Lake fault (BLF), Chateauguay Lake fault (CLF), Russel-Rigaud Fault (RRF) and Ste. Justine fault (SJF). Red dots and numbers mark the location and identity (respectively) of wellbores used for isopach interpolation and regional correlation. Stratigraphy and correlation of cores from wellbores are shown in figure 4.

159x107mm (300 x 300 DPI)

Figure 2: Paleogeographic and tectonic map of Southern Laurentia during the Cambrian and earliest Ordovician with the modern North American coastline overlain for reference compiled using a number of sources (see "Paleogeographic and tectonic setting"), but mainly modified from modified from Thomas (2006) and Allen et al. (2010). Dashed black lines correspond to the presumed margin of Laurentian continental crust, and dashed red lines correspond to major oceanic transform faults. The Ottawa graben (OG) is outlined in red, along with related intracratonic rifts such as the Saguenay graben (SG), Rome trough (RT) and Rough Creek graben (RC). The shaded area indicates the known distribution of the Potsdam Group in the Ottawa Embayment and Quebec Basin, at the paleo-southern end of the Ottawa Graben. The numbers correspond to the locations of the different the cratonic, shelf and slope successions across southern Laurentia stratigraphic shown in figure 26.

147x118mm (300 x 300 DPI)

Figure 3: Stratigraphic correlation of units and lithofacies across the northern and southern parts of the Ottawa Embayment and Quebec Basin. Locations of biostratigraphic age control are indicated by the red stars. Potsdam allounits, discussed in the latter part of this paper, are labelled as A1 – A3. Sources of these biostratigraphic constrains come from: (a) Landing et al. (2009), (b) Walcott (1891), Flower (1964), Lochman (1968), Landing et al. (2009) (c) Fisher (1968), (d) this study, (e) Greggs and Bond (1971), (f) this study, (g) Brand and Rust (1977) and Dix et al. (2004), and (h) Salad Hersi et al. (2002). See text for more detail regarding the correlation and age of Potsdam strata.

208x237mm (300 x 300 DPI)

Figure 4: East – West correlation of units and lithofacies associations from cores of the Potsdam Group across the Ottawa Embayment and Quebec Basin. Numbers correspond to those on figure 1, which gives the location of each wellbore. The cores are from: (1) Lanark County No.1, (2) Lanark County No.2, (3) AMEC MW-301 monitoring well, (4) Dominion Observatory No.1, (5) GSC LeBreton No. 1, (6) GSC Russell No.1 and Consumers No. 12023, (7) GSC McCrimmon No. 1, (8) Gastem Dundee No.1, (9) St. Lawrence River No.1, (10) Quonto-International St. Vincent de Paul No.1, (11) Quonto-International Mascouche No.1. Faults shown here are the Hazeldean fault (HF), Gloucester fault (GF) and Ste. Justine fault (SJF). HF Fm. = Hannawa Falls Formation, RAO mb. = Riviere Aux Outardes Member.

190x197mm (300 x 300 DPI)

Figure 5: Examples of sections belonging to the Ausable Formation. A) coarse- and very coarse-grained arkose interstratified cobble conglomerate of braided fluvial affinity (FA1); Briton Bay, ON (locality 12). B) Pinkish cross-stratified, pebbly coarse-grained arkose with rare pebble conglomerate and thin silty mudstone beds of braided fluvial affinity (FA1); Flat Rock State Forest, NY (locality 251). Arrow points to person for scale. C) Same lithofacies as above exposed on Ile Perrot, QC (locality 194). Arrow points to hammer for scale. Scale on y-axis of stratigraphic logs is in meters.

188x193mm (300 x 300 DPI)

Figure 6: Correlation of Altona Member strata from its type locality near Chazy, NY (see Landing et al. (2009) for more details) northward to Quonto St. Vincent de Paul No.1 near Montreal, QC. Datum at the base is the contact with ~1.0 Ga Grenville basement.

56x17mm (300 x 300 DPI)

Draft

Figure 7: Detailed stratigraphic log of the Altona Member from Quonto St. Vincent de Paul No.1, and core photographs illustrating various lithological features. A) Intergradational basal contact of the coastal tidal flat strata (FA6) of the Altona with underlying braided fluvial arkose. Arrow marks the proposed base of the Altona member. B) Red silty mudstone of tidal flat origin interstratified with a thin ($\leq 1\text{cm}$) erosively-based, normally graded arkose stratum (arrow), possibly deposited by strong wave and/or tidal currents. C) Erosively-based, normally-graded coarse- to medium-grained arkose, interpreted as an event bed deposited rapidly by a high-energy waning current, possibly a fluvial sheetflood onto the tidal flat, or a high-energy storm/wave-driven flood. D) Well-sorted, fine- to medium-grained, low angle cross-stratified arkose, interpreted as hummocky cross-stratification. E) fine- to very-fine grained planar- and ripple cross-stratified arkose. F) Mottled and variegated red and green silty mudstone.

200x220mm (300 x 300 DPI)

Figure 8: Features of the Altona Member in outcrop, in its type area near West Chazy, NY (see Landing et al., 2009). A) Arrow points to the contact between sparsely bioturbated red silty mudstone (below) and fine-grained hummocky cross-stratified sandstone; located at Stillwater Creek near Jericho, NY (locality 138). B) Blocky and laminated peritidal dolostone exposed at Atwood Farm near Chazy New York (locality 185). C) Thin section photomicrograph of laminated dolostone. This image is centered on finely alternating laminae of dolomicrite (light pink/brown) and iron-oxide rich clay (opaque) interpreted as the by-product of the growth and decay of successive microbial mats. The red arrow points to a fossil fragment surrounded by a redox halo. D) Massive, coarse-grained normally graded sandstone beds interstratified with red mudstone, near the top of the Altona Member at Atwood Farm (locality 233). The sandstone beds are interpreted to have been deposited quickly from high-energy, high-concentration, rapidly-waning fluvial sheetfloods near the mouth of a nearby braided river. Scale on y-axis of stratigraphic log is in meters.

199x218mm (300 x 300 DPI)

Figure 9: Contact between arkosic fluvial strata of the Ausable Formation and overlying quartz arenitic and aeolian Hannawa Falls Formation at Jones Falls Locks, ON (locality 53). These formations are separated here by a ~m thick transitional bed consisting of massive boulder lags and planar wind ripple stratified sandstone. A) Contact between the Ausable and the transitional bed (red dashed line). Subangular boulders and cobbles are outlined in black in the transitional bed. B) Close-up of quartzite cobble showing pitted and striated surface texture interpreted to have formed by prolonged windblown abrasion. C) Thin section photomicrograph of wind-ripple stratified sandstone from the transitional bed with abundant interstitial illuvial matrix. Scale on y-axis of stratigraphic log is in meters.

161x142mm (300 x 300 DPI)

Figure 10: Example of the top of the arkosic Ausable Formation from the eastern Ottawa Embayment and Quebec Basin, near Franklin, QC (locality 176). A) Here the contact is a cryptic unconformity separating arkose of the Ausable and quartz arenite of the lower Keeseville, both of braided fluvial origin (FA1). B) Close-up of the unconformity showing the ~10 – 15 cm thick massive and silicified granule to pebble lag that caps Ausable strata. C) Same contact in core (Gastem Dundee No. 1, southern Quebec; see table 1). Scale on y-axis of stratigraphic log is in meters.

212x246mm (300 x 300 DPI)

Figure 11: Thin section photomicrographs showing characteristics of the silcrete that caps Ausable strata at the outcrop section in Figure 11 (locality 176). A) & B) are taken from the capping conglomerate, where early pore-filling non-syntaxial silica cements and minor illuvial matrix are present. Qtz= quartz grain, Qtz cem= quartz cement, il= illuvial matrix. C) & D) are photomicrographs of a sample taken ~1.5 m beneath the capping conglomerate. This sample lacks the early silica cements present in the overlying conglomerate, and instead contains abundant illuvial matrix (il) and possible authigenic matrix from degraded feldspars.

