Before the Great North American Carbonate Bank: A Complex Cambrian - Lower Ordovician Transgressive History Recorded in Siliciclastic Strata of he Potsdam Group, Southeast Laurentia*

David G. Lowe[1], R. W. C. Arnott[1], and B. V. Sanford[2]

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[1]University of Ottawa, Ottawa, ON, Canada (davelowe_atmun@hotmail.com)
[2]Geologic Survey of Canada, Ottawa, ON, Canada (retired)

Introduction

In the Ottawa Embayment and Quebec Basin rocks of the Potsdam Group form the base of the Cambrian-Ordovician Sauk Megasequence and record siliciclastic deposition during early marine transgression that preceded deposition of marine carbonates here and in basins across most of southern Laurentia. The Ottawa Embayment is a physiographic element bounded largely to the north and south by the limits of a Neoproterozoic rift, and to the west and east by two transcontinental arches, the Frontenac and the Oka-Beauharnois arch, respectively (Figure 1). The Quebec Basin is bounded to the west by the Oka-Beauharnois Arch and to the east by the Appalachians, and at the time of deposition it was presumably open to the Iapetus Ocean. Movement along faults in the area is post-Ordovician, and as a result the Late Cambrian to Early Ordovician basin configuration and basin dynamics are generally poorly understood.

Recent investigations show that the Potsdam isopach, lithofacies, and bounding contacts change dramatically from east to west (Figures 1 and 2). Sanford and Arnott (2010) recognized that strata of the Potsdam thin from up to 700 m along the western margin of the Oka-Beauharnois Arch to less than 50 m along the eastern margin of the Frontenac Arch (Figure 1). This dramatic thinning coincides also with significant changes in stratal make-up (Figure 2). This paper focuses on these stratal differences and specifically in two areas where outcrops are particularly well exposed: (a) along the southeastern margin of the Ottawa Embayment and southwestern margin of the Quebec basin, straddling the Oka-Beauharnois Arch; and (b) the southwest to the northwest margin of the Ottawa Embayment, much of which is situated along the Frontenac Arch (Figure 1). Strata generally crop out poorly between these areas, and as a consequence regional correlations are problematic. In area (a) the Potsdam comprises three thick conformably stacked units with a marine affinity (eastern succession). Area (b), on the other hand, consists of three relatively thin unconformity-bounded units with mostly continental lithofacies (western succession) (Figure 2).

In this article we first describe and interpret these successions. Paleoenvironmental interpretations are based on detailed facies analysis, but for brevity are not described here. Following this we explore possible regional correlations and elucidate some of the complicated depositional history of this clastic-dominated succession and the basin dynamics that preceded platform transgression and initiation of the widespread carbonate platform of the Sauk Megasequence.

The Eastern Succession

The eastern succession is made up of three units: Unit 1 (E1), comprising a marine succession of arkosic sandstone grading upward to mudstone, siltstone, dolomicrite overlain by interbedded mud (Jericho Member of Sanford and Arnott, 2010, or similarly the Altona Formation of Landing et al., 2009); Unit 2 (E2), a thick package of fluvial-deltaic arkosic sandstone and pebble conglomerate (Ausable/Covey Hill Formation of Sanford and Arnott, 2010); and Unit 3 (E3), a succession of aeolian and marginal marine to shallow-marine quartz arenite (Keeseville/Cairnside Formation of Sanford and Arnott, 2010) (Figure 2).

The E1 stratal succession is only recognized east of the Oka-Beauharnois Arch and is interpreted to record an initial marine transgression that peaked with deposition of the dolomicrite beds (Figure 3); it in turn was followed by highstand progradation caused by an increased flux of feldspar-rich (~20-30%) clastic sediment from a first-cycle sediment source. According to detrital zircon ages from Chiarenzelli et al. (2010), these sediments were locally sourced from nearby ~1160 Ma AMGC plutonic rocks currently exposed in the northeast Adirondack Massif. Based on trilobite assemblages, Landing et al (2009) interpreted the E1 to be Middle Cambrian to upper Late Cambrian.

The volume of clastic input increased dramatically with the initiation of E2 and the deposition of more than 500 m of arkosic sandstone locally. The locus of E2 deposition was along the axis of the Oka-Beauharnois Arch, and thick deposits are present on its eastern and western margins, thinning rapidly towards the south and farther to the west. High modal percentages of unaltered detrital feldspar (locally up to 40%) suggest an influx of first-cycle material, which according to the detrital zircon ages of Chiarenzelli et al (2010), indicates a source very similar to that for E1. Paleoflow measurements from strata east and on the axis of the Oka-Beauharnois Arch indicate paleodrainage toward the SE, E, and NE. Importantly a small number of measurements just west of the arch indicate W-NW paleoflow, suggesting the Oka-Beauharnois Arch formed a local drainage divide (Figure 4). This indicates that basement highs along the current trend of the Oka-Beauharnois Arch acted as both a sediment source and a topographic barrier that exerted a major influence on drainage patterns during at least E2 time. Additionally, despite the thickness of E2, its depositional architecture is remarkably uniform from bottom to top, comprising tabular beds of coarse 3D dune cross-strata with occasional pebble layers and thin siltstone and mudstone lenses (Figure 5). This uniformity indicates a protracted balance or excess of sediment supply over accommodation space along the margins of the Oka-Beauharnois Arch. We suggest that accommodation was a result of localized subsidence along the Oka-Beauharnois Arch, and also that the arch acted as a barrier and sediment source not only during E2 deposition but also extending back to the deposition of the E1 (which is also arkosic, sourced locally and confined to the east side of the arch).

The contact between E2 and E3 is marked by a dramatic change in mineralogy from arkose to subarkose/quartz arenite and coincides with a change from fluvial to marginal marine strata. This dramatic change in mineralogy most probably represents a change from local to more regional sediment sources. We are currently processing samples for detrital zircon age dating to evaluate this hypothesis.

East of the Oka-Beauharnois Arch, E3 forms a relatively thick (at least 150-200 m) transgressive succession of marginal marine to fully marine strata. Equivalent strata on the west side of the arch, in contrast, are interpreted to be aeolian to marginal marine that progressively thin westward. This lateral facies change represents an east-to-west continuum of marine to continental facies. In addition it indicates that, although the arch had diminished as an active sediment source, it still remained a partial barrier that stalled the Sauk seaway transgression over the

Laurentian platform and resulted in the accumulation of a thick marginal marine succession east of the arch. Locally thick accumulations (up to 150 m) of “knee-deep” marginal marine facies at the famous Ausable Chasm section (and a few other locations) suggest that accommodation along the arch margin continued, and that sediment flux and accommodation remained balanced.

Stratigraphically-upward siliciclastic strata of E3 become increasingly interbedded and eventually replaced by dolomitic sandstone of open-marine affinity. Farther to the north (north of Montreal), however, a convincing unconformity between the Potsdam and the overlying clastic-carbonates was described by Salad-Hersi et al. (2002) from subsurface cores.

Overall, the eastern succession records a stratal succession related to the stalling of the Sauk seaway transgression by uplift along the Oka-Beauharnois Arch -- a physiographic feature that acted both as a topographic barrier and sediment source.

The Western Succession

Like the eastern succession the western succession comprises three units: Unit 1 (W1), composed of aeolian sandstones (Hannawa Falls Member of Sanford and Arnott, 2010); Unit 2 (W2), made up of alluvial, fluvial sandstone and conglomerate, including probable syn-rift deposits, overlain by aeolian sandstone (Chippewa Bay Member of Sanford and Arnott, 2010); and Unit 3 (W3), comprising marginal- and shallow-marine sandstone (Nepean/Keeseville Formation of Sanford and Arnott, 2010). Most of the western succession is composed of quartz arenite and conglomerates with quartz clasts, with only rare arkose in fluvial strata of W2.

Aeolian strata of W1 are only locally preserved but appear to extend quite far north and east (Figure 2). A significant angular unconformity exists above W1 and locally truncates structural deformation (Figure 6). This unconformity and the structural deformation present beneath it are interpreted to represent not only a significant stratal hiatus, but also a period of localized tectonic deformation and attendant widespread erosion.