137x103mm (300 x 300 DPI)

Figure 12: Examples of the Hannawa Falls Formation. A) Red, large-scale cross-bedded, well-sorted medium-grained aeolian (FA3) sandstone that characterizes the Hannawa Falls Formation at its type section in the Raquette River at Hannawa Falls, NY (locality 220). B) Thin section photomicrograph of sample taken from the same section. The pervasive red coloration is due to early iron-oxide rims on quartz grains. Fox= iron oxide, Qtz = quartz grain; il= illuvial matrix. C) Large-scale aeolian dune cross-stratification at Sloan Quarry, ON (locality 27).

117x75mm (300 x 300 DPI)

Figure 13: Examples of the erosional unconformity separating the Hannawa Falls (HF) and lower Keeseville (KV). A) Erosional unconformity (red dashed line) with minor (≤ 10 cm) erosional relief near Millsite Lake, Redwood, NY (locality 124). B) Same unconformity exposed at Sloan Quarry, ON (locality 27). Here the unconformity is mostly a flat erosional surface with progressive upward-reddening of the underlying Hannawa Falls (left side of photo). However a channel feature (Ch) in basal ephemeral fluvial strata of the Keeseville locally incises Hannawa Falls strata. C) & D) show close-ups of the unconformity from A) and B), location shown in inset yellow boxes. C) At Millsite Lake, a $\sim 5 - 10$ cm thick regolithic lag caps the Hannawa Falls, and includes clasts of the red Hannawa Falls sandstone (outlined in white) and quartzite (Qtz). D) At Sloan Quarry abundant clasts of finely-laminated Hannawa Falls material are present at the base of the Keeseville channel feature (outlined in white).

233x296mm (300 x 300 DPI)

Draft

Figure 14: Example of the angular unconformity between the Hannawa Falls (HF) and lower Keeseville (KV) exposed along route 42 east of Phillipsville, ON (locality 41). A) View of the section from the roadside, here Hannawa Falls strata exhibit minor folding and/or slumping and brittle faulting that contrasts the flat-lying, comparatively undeformed strata of the overlying Keeseville. Red circle shows rock hammer for scale. B) Close-up of the angular unconformity at the same location, location given in the inset yellow box in figure 16a. Here, fractured and folded Hannawa Falls strata are truncated erosively by relatively unaffected Keeseville strata. The basal Keeseville here is channelized like locally at Sloan Quarry (figure 15 b), and clasts of eroded Hannawa Falls strata (HF, in red) and quartzite clasts (Qtz) are mixed at the base of the Keeseville Formation.

109x66mm (300 x 300 DPI)

Figure 15: Photomicrographs of Hannawa Falls strata immediately beneath the allounit 1–2 unconformity at Millsite Lake (locality 124, see figure 13a). A) & B) thin section photomicrographs in plane-polarized (A) and cross-polarized (B) light. Quartz grains (Qtz) are rimmed with iron oxide cement (Feox), and surrounded by intergranular illite (ilt) and disseminated iron oxide cement. B) & C) are scanning electron microscopic images of the same horizon, showing the fibrous nature of the authigenic illite (ilt) cement.

136x102mm (300 x 300 DPI)

Figure 16: Outcrop examples of the Keeseville Formation from across the study area. A) Mostly planar-stratified coastal plain ephemeral fluvial strata (FA2) exposed in the Great Chazy River in Woods Falls, NY (locality 148). Arrows demarcate the top and base of a coset of antidune stratification. B) Aeolian dune cross-stratification (FA3) exposed in the Rainbow Quarry, Near Malone, NY (locality 188). C) Planar- and cross-stratified coastal sabkha (FA4) strata exposed in the Melocheville Quarry, near Melocheville, QC (locality 275). D) Ephemeral fluvial strata (FA2) exposed along highway 12 near Alexandria Bay, NY (locality 100). The high-angle set at the base is interpreted as a high-angle, upstream-dipping cyclic step set (see Lowe and Arnott, 2016). E) Gravelly braided fluvial strata (FA1) at Charleston Lake Provincial Park, ON (locality 57). F) Bioturbated, mostly dune cross-stratified, high-energy tide-dominated marine strata (FA5) exposed along highway 15 southwest of Smiths Falls, ON (locality 16).

200x220mm (300 x 300 DPI)

Figure 17: Unconformity (red line) between the lower and upper Keeseville Formation at Rockland, ON (locality 2). Here conodonts occur in rare dolostone interbeds in tide-dominated marine (FA5) strata ~0.9 m beneath the unconformity, and indicate an earliest Ordovician depositional age (see text and appendix A for details). A) The unconformity is erosional with ~5 – 10 cm of local relief. Immediately above the unconformity is a ~30 cm thick, massive, regolithic conglomerate overlain by braided fluvial strata (FA1) of the upper Keeseville. B) Close-up of the unconformity showing clasts in the regolithic conglomerate layer. Most consist of quartzite, but near the contact dolomitic sandstone clasts sourced the underlying lower Keeseville (outlined in yellow) are common. Scale on y-axis of stratigraphic log is in meters.

180x177mm (300 x 300 DPI)

Figure 18: Examples of the unconformity separating the fluvial lower Keeseville and marine upper Keeseville Formation in the western Ottawa Embayment. A) Localized, high-relief undulations characterize the erosive basal transgressive surface of erosion of the tide-dominant marine upper Keeseville, exposed on Wellesley Island, NY (locality 117). These are interpreted as gutter casts. B) Contact exposed along highway 15, southwest of Smiths Falls, ON. Here, fluvial strata with obscured sedimentary fabric are erosively overlain by a transgressive surface of erosion (TSE) capped by a transgressive cobble conglomerate lag (TL) overlain by tide-dominated marine strata (FA5).

136x102mm (300 x 300 DPI)

Figure 19: Examples of the silicified horizon that locally caps the lower Keeseville in the southwest Ottawa Embayment, along the southern Frontenac Arch (see text for details). A) Massive silicified horizon with its base outlined by a yellow dashed line. Hammer for scale. Exposed along highway 12 in Chippewa Bay, NY (locality 86). B) Bedding plane of round silicified nodules exposed in strata of the uppermost lower Keeseville Formation, on Wellesley Island, NY (locality 118).

173x165mm (300 x 300 DPI)

Figure 20: Coastal ephemeral fluvial (FA2) to tide-dominated marine (FA5) transition in upper Keeseville strata exposed in the upper part of Ducharme Quarry in Quebec (locality 201). The section below 4 m is dominated by coastal ephemeral fluvial strata (FA2) shown in more detail in A: exposed here are low relief antidune cosets (AD), including rare convex-up formsets (white arrow). Also present in planar strata are low angle climbing wind ripple laminae (WRS) and diffuse adhesion lamination (AH). The base of the ~1.8 m transitional layer occurs at ~4.6 m (lower FS). This layer contains six thin, massive pebble conglomerate layers, each interpreted as a transgressive lag. B) Each lag is capped by a thin (≤ 1 cm) bioturbated (simple *Cruziana* ichnofacies) silty mudstone interpreted to record deposit feeders in flooded, sediment-starved conditions (bedding plane surface). Arrows indicate *Cruziana* trace fossils. C) & D) close-up of a pebble lag and its capping mudstone; bedding plane and cross section views, respectively. In D) the yellow dashed lines outline the capping mudstone. E) Intervening strata is mostly medium- to lower coarse-grained coastal sabkha (FA4) strata, and record the reestablishment of intertidal and supratidal conditions following each flooding event. Voids (arrows) are interpreted to be weathered evaporite nodules. F) Vertical filter feeder forms of the *Skolithos* ichnofacies in tide-dominated marine (FA5) strata exposed above the transitional section. Trace fossils include *Diplocraterion* (Dp) and *Skolithos* (Sk). Also shown on the stratigraphic log is the conformable Keeseville – Theresa contact, which here is defined by the lowest carbonate cemented bed ≥ 4 cm thick. Scale on y-axis of stratigraphic log is in meters.