Strata of W2 are interpreted to be alluvial and fluvial overlain locally by thin aeolian strata. Very coarse (boulder) sediment-gravity flow deposits occur adjacent to some major normal faults that locally form steep basement escarpments that suggest deposition coincided with a period of active tectonism (Figures 7 and 8). In addition, rare fluvial arkoses with up to 30% detrital feldspar are present locally and in close proximity to an extensive normal fault, indicating first-cycle sourcing from the granitoid rocks on the adjacent footwall. Paleoflow measurements, correlations and mapping of sedimentary facies indicate that W2 was deposited over an irregular topography that was subdivided into a number of smaller catchment basins (Figure 8). Overall, strata of W2 record continental deposition over an irregular tectonically generated topography that formed either before or coincident with W2 deposition. The tectonic activity that influenced W2 deposition may have been part of the same event that caused structural deformation and erosion of W1.

The contact between W2 and W3 is also an unconformity characterized by an erosional surface (locally an erosive transgressive ravinement surface) and thin lag deposit overlain by onlapping marine strata (Figure 9). Selleck (1978) described a pedogenic silcrete present locally in the upper 1-2 m of W2 overlain by an abrupt flooding surface and strata of W3. This unconformity is interpreted to represent a significant hiatus in deposition, but one that was not as significant as the underlying unconformity above W1.

Deposits of W3 are interpreted to be mostly fully marine except in the NW part of the Ottawa Embayment (near Ottawa) where they are interpreted to be marginal marine. Coincidently these latter strata are bounded by two well recognized post-Ordovician normal faults (Figure 1). Here, however, these faults are interpreted to have been active during Potsdam time and generated local topography that separated marginal and fully marine depositional conditions.

In most places siliciclastic strata are overlain conformably by open-marine carbonates. In the NW Ottawa Embayment, on the other hand, this contact is unconformable and is interpreted to reflect a relatively localized hiatus occurring only where faulted topography has generated uplands where marginal marine strata of W3 was eroded and later transgressed. This contrasts the interpretation of Dix et al. (2003) that envisages a widespread sequence boundary. Moreover, biostratigraphic ages of the base of the carbonate succession young from the south to the north, suggesting it is a diachronous surface (Greggs and Bond, 1971, Brand and Rust, 1977) (Figure 2).

In summary, the western succession records a protracted history of continental deposition punctuated by erosional unconformities and tectonism and ending in the transgression of the Sauk seaway over irregular topography.

Summary and Discussion

Dramatic differences in thickness and nature of the internal bounding surfaces in the Potsdam Group across the study area reflect major differences in accommodation space, most likely related to differences in rates of subsidence. Subsidence rates were apparently highest along the flanks of the Oka-Beauharnois arch, where the thickest succession of conformable strata is preserved. In contrast, the western succession is an order of magnitude thinner and dissected by unconformities, reflecting limited accommodation space and minimal subsidence.

Moreover, although three regionally extensive stratal units can be identified on opposite sides of the arch, it is currently uncertain how each of the respective lower two units correlate. Due to the ubiquitous occurrence of aeolian strata in both W1 and E3 along the southern Ottawa Embayment, it is possible that these units are correlative. If true, this would indicate an even more diachronous relationship between the eastern and western successions than originally thought. Alternatively, it is also possible that material eroded at the unconformity above W1 became the source of the voluminous quartz-rich sands of E3. In this case, the deactivation of the Oka-Beauharnois Arch as a source area would be more or less coeval with uplift and erosion along the western margin of the Ottawa Embayment - implying some interesting basin dynamics worth further investigation. Ongoing detrital zircon geochronology should be useful in evaluating these alternative regional correlations.

Strata of W3 and E3 are likely correlative and, in the study area, represent the base of the transgressive systems tract that culminated in the thick carbonate succession of the Sauk Megasequence. Existing age relationships and contact relationships suggest that this transgression was diachronous from the SE to the NW. This study suggests that the earliest stages of the transgression were stalled by the Oka-Beauharnois Arch, which acted as a physiographic barrier that fully separated continental conditions in the Ottawa Embayment to the west from marine and marginal marine conditions in the Quebec Basin to the east. Later, however, marine and marine-influenced strata of W3 spread progressively westward from the Quebec Basin, ultimately breaching the Oka-Beauharnois Arch and moving into the Ottawa Embayment. Continued transgression eventually replaced siliciclasic with carbonate sedimentation throughout the entire area.