168x155mm (300 x 300 DPI)

Figure 21: Contacts between the fluvial lower Keeseville, marine upper Keeseville and Theresa formations, exposed along interstate 81 on Wellesley Island, NY (locality 236). Here, strata of the lower Keeseville (allounit 2) are erosively truncated by an erosional surface capped by a massive cobble conglomerate. This surface is interpreted as a transgressive surface of erosion (TSE), and the overlying conglomerate a transgressive lag. The lag is overlain by a subtle onlap surface, over which tide-dominated marine strata of the upper Keeseville (allounit 3) onlap at a very low angle ($\leq 5^\circ$). The base of the Theresa is defined by the lowest carbonate cemented bed > 4 cm thick, and here conformably overlies the upper Keeseville.

96x39mm (300 x 300 DPI)

Figure 22: Nature of the Keeseville-Theresa contact from Quonto Gastem No.1 in southern Quebec. (a) and (d) on the core photo demarcate the base and the top of the section shown on the right. Here, quartz arenitic sabkha (FA4) strata are overlain by a flooding surface (FS, bm (b)) and ~2.5 m of bioturbated marine quartz arenite (FA5) before the first carbonate-cemented bed ≥ 4 cm thick, which defines the base of the Theresa Formation (bT (c)). Here the Keeseville -Theresa contact is conformable, and lithofacies above the contact are similar to those below except for the occurrence of pervasively carbonate-cemented arenite beds.

203x226mm (300 x 300 DPI)

Figure 24: Stratigraphic log of the "Nepean Formation" (here abandoned) type section along highway 417 in Ottawa (locality 222, see figure 27d). Red dashed line marks the paraconformity between the upper Keeseville (allouit 3) and the Theresa Formation. A- F show the approximate locations of samples used for conodont biostratigraphy by Dix et al. (2004) (A-C) and by Brand and Rust (1977) (D-F). Scale on y-axis of stratigraphic logs is in meters.

234x373mm (300 x 300 DPI)

Figure 25: New and previously published biostratigraphic age control in the basal and medial parts of the Theresa Formation. (1) Nowlan (2003) and Salad Hersi and Dix (2006), basal Theresa; (2) Brand and Rust (1977), basal Theresa; (3) Dix et al. (2004), basal Theresa; (4) Greggs and Bond (1971), basal Theresa; (5) Salad Hersi et al. (2002); basal and medial Theresa; (6) this study, medial Theresa; (7) Salad Hersi et al. (2003), basal Theresa. Stages of the Ordovician Period are given as well as stages of the Ibexian conodont series from Ross et al. (1997). Sk. = Skullrockian. Numbers on the left y-axis are millions of years ago.

237x308mm (300 x 300 DPI)

Figure 26: Correlation of Potsdam strata to coeval strata deposited across Southern Laurentia. (1) Michigan and northern Appalachian basins; (2) Mohawk Valley and southern Lake Champlain Valley in New York State; (3) Potsdam Group in the Ottawa Embayment and Quebec Basin, with allounits 1 – 3 indicated by A1, A2, A3; (4) Laurentian shelf succession in western Vermont and southeastern New York State.; (5) Franklin Basin succession in northern Vermont and Quebec; (6) Laurentian shelf succession of the Phillipsburg slice in southern Quebec and northern Vermont; (7) Laurentian slope succession of the allochthons in southwestern Vermont and eastern New York State; (8) Laurentian slope succession of the Bacchus nappe in southeastern Quebec; (9) Laurentian slope succession of the Riviere-Boyer Nappe in southeastern Quebec; (10) Laurentian shelf succession of the St. Lawrence Promontory, western Newfoundland; (11) Laurentian slope succession of the St. Lawrence Promontory, western Newfoundland. See text for detailed discussion, proposed stratigraphic correlations and references. Alt. = Altona Member, HF = Hannawa Falls Formation, RAO = Riviere aux Outardes Member, SI = Stearing Island Member, FC = Factory Cove Member, SP = Saint Pauls Member. A1 – A3 label the allounits of the Potsdam discussed in the text.

169x122mm (300 x 300 DPI)

Appendix A: Biostratigraphic analysis from the Riviere Aux Outardes Member, Rockland, ON.

Report No. 004-GSN-2013

Report on two samples from Lower Ordovician strata in the vicinity of Rockland in eastern Ontario submitted for conodont analysis by David Lowe and Bill Arnott (University of Ottawa); NTS 031G/11; CON # 1777.

All references to age determinations and paleontological data must quote the authorship of the report, and the unique GSC Curation Number of the fossil collection. If the report is cited in a publication, it should be included in the References Cited section as:

"Nowlan, G.S., 2013. Report on two samples from Lower Ordovician strata in the vicinity of Rockland in eastern Ontario submitted for conodont analysis by David Lowe and Bill Arnott (University of Ottawa); NTS 031G/11; CON # 1777. Geological Survey of Canada, Paleontological Report 004-GSN-2013, 4 p."

Reference to, or reproduction of, paleontological data and age determinations in publications must be approved by the author of the Paleontological Report prior to manuscript submission. If the author is not available, the Chief Paleontologist, Geological Survey of Canada (Calgary) should be consulted for possible revision. Substantial use of paleontological and age data in publications should be reflected in the publications' authorship.

Material: Two rocks samples processed completely in the GSC Calgary Conodont Laboratory. The first sample was submitted by David Lowe and Bill Arnott from the University of Ottawa and the second sample was collected by the author and David Lowe, taking advantage of a visit to Ottawa by the author. The samples, both from the same unit, broke down very slowly but completely in acid; however, the separation of the residue resulted in extremely large heavy fractions to be picked for conodonts. Both samples were picked for about ten hours each until a point was reached that no conodonts were observed on the picking tray for five consecutive trays. Much heavy residue remains for both samples, but we believe we have recovered a majority of specimens in the samples.

1. Locality: GSC loc. C-450794; Chippewa Bay Member of the Covey Hill Formation; isolated outcrop in north Rockland, Ontario: outcrop is west of Edward Street and northwest of Woods Street at the south end of an apartment building; latitude 45°33'10.0"N; longitude 075°17'53.22W; NTS 031G/11.

Mass dissolved: 2512 g (99% breakdown)

Fauna: The sample yielded 2 fragmentary conodont elements (CAI 3) assignable as follows:

?*Cordylodus* sp.: 1

Variabiloconus bassleri (Furnish): 1

Remarks: The presence of specimens of *V. bassleri* indicates an Early Ordovician age. In North American stage terminology, it indicates a late Skullrockian age in the *Rossodus manitouensis* Zone (Ross et al., 1997). In international terms, the age is Early Tremadocian. The specimen assigned to *V. bassleri* is reasonably well preserved and possesses a short cusp that shows evidence of repair after breakage in life. The specimen tentatively assigned to the genus *Cordylodus* is fragmentary with a broken posterior process and anterobasal corner; it most resembles *Cordylodus angulatus* Pander.

2. Locality: GSC loc. C-450795; field sample no. **NI-2012-1;** Chippewa Bay Member of the Covey Hill Formation; isolated outcrop in north Rockland, Ontario; outcrop west of Edward Street and northwest of Woods Street at the south end of an apartment building; sample is 52 m WSW of C-450794 around the small cliff towards the Ottawa River; latitude 45°33'10.13"N; longitude 075°17'55.64"W; NTS 031G/11.

Mass dissolved: 2550 g (99% breakdown)

Fauna: The sample yielded 7 fragmentary to moderately well preserved conodont elements (CAI 3) assignable as follows:

Variabiloconus bassleri (Furnish): 6

Denticle fragment: 1

The sample also yielded fragments of phosphatic inarticulate brachiopods.

Remarks: As with the previous sample (C-450794) the presence of *V. bassleri* indicates an Early Ordovician age for the sample. Several well preserved specimens are represented in the fauna. The denticle fragment is likely a part of a *Cordylodus* specimen. In North American stage terminology, it indicates a late Skullrockian age in the *Rossodus manitouensis* Zone (Ross et al., 1997). In international terms, the age is Early Tremadocian.

General Comments

These two samples, not surprisingly, produced similar results. The samples are from a relatively well exposed section of the Chippewa Member of the Covey Hill Formation as defined by Sanford and Arnott (2010). In other places, the Covey Hill Formation is thought to be Late Cambrian (see for example, Salad Hersi et al., 2002a). The specimens

recovered Draft Report 004-GSN-2013, page 3 from the Covey Hill Formation in this report are few in number but do appear to be within the range of variation of *V. bassleri* a species indicative of late Skullrockian (Early Ordovician) age. The presence of fragments of probable *Cordylodus* being additionally suggestive of this age.

The age of the samples is older than those found in the March Formation above the Nepean Formation type section (Brand and Rust 1977; Dix et al. 2004) and in the March Formation of the Brockville area to the south (Greggs and Bond 1971). In both of these areas, specimens of *Colaptoconus quadraplicatus* (Branson & Mehl) are present in the samples and this species, although long-ranging, does not appear until the Stairsian. Specimens were not illustrated by Brand and Rust (1977) and so evaluation of their faunas is necessarily limited, as noted by Dix et al. (2004). Dix et al. (2004) recovered very few specimens, but those present indicate a Stairsian - Tulean age for the March Formation.

A fauna similar to that reported from the Covey Hill Formation herein was recovered from the Wallace Creek Formation in the Philipsburg slice in Quebec (Salad Hersi et al., 2007). It includes *Variabiloconus bassleri* but is much more diverse than the samples reported herein. The Wallace Creek Formation overlies the Strites Pond Formation, which yields a Late Cambrian fauna but the immediately overlying basal Wallace Creek Formation yields a restricted fauna with specimens of *V. bassleri* and possible *Cordylodus angulatus* (Salad Hersi et al. 2002b), similar to those reported herein from the Covey Hill Formation. Almost all of the biostratigraphic data from this region of eastern Canada are from relatively poorly sampled sections. It is clear that many more biostratigraphic data are needed before the age relationships of mapped units in the Ottawa region and their broader regional relationships can be fully understood.

Thermal Alteration

Specimens from both samples in this report record the prevailing thermal alteration for the Ottawa region as reported by Legall et al. (1981). Rockland is located about exactly on their CAI 3 isograd and these specimens reflect that level of thermal maturity exactly. A CAI value of 3 indicates heating in the 110° to 200°C range (Nowlan and Barnes 1987).

References Cited

- Brand, U. And Rust, B.R. 1977. The age and upper boundary of the Nepean Formation in its type section near Ottawa, Ontario. Canadian Journal of Earth Sciences, v. 14, p. 2002-2006.
- Dix, G.R., Salad Hersi, O. and Nowlan, G.S. 2004. The Potsdam - Beekmantown Group boundary, Nepean Formation type section (Ottawa, Ontario): a cryptic sequence

boundary, not a conformable transition. Canadian Journal of Earth Sciences, v. 41, p. 897-902.

Greggs R.G. and Bond, I.J. 1971. Conodonts from the March and Oxford formations in the
Draft Report 004-GSN-2013, page 4

Brockville area, Ontario. Canadian Journal of Earth Sciences, v. 8, p. 1455-1471. Legall, F.D., Barnes, C.R. and Macqueen, R.W. 1981. Thermal maturation, burial history and hotspot development, Paleozoic strata of southern Ontario - Quebec, from conodont and acritarch colour alteration studies. Bulletin of Canadian Petroleum Geology, v. 29, p. 492-539.

Nowlan, G.S. and Barnes, C.R. 1987. Application of conodont colour alteration indices to regional and economic geology. *In* Conodonts: Investigative Techniques and Applications, R.L. Austin (editor), Ellis Horwood, p. 188-202.

Ross, R.J., Hintze, L.F., Ehtington, R.L., Miller, J.F., Taylor, M.E. and Repetski, J.E. 1997. The Ibexian, lowermost series in the North American Ordovician. U.S. Geological Survey Professional Paper 1579, p.1-84.

Salad Hersi, O., Lavoie, D., Mohamed, A.H. and Nowlan, G.S. 2002a. Subaerial unconformity at the Potsdam - Beekmantown contact in the Quebec Reentrant: regional significance for the Laurentian continental margin history. Bulletin of Canadian Petroleum Geology, v. 50, p. 419-440.

Salad Hersi, O., Lavoie, D. And Nowlan, G.S. 2002b. Stratigraphy and sedimentology of the Upper Cambrian Strites Pond Formation, Philipsburg Group, southern Quebec, and implications for the Cambrian platform in eastern Canada. Bulletin of Canadian Petroleum Geology, v. 50, p. 542-565.

Salad Hersi, O., Nowlan, G.S. and Lavoie, D. 2007. A revision of the stratigraphic nomenclature of the Cambrian-Ordovician strata of the Philipsburg tectonic slice, southern Quebec. Canadian Journal of Earth Sciences, v. 44, p. 1775-1790.

Sanford, B.V. and Arnott, R.W.C. 2010. Stratigraphic and structural framework of the Potsdam Group in eastern Ontario, western Quebec and northern New York State. Geological Survey of Canada Bulletin 597.

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Appendix B: Biostratigraphic analysis from the Keeseville Formation at Ducharme Quarry, QC, and the lower Theresa Formation, Ste. Chrysostome, QC.

2-ADM-2014

Report on 2 Early Ordovician conodont samples from the Potsdam Group near Saint Chrysostome, southwestern Quebec submitted by David Lowe and Bill Arnott (University of Ottawa). NTS 031H/04. Con. No. 1791

A. D. McCracken

All references to age determinations and paleontological data must quote the authorship of the report, and the unique GSC Curation Number of the fossil collection. If the report is cited in a publication, it should be included in the References Cited section as:

“McCracken, A.D., 2014. Report on 2 Early Ordovician conodont samples from the Potsdam Group near Saint-Chrysostome, southwestern Quebec submitted by David Lowe and Bill Arnott (University of Ottawa). NTS 031H/04. Con. No. 1791; Geological Survey of Canada, Paleontological Report 2-ADM-2014, 7 p.”

Reference to, or reproduction of, paleontological data and age determinations in publications must be approved by the author of the Paleontological Report prior to manuscript submission. If the author is not available, the Chief Paleontologist, Geological Survey of Canada (Calgary), should be consulted for possible revision. Substantial use of paleontological and age data in publications should be reflected in the publications' authorship.

The two samples are part of David Lowe and Bill Arnott's study on the Cambrian Ordovician Potsdam Group in the Ottawa Embayment and Quebec Basin in Ontario, Quebec and adjacent New York State. They wrote (External Request for Laboratory Consultative Services 330403-007-14-EXT) “This project is an integrative sedimentology and stratigraphy project spearheaded by David Lowe (PhD Candidate, University of Ottawa) and uses facies analysis, sequence stratigraphic correlations, petrography, detrital zircon dating and biostratigraphic ages to build a comprehensive depositional model for the Potsdam Group. We are requesting the use of the lab as well as the expertise of biostratigrapher Godfrey Nowlan to obtain conodont specimens and age correlations from two samples in the Potsdam Group. Nowlan (2013) (GSC report #004-GSN-2013) has already provided a very useful and informative age determination from a sample in Eastern Ontario, that has helped immensely in understanding the complexities of this unit.”