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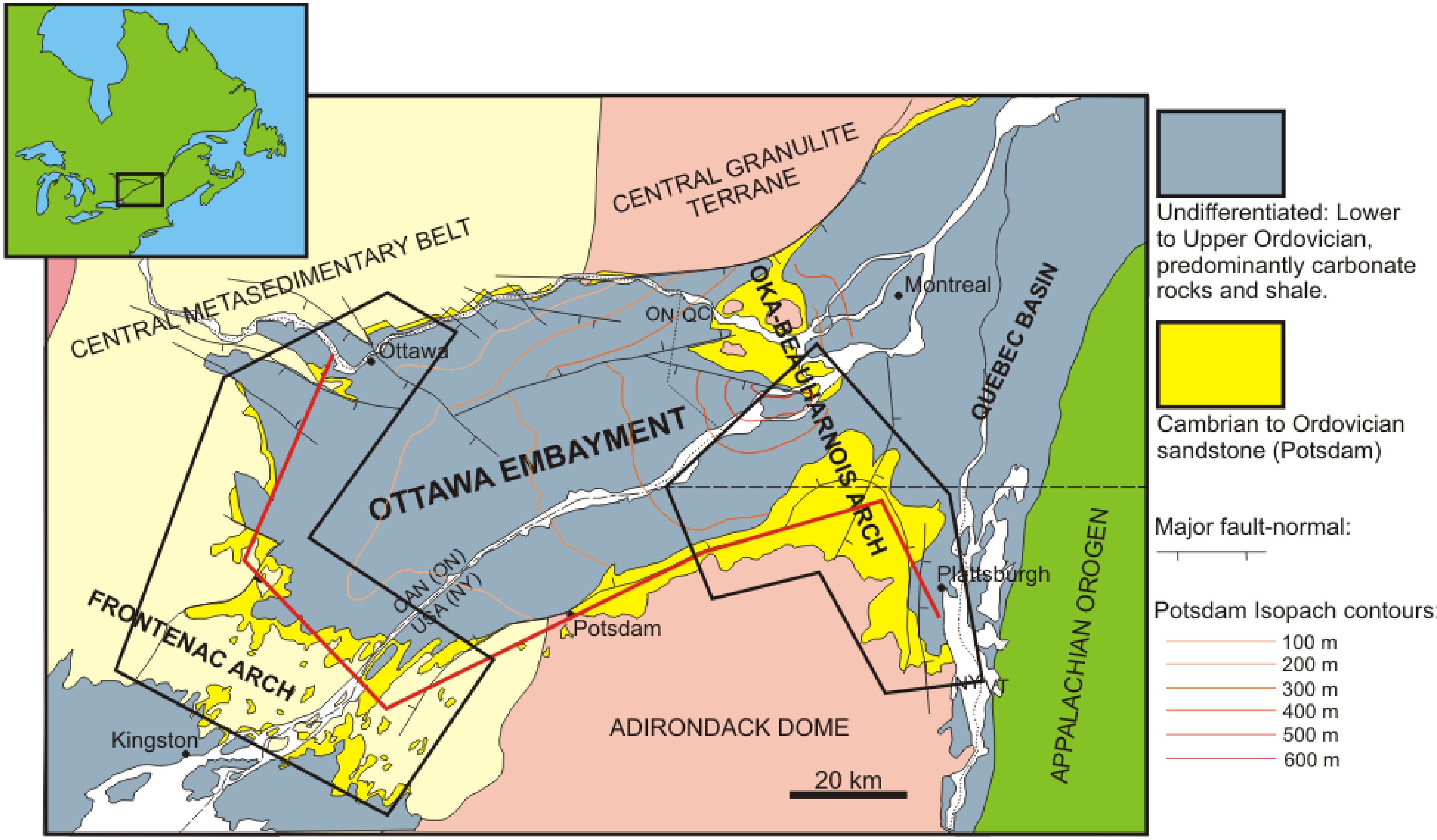

Figure 1: Base map of study area. Outlined in black lines are the two areas in which outcrops are well exposed and where field investigations are focused. The red line correlates with Figure 2.