The samples were processed in the GSC Calgary Conodont Laboratory. Both were huge in comparison to our lab's usual sample size. One sample, GSC C-450796 was barren - this was processed at our usual 2.5 kg sample size, and essentially did not dissolve. Even so, the little residue there was picked to completion. The second sample (GSC C-450797) was processed in its entirety - 9.6 kg. The sample went through 6 weeks of digestions, and processing was stopped at 63% dissolution. However, over 6 kg were dissolved - over twice the standard amount. The heavy liquid residue of this sample was picked for 4 hours, also twice the standard amount. There is some residue left, but I believe that there is no point in doing more work - the second phase of picking brought only more of the same, but smaller (which is typical of a "repick").

The study and report were completed by Sandy McCracken. The taxonomic identifications and biostratigraphy was done in consultation with Godfrey Nowlan. Material: 2 rock samples processed completely in the GSC laboratory.

GSC Curation Number: C-450796

Sample 201-A; Ducharme Quarry (carrières Ducharme) near New York border; uppermost Potsdam Group, upper ca. 20 m of Cairnside Formation; latitude 45° 00' 23.03" N; longitude 73° 44' 44.48" W; NAD83; NTS 031-H-04. Con. No. 1791-1: Mass in 2500 g, out 2483 g, 0.7 % breakdown, 0 slide, Barren.

Fossils: Barren

GSC Curation Number: C-450797

Sample 243-A; Sainte Clotilde de Châteauguay, Rivière Châteauguay and QC Rt 209; Potsdam Group, Lower Theresa Formation; latitude 45° 08' 59.51" N; longitude 73° 42' 21.48" W; NAD83; NTS 031-H-04. Con. No. 1791-2: Mass in 9609 g, out 3581 g, 62.7 % breakdown, 2 slides, repicked.

Fossils:

Acodus? sp. - 3 specimens

Colaptoconus quadriplicatus (Branson & Mehl 1933) - 108 specimens

Drepanodus? sp. - 1 specimen

Drepanoistodus gracilis (Branson & Mehl 1933) - 46 specimens

Oneotodus costatus Ethington & Brand 1981 - 14 specimens

Thermal: CAI 3.

Remarks: Probable age range: Ibexian Series, *Acodus deltatus*-*Oneotodus costatus* Zone (lower Stairsian Stage) through to about mid *Reutterodus andinus* Zone (mid Blackhillsian Stage) based on *Drepanoistodus gracilis*, but in part supported by the other taxa.

Discussion

Colaptoconus quadriplicatus (Branson & Mehl) is the most abundant taxon in sample C-450797. The range of this species, as reported by Ross et al. (1997) is from the lower

“Low diversity interval” (lower Stairsian Stage, Ibexian Series) through to about mid *Reutterodus andinus* Zone (mid Blackhillsian Stage, Ibexian Series). McCracken (in Desbiens et al. 1996) identified this species in the lower Beauharnois Formation of Quebec (see table of stages and zones).

Drepanoistodus gracilis (Branson & Mehl) has been assigned previously to *Drepanodus*, but this collection clearly (and fortunately) includes two *q* (subrectiform) elements. In retrospect, the elements McCracken (in Desbiens et al. 1996) called *Drepanoistodus angulensis* (Harris) from the lower Beauharnois Formation are more likely this species because of the similar *r* (oistodiform) element.

Ross et al. (1997) give the range of this species (their *Drepanodus gracilis*) from the *Acodus deltatus*-*Oneotodus costatus* Zone [lower Stairsian (Ibexian)] through to about mid *Reutterodus andinus* Zone [mid Blackhillsian (Ibexian)].

Oneotodus costatus Ethington & Brand is represented by a few costate and short specimens. Two are reminiscent of the symmetrical quadricostate element of *Colaptoconus quadriplicatus* but are thought to be part of *O. costatus* because of their short, squat nature (as opposed to long and thin). The species has a range from the base of the *Acodus deltatus*-*Oneotodus costatus* Zone [lower Stairsian (Ibexian)] through to about mid *Reutterodus andinus* Zone [mid Blackhillsian (Ibexian)] (Ross et al. 1997).

The three specimens assigned to *Acodus*? sp. are oistodiform elements. These are not part of *Drepanoistodus*, and are not compressed enough to be considered oistodiform elements of *Oepikodus communis* (see below).

The collectors previously submitted two samples from the Covey Hill Formation near Rockland, Ontario. Nowlan (2013) reported that these were from the upper Skullrockian Stage of the Ibexian Series. He (2013) also commented on the occurrences of *Colaptoconus quadriplicatus* in the Nepean and March formations of the Ottawa area and the March and Oxford formations of the Brockville area (Brand & Rust 1977; Dixon et al. 2004; Greggs & Bond 1971). There are no other forms in common with those occurrences, and none at all with Nowlan's (2013) study.

McCracken's (in Desbiens et al. 1996) work in Montreal, Quebec was mentioned above. Although *Colaptoconus quadriplicatus* and *Drepanoistodus gracilis* (as *D. angulensis*) were present, the fauna also contained *Oepikodus communis* (Ethington & Clark) which ranges from the *O. communis* Zone (mid Tulean Stage, Ibexian Series) through the *Reutterodus andinus* Zone (top of the Blackhillsian Stage, Ibexian Series). At this location, the Beauharnois Formation overlay the Theresa Formation.

This sample from the Lower Theresa Formation thus is older than the Desbiens et al. (1996) Beauharnois material and younger than Nowlan's (2013) Covey Hill Formation material. It does not have anything in common with the faunas from the Nepean Formation type section but it overlaps in age - Nowlan (in Dix et al. 2004) interpreted the fauna of the Nepean Formation type section as ranging from Stairsian to Tulean stages.

References cited

Brand, U. and Rust, B.R. 1977: The age and upper boundary of the Nepean Formation in its type section near Ottawa, Ontario. *Canadian Journal of Earth Sciences*, v. 14, no. 9, p. 2002-2006.

Desbiens, S., Bolton, T.E., and McCracken, A.D. 1996: Fauna of the lower Beauharnois Formation (Beekmantown Group, lower Ordovician), Grande-île, Quebec. *Canadian Journal of Earth Sciences*, v. 33, p. 1132-1153.

Dix, G.R., Salad Hersi, O., and Nowlan, G.S. 2004: The Potsdam-Beekmantown Group boundary, Nepean Formation type section (Ottawa, Ontario): a cryptic sequence boundary, not a conformable transition. *Canadian Journal of Earth Sciences*, v. 41, no. 8, p. 897-902.

Greggs, R.G. and Bond, I.J. 1971: Conodonts from the March and Oxford Formations in the Brockville area, Ontario. *Canadian Journal of Earth Sciences*, v. 8, no. 11, p. 1455-1471.

Ross, R.J.Jr., Hintze, L.F., Ethington, R.L., Miller, J.F., Taylor, M.E., and Repetski, J.E. 1997: The Ibexian, lowermost series in the North American Ordovician. *In* Early Paleozoic biochronology of the Great Basin, western United States. Taylor, M.E. (ed.). United States Geological Survey, Professional Paper 1579-A, p. 1-50.

Nowlan, G.S. 2013: Report on two samples from Lower Ordovician strata in the vicinity of Rockland in eastern Ontario submitted for conodont analysis by David Lowe and Bill Arnott (University of Ottawa); NTS 031G/11; CON # 1777. Geological Survey of Canada, Paleontological Report 004-GSN-2013, 3 p.

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June 6, 2014	

System Series	Stage	Formation	Shelly Fossil Zones (this report)	Conodont Zones (this report)	Shelly Fossil Zones		Conodont Faunas W. Utah Ethington & Clark (1971)
					N. Utah - SE. Idaho Ross (1951, 1968)	W. Utah Hintze (1953)	
White-rockian Series	Rangerian	Wah Wah Fm.	PO <i>Paralenorthis-Orthidiella</i>	TI <i>Tripodus laevis</i>	L K	L	E
Lower Ordovician Ibexian Series	Blackhillian		Hm <i>Hesperonomiella minor</i>	Ra <i>Reutterodus andinus</i>	J	"K"	
			Pn <i>Pseudocybele nasuta</i>		I	I	
			Pi <i>Presbynileus ibexensis</i>		H	H	
			Tt <i>Trigonocerca typica</i>		G-2	G-2	
	Tulean	Fillmore Formation	Pc <i>Protopliomerella contracta</i>	AO <i>Acodus deltatus - Oneotodus costatus</i>	G-1	G-1	D
			Hc <i>Hintzeia celsaora</i>		F	F	
			Rs <i>Rossaspis superciliosa</i>		E	E	
			Te <i>Tesselacauda</i>		D	D	
	Stairsian		LK <i>Leiostegium-Kainella</i>	LD "Low diversity interval"	C	C	C
			Pa <i>Paraplethopeltis</i>	Rm <i>Rossodus manitouensis</i>	A + B	B	
			BX <i>Bellefontia-Xenostegium</i>	Ca <i>Cordylodus angulatus</i>			
			Sy <i>Symphysurina</i>	la <i>lapetognathus</i> n. sp.			
Up. C Croixian Series	Trempealeau	Notch Peak Formation	Mi <i>Missisquoia</i>	Cl <i>Cordylodus lindstromi</i>			A
			Ea <i>Eurekia apopsis</i>	Ci <i>Cordylodus intermedius</i>			
			Ss <i>Saukiella serotina</i>	Cp <i>Cordylodus proavus</i>			
			Sj <i>Saukiella junia</i>	Eo <i>Eoconodontus</i>			

Figure: Stages of the Ibexian Series showing the shelly fossil and conodont zones by which they are characterized. Also shown are correlations with previous zones and faunas. From Ross et al. 1997.

PLATE B1

All specimens are from GSC Curation No. C-450797

Figs. A-C. *Drepanoistodus gracilis* (Branson & Mehl 1933)

Fig. D. *Drepanodus?* sp. (upper left), *Acodus?* sp. (3 oistodiform elements on right)

Fig. E. *Oneotodus costatus* Ethington & Brand 1981

Figs. F-H. *Colaptoconus quadriplicatus* (Branson & Mehl 1933)

2-ADM-2014 Plate 1

Supplementary Data File 1: Outcrop locations

Station	Easting	Northing	Lithostratigraphic unit(s)	Allounit(s)	Facies association(s)
1	428410E	5017535N	Keeseville	A3	FA4
2	476500E	5041500N	Keeseville, Riviere Aux Outardes Mb	A2,A3	FA5,FA2
3	456144E	5017333N	Keeseville, Theresa	A3	
4	431613E	5016545N	Keeseville	A3	FA4
5	428366E	5017546N	Keeseville	A3	FA4
6	433101E	5019021N	Keeseville	A3	FA4
7	432561E	5019471N	Keeseville	A3	FA4
8	451415E	5037084N	Keeseville	A3	FA5
9	446257E	5038385N	Keeseville	A3	FA5
10	434158E	5016130N	Keeseville	A3	FA4
11	404625E	5007425N	Keeseville/Theresa	A3	FA4
12	406309E	4958089N	Ausable	A1	FA2
13	424892E	5021437N	Keeseville	A3	FA4
14	428532E	5017954N	Keeseville	A3	FA4
15	432100E	5018900N	Keeseville	A2,A3	FA5,FA4
16	412659E	4959755N	Keeseville	A2,A3	FA2,FA5
17	409459E	4943600N	Theresa		
18	466858E	5043335N	Keeseville	A2,A3	FA1,FA2, FA5
19	466735E	5043381N	Keeseville	A2,A3	FA1,FA2, FA5
20	438347E	4936282N	Keeseville	A3	
21	437243E	4936854N	Keeseville	A3	
22	409758E	4910883N	Keeseville	A2	FA1,FA2
23	409935E	4911053N	Keeseville	A2	FA2
24	400334E	4907867N	Keeseville	A2	FA2
25	394883E	4905508N	Ausable	A1	FA1 (talus)
26	389520E	4912016N	Hannawa Falls	A1	FA3
27	390789E	4912949N	Hannawa Falls, Keeseville	A1,A2	FA3,FA2,FA5
28	393900E	4916616N	Hannawa Falls, Keeseville	A1,A2	FA3,FA2
29	388789E	4915324N	Hannawa Falls, Keeseville	A1	FA3
30	420310E	4916935N	Keeseville	A3	FA5
31	418837E	4918914N	Keeseville	A3	FA5
32	414065E	4918878N	Keeseville	A3	FA5
33	411073E	4934054N	Keeseville	A2(?)	FA1(?)
34	411723E	4935120N	Keeseville	A2, A3	FA1/FA2(?),FA5

Station	Easting	Northing	Lithostratigraphic unit(s)	Allounit(s)	Facies association(s)
35	41128E	4934508N	Keeseville	?	?
36	411789E	4935700N	Keeseville	A2,A3	FA1,FA5
37	413074E	4938852N	Keeseville	A3	FA5
38	412637E	4939140N	Hannawa Falls, Keeseville	A1,A3	FA3(?),FA5
39	410906E	4941216N	Keeseville	A2	FA2
40	410302E	4942614N	Theresa, Keeseville(?)	A3(?)	FA5
41	410200E	4926500N	Hannawa Falls, Keeseville	A1,A2	FA3,FA2
42	400801E	4942483N	Keeseville	A3	FA5
43	400635E	4942884N	Keeseville	A3	FA5
44	408050E	4952939N	Keeseville	A3	FA4
45	410236E	4943153N	Theresa		
46	406186E	4938443N	Keeseville	A2	FA2
47	406002E	4936441N	Keeseville	A2	FA2
48	406107E	4937167N	Keeseville	A2	FA2
49	406436E	4938186N	Keeseville	A2	FA2
50	405868E	4938840N	Keeseville	A2	FA2
51	403630E	4939348N	Keeseville, Theresa	A3	FA5
52	404090E	4934500N	Ausable(?), Keeseville	A1(?), A2	
53	401924E	4933165N	Ausable, Hannawa Falls, Keeseville	A1,A2,A3	FA1,FA3,FA2
54	392520E	4919926N	Hannawa Falls, Keeseville	A1,A2	FA3(?),FA2
55	417600E	4928400N	Keeseville	A2	FA1
56	418797E	4929750N	Keeseville	A2	FA1
57	419185E	4929705N	Keeseville	A2	FA1
58	419237E	4929533N	Keeseville	A2	FA1
59	419377E	4929413N	Hannawa Falls, Keeseville	A1,A2	FA3(?), FA1
60	417986E	4928498N	Keeseville	A2	FA1
61	402834E	4940012N	Keeseville	A3	FA5
62	419020E	4934942N	Hannawa Falls(?)/Keeseville(?)	A1(?)/A2(?)	FA3 or FA2
63	419521E	4936705N	Keeseville	A3	FA5
64	418470E	4937296N	Keeseville	A3	FA5
65	416993E	4937131N	Theresa		
66	409120E	4943496N	Theresa		
67	397051E	4936100N	Hannawa Falls	A1	FA3
68	408560E	4926077N	Hannawa Falls, Keeseville	A1,A2	FA3,FA2
69	439420E	4934025N	Theresa		
70	427442E	4937404N	Keeseville, Theresa(?)	A2,A3	FA1,FA5
71	411723E	4935120N	Keeseville	A2	FA1 (talus)
72	439028E	4932723N	Theresa		