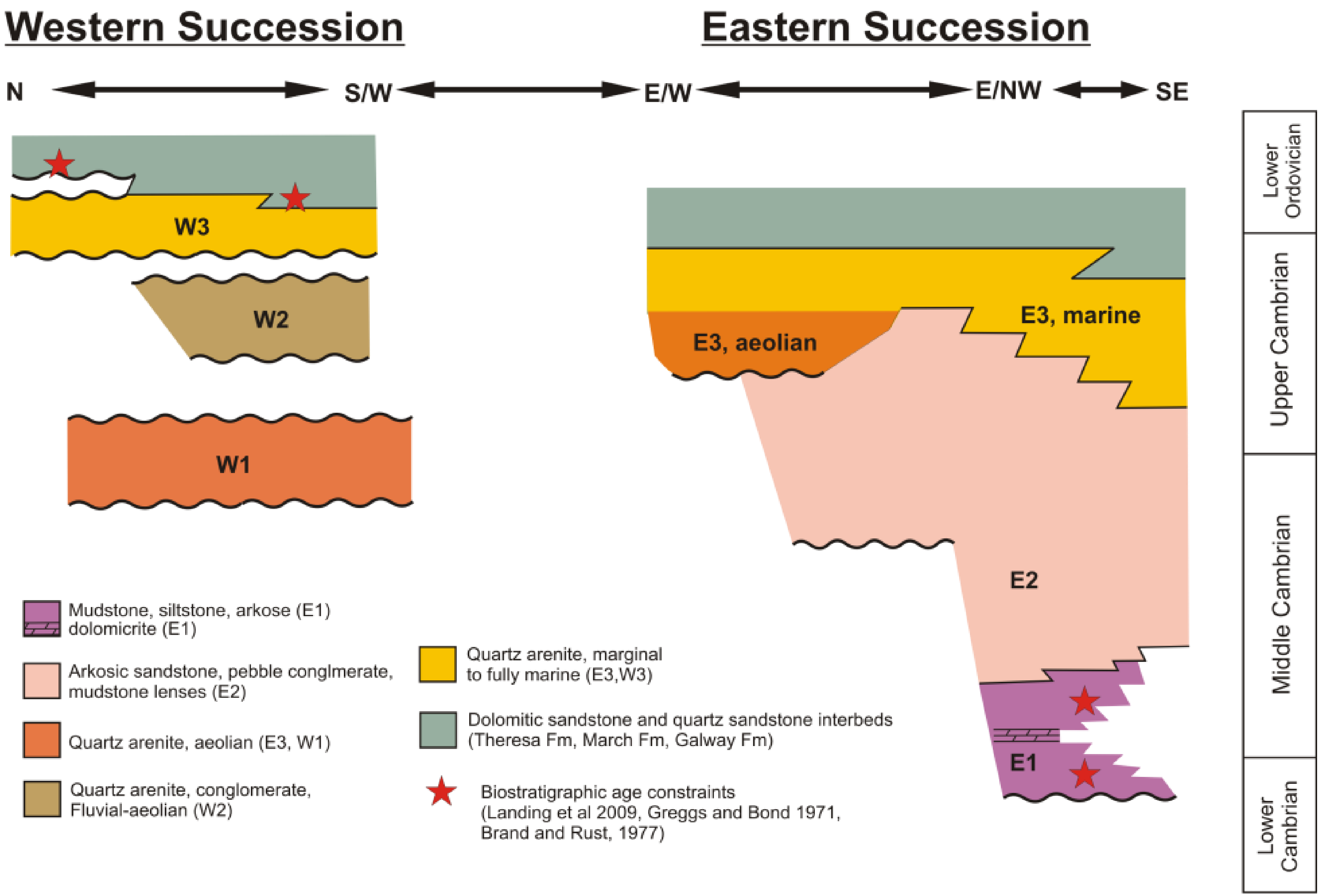

Figure 2: Cross-sectional stratigraphic columns of the eastern and western successions. The distributions of these successions are outlined in black lines in Figure 1, and the extent of this cross sectional profile is given by the red line in Figure 1.

Figure 3: Tabular dolomicrite beds interbedded with maroon mudstone in the middle to upper part of E1. Location is near West Chazy, NY. Hammer for scale.