Station	Easting	Northing	Lithostratigraphic unit(s)	Allounit(s)	Facies association(s)
73	436810E	4929860N	Ausable	A1	FA1 (talus)
74	408423E	4967610N	Hannawa Falls, Keeseville	A1,A2	FA3,FA2
75	405884E	4967820N	Hannawa Falls, Keeseville	A1,A3	FA3,FA5
76	405560E	4969200N	Keeseville	A3	FA5
77	445044E	4918560N	Theresa		
78	445882E	4922357N	Keeseville	A2	FA2,FA1
79	446373E	4922953N	Keeseville	A2,A3	FA2,FA1,FA5
80	446578E	4923110N	Keeseville	A2	FA2(?)
81	443393E	4918878N	Keeseville	A2	FA2
82	443719E	4919166N	Keeseville	A2	FA2
83	443794E	4919361N	Theresa		
84	442480E	4917865N	Keeseville	A2	FA1
85	441971E	4916836N	Keeseville	A2	FA2,FA1
86	437384E	4917814N	Hannawa Falls, Keeseville	A1, A2, A3	FA3,FA2,FA5
87	439288E	4924031N	Keeseville, Theresa	A2,A3	FA2,FA5
88	438760E	4925121N	Keeseville, Theresa	A2,A3	FA2,FA5
89	445809E	4934582N	Theresa		
90	446606E	4935379N	Theresa		
91	451726E	4934628N	Theresa		
92	451129E	4934422N	Theresa		
93	445752E	4927775N	Keeseville	A2	FA2
94	445788E	4927349N	Keeseville	A2	FA2
95	440606E	4915124N	Keeseville	A2	FA2
96*	439850E	4914411N	Keeseville	A2	FA2
97*	439147E	4903800N	Hannawa Falls, Keeseville	A1,A2,A3	FA3,FA2,FA5
98	433100E	4906750N	Keeseville	A2	FA2
99	433345E	4909883N	Keeseville	A2	FA2
100	432072E	4912176N	Keeseville	A2	FA1,FA2
101	433061E	4913021N	Keeseville	A2	FA2
102	438315E	4919418N	Keeseville	A2	FA2
103	438570E	4919804N	Keeseville	A2	FA2
104	440433E	4921840N	Keeseville	A2,A3	FA2,FA5
105	437087E	4908957N	Hannawa Falls(?), Keeseville	A1(?),A2	FA3(?),FA2
106	437437E	4908477N	Keeseville	A2	FA2
107	437279E	4908026N	Hannawa Falls	A1	FA3(?),FA2(?)
108	435928E	4912880N	Keeseville	A2	FA2
109	435692E	4911863N	Keeseville	A2	FA2
110	435716E	4910730N	Keeseville	A2	FA2
111	439278E	4919731N	Keeseville	A2	FA2

Station	Easting	Northing	Lithostratigraphic unit(s)	Allounit(s)	Facies association(s)
112	430118E	4910676N	Keeseville	A2	FA2, FA1
113	428485E	4910354N	Keeseville	A2	FA2
114	427991E	4907977N	Keeseville	A2	FA2
115	428384E	4907702N	Keeseville	A2	FA2, FA1
116	420262E	4902815N	Keeseville	A2	FA1
117	419813E	4907507N	Keeseville	A2,A3	FA1,FA5
118	419304E	4907018N	Keeseville	A2	FA1
119	420556E	4905987N	Keeseville	A2	FA1
120	42096E	4906258N	Keeseville	A2	FA1
121	428739E	4905147N	Ausable	A1	FA1
122	459204E	4935637N	Keeseville	A2	FA2
123	435912E	4906623N	Keeseville	A3	FA5
124	436930E	4904803N	Ausable, Hannawa Falls, Keeseville	A1, A2, A3	FA3,FA1,FA2,FA5
125	438709E	4902532N	Keeseville	A2	FA1,FA2
126	438835E	4903238N	Keeseville	A2	FA2
127	438035E	4901897N	Keeseville	A2	FA1,FA2
128	436662E	4901203N	Keeseville	A3	FA5
129	436714E	4896198N	Hannawa Falls, Keeseville	A1,A2	FA3,FA2
130	434488E	4897850N	Keeseville	A2	FA2
131	434524E	4898624N	Keeseville	A2	FA2(?)
132	444644E	4919555N	Keeseville	A2	FA2
133	441881E	4925625N	Keeseville, Theresa	A2,A3(?)	FA2,FA5(?)
134	438818E	4911917N	Keeseville	A2	FA2
135	438131E	4910922N	Keeseville	A2,A3	FA2,FA5
136	453297E	4930718N	Keeseville, Theresa	A2	FA2
137	609246E	4951133N	Keeseville	A2 or A3 (?)	FA2
138	605142E	4962498N	Ausable (Altona Mb)	A1	FA6
139	604306E	4964042N	Ausable	A1	FA1
140	606289E	4965515N	Ausable	A1	FA1
141	613796E	4964152N	Ausable	A1	FA1
142	616944E	4968144N	Ausable	A1	FA1
143	615550E	4977500N	Ausable	A1	FA1
144	614909E	4972049N	Ausable	A1	FA1
145	612041E	4979382N	Keeseville	A2	FA1
146	613126E	4979347N	Keeseville	A2/A3(?)	FA2
147	607190E	4978930N	Theresa		
148	607489E	4975630N	Keeseville	A3(?)	FA2
149	607362E	4975009N	Keeseville	A2/A3(?)	FA2

Station	Easting	Northing	Lithostratigraphic unit(s)	Allounit(s)	Facies association(s)
150	607553E	4975171N	Keeseville	A2/A3(?)	FA2
151	606954E	4971427N	Keeseville	A2/A3(?)	FA2
152	606129E	4970511N	Keeseville	A3	FA2
153	601528E	4968118N	Keeseville	A2	FA1
154	593181E	4965010N	Ausable	A1	FA1
155	596018E	4968465N	Keeseville	A2	FA1
156	602060E	4971946N	Keeseville	A2/A3(?)	FA2
157	602346E	4973096N	Keeseville	A2/A3(?)	FA2
158	599828E	4974794N	Ausable	A1	FA1
159	599432E	4975691N	Keeseville	A2/A3(?)	FA1/FA2(?),FA5
160	599401E	4979574N	Keeseville	A3	FA2,FA4/FA5(?)
161	590915E	4979343N	Keeseville	A2/A3(?)	?
162	595059E	4974729N	Keeseville	A2	FA1
163	596210E	4973222N	Keeseville	A2	FA1
164	553696E	4971879N	Keeseville	A2/A3(?)	FA2
165	555281E	4968634N	Keeseville	A2/A3(?)	FA2
166	566954E	4967703N	Keeseville	A3	FA3
167	565785E	4971310N	Keeseville	A2/A3(?)	FA2
168	571974E	4972971N	Keeseville	A2,A3(?)	FA1,FA2
169	578785E	4976078N	Keeseville	A2/A3(?)	FA2
170	578778E	4979604N	Theresa		
171	594549E	4985748N	Ausable	A1	FA1
172	591513E	4987598N	Ausable	A1	FA1
173	591518E	4987409N	Ausable	A1	FA1
174	596274E	4988706N	Ausable	A1	FA1
175	591518E	4987409N	Ausable	A1	FA1
176	582697E	4986664N	Ausable, Keeseville	A1,A2	FA1,FA2
177	587545E	4996190N	Keeseville	A2	FA1
178	588478E	4995998N	Keeseville	A2/A3(?)	FA1/FA2(?)
179	597337E	4994954N	Ausable	A1	FA1
180	605274E	4969400N	Keeseville	A3	FA2
181	594313E	4983944N	Ausable	A1	FA1
182	596999E	4982373N	Keeseville	A3	FA4
183	596829E	4982215N	Ausable	A1	FA1
184	613811E	4964510N	Ausable (Altona Mb)	A1	FA6
185	613697E	4964682N	Ausable (Altona Mb)	A1	FA6
186	613609E	4964838N	Ausable (Altona Mb)	A1	FA6
187	606790E	4971231N	Keeseville	A3	FA2
188	567998E	4968956N	Keeseville	A3	FA3
189	618328E	4972073N	Keeseville	A2	FA1

Station	Easting	Northing	Lithostratigraphic unit(s)	Allounit(s)	Facies association(s)
190	622110E	4931262N	Keeseville	A2/A3(?)	FA4
191	614416E	4942797N	Keeseville	A2/A3(?)	FA2/FA4(?)
192	502050E	4941190N	Hannawa Falls	A1	FA3
193	426429E	5021230N	Keeseville	A3	FA4
194	581384E	5026425N	Ausable	A1	FA1
195	406748E	4987293N	Theresa		
196	410500E	4931581N	Keeseville	A3	FA5
197	402960E	4994955N	Theresa		
198	410267E	4943141N	Theresa		
199	609922E	4985482N	Theresa		
200	598852E	4985199N	Keeseville	A3	FA2
201	598892E	4984397N	Keeseville	A3	FA4,FA5
202	583224E	4983511E	Keeseville	A2/A3(?)	FA2
203	599473E	4984382E	Keeseville	A2/A3(?)	FA2,FA3
204	582677E	4986297N	Keeseville	A2	FA1
205	580882E	5018775N	Keeseville	A3	FA4?
206	582693E	5018872N	Theresa		
207	583452E	5018314N	Keeseville	A3	FA4
208	584834E	5018560N	Theresa		
209	606640E	4999246N	Keeseville	A3	FA2,FA4
210	606398E	4998249N	Keeseville	A3	FA2,FA4
211	413363E	4898029N	Keeseville	A2,A3	FA1,FA5
212	438023E	4895608N	Keeseville	A2	FA2
213	438224E	4895489N	Keeseville	A2	FA2
214	433832E	4895554N	Keeseville	A2	FA2
215	440768E	4905993N	Keeseville	A2,A3	FA2,FA4
216	456401E	4926435N	Keeseville	A2	FA2
217	456684E	4926584N	Hannawa Falls, Keeseville	A1,A2	FA3,FA1
218	463886E	4915571N	Grenville, Potsdam(?)		
219	463703E	4922376N	Keeseville	A2	FA1,FA2
220	501982E	4940024N	Hannawa Falls	A1	FA3
221	428581E	5017967N	Keeseville	A3	FA4
222	432025E	5019788N	Keeseville, Theresa	A3	FA4, FA5
223	435048E	4926711N	Keeseville, Theresa	A3	FA5
224	410540E	4932214N	Keeseville	A3	FA5
225	408856E	4943563N	Theresa		
226	590138E	4969888N	Ausable	A1	FA1
227	589065E	4972039N	Ausable	A1	FA1
228	588932E	4970698N	Ausable	A1	FA1
229	585834E	4970134N	Ausable	A1	FA1

Station	Easting	Northing	Lithostratigraphic unit(s)	Allounit(s)	Facies association(s)
230	585361E	4970054N	Ausable	A1	FA1
231	581656E	4971334N	Keeseville	A2	FA1
232	613553E	4964937N	Ausable (Altona Mb)	A1	FA6
233	613507E	4964930N	Ausable (Altona Mb)	A1	FA6
234	613695E	4964708N	Ausable (Altona Mb)	A1	FA6
235	418867E	4929772N	Keeseville	A2	FA1
236	419593E	4907399N	Keeseville	A2,A3	FA1,FA5
237	598869E	4978700N	Keeseville	A2	FA4
238	598187E	4981380N	Keeseville	A2	FA2
239	607972E	4975007N	Theresa		
240	437567E	5016003N	Theresa		
241	419635E	4929836N	Keeseville	A2	FA1
242	610377E	4963628N	Ausable	A1	FA1
243	601718E	5000408N	Theresa		
244	620920E	4929374N	Keeseville	A2	FA4
245	619411E	4938962N	Ausable	A1	FA1
246	527007E	4949163N	Ausable	A2	FA2
247	593625E	4971348N	Keeseville	A2/A3(?)	FA4(?)
248	594515E	4970959N	Keeseville	A2/A3(?)	FA4(?)
249	593134E	4976793N	Keeseville	A2/A3(?)	FA4
250	594572E	4978219N	Keeseville	A2	FA1
251	611651E	4966942N	Ausable	A1	FA1
252	611039E	4967555N	Ausable	A1	FA1
253	611507E	4967118N	Ausable	A1	FA1
254	611451E	4966948N	Ausable	A1	FA1
255	611470E	4967221N	Ausable	A1	FA1
256	612969E	4965082N	Ausable (Altona Mb)	A1	FA6,FA1
257	612135E	4961074N	Ausable (Altona Mb)	A1	FA6
258	607422E	4970155N	Ausable/Keeseville	A1/A2	FA1/FA2
259	608632E	4969178N	Ausable	A1	FA1
260	523192E	4949375N	Keeseville	A2	FA2
261	522532E	4950295N	Keeseville	A2	FA2
262	512010E	4944717N	Ausable	A1	FA1
263	583425E	4985478N	Keeseville	A2	FA1
264	461662E	4917918N	Keeseville	A2	FA2
265	623408E	4972301N	Ausable	A1	FA1
266	612817E	4942641N	Keeseville	A2	FA1
267	595257E	4973408N	Keeseville	A2	FA1
268	594708E	4973110N	Keeseville	A2	FA2
269	589648E	5024071N	Keeseville	A3	FA4

Station	Easting	Northing	Lithostratigraphic unit(s)	Allounit(s)	Facies association(s)
270	582629E	5025250N	Ausable	A1	FA1
271	582128E	5020372N	Ausable	A1	FA1
272	583763E	4985439N	Keeseville	A2	FA2
272	584159E	4985505N	Keeseville	A3	FA3
272	582300E	5020399N	Keeseville	A4	FA4
273	584861E	5020399N	Keeseville	A5	FA5
273	584577E	4985448N	Keeseville	A2	FA2
274	587817E	5018305N	Keeseville	A2	FA3
275	584229E	5018019N	Keeseville	A3	FA4
276	599568E	4771806N	Galway		
277	624473E	4809849N	"Potsdam"/Keeseville		FA5
278	629392E	4823707N	"Potsdam"/Keeseville		FA4
279	628073E	4843876N	Galway(?)		
280	628335E	4846028N	Ausable	A1	FA1
281	626965E	626965N	"Potsdam"/Keeseville		FA4
282	582586E	5020461N	Ausable	A1	FA1
283	431772E	5020145N	Keeseville	A3	FA4
284	418558E	4929140N	Keeseville	A2	FA1
285	437746E	4898717N	Hannawa Falls, Keeseville	A1,A2	FA3,FA2
286	396072E	4968341N	Keeseville	A3	FA5
287	402586E	4969931N	Keeseville	A3	FA5
288	399173E	4962399N	Keeseville	A3	FA5
289	397831E	4961590N	Hannawa Falls	A1	FA3
290	396844E	4949974N	Keeseville	A2	FA2
291	383376E	4945381N	Ausable	A1	FA1
292	381535E	4945977N	Ausable	A1	FA1
293	447399E	5041600N	Keeseville	A3	FA5
294	445667E	5040881N	Keeseville	A3	FA5
295	562758E	5049488N	Keeseville	A3	FA4
296	564490E	5058740N	Keeseville	A3	FA4