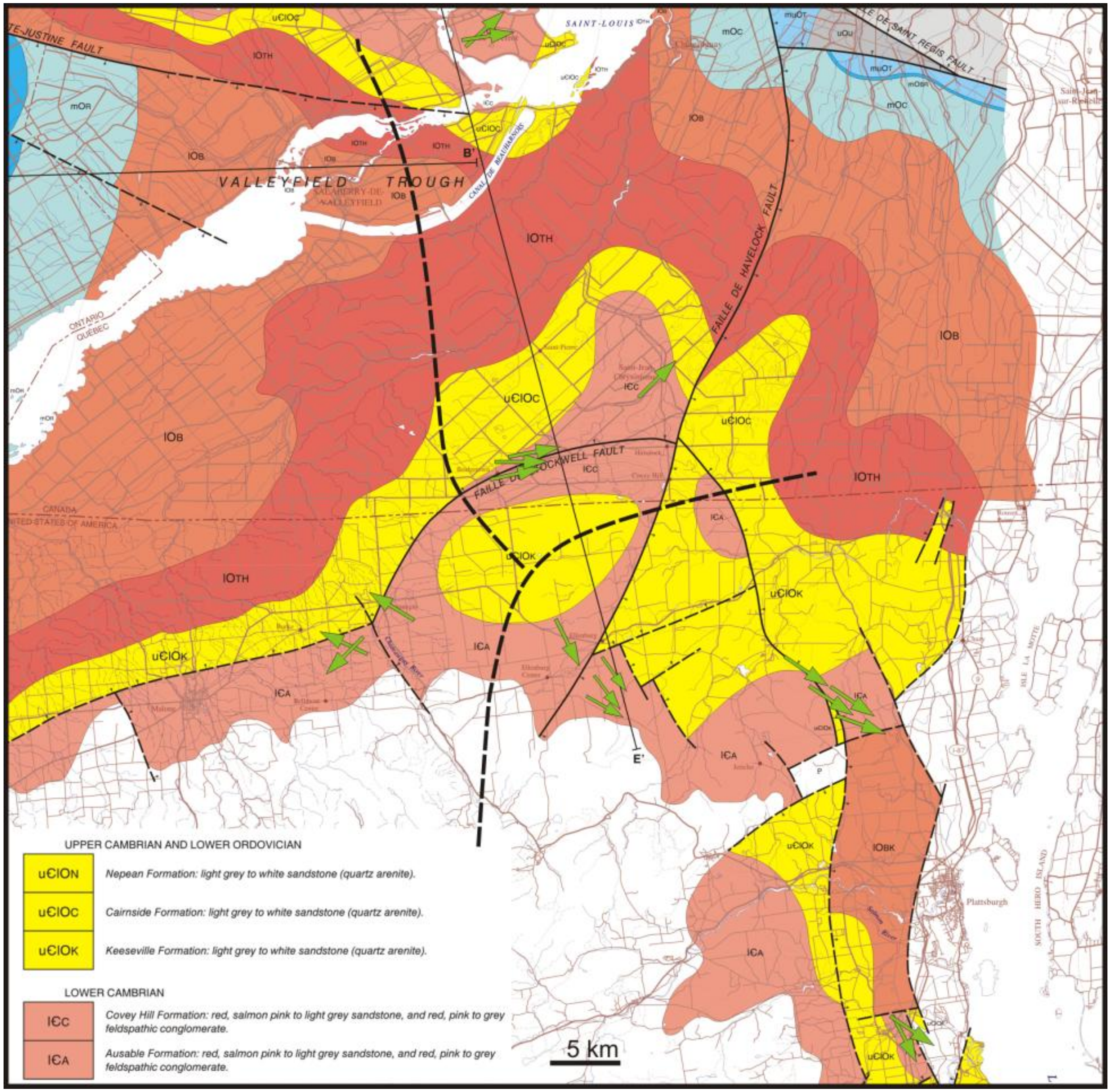

Figure 4: Geologic map of the southern Oka-Beaharnois Arch area showing paleoflow directions from E2 (E2 is lC_C/lC_A, and paleoflow is shown by green arrows). Based on the paleoflow data, a complex drainage divide is interpreted in the vicinity of the arch axis (black dashed lines).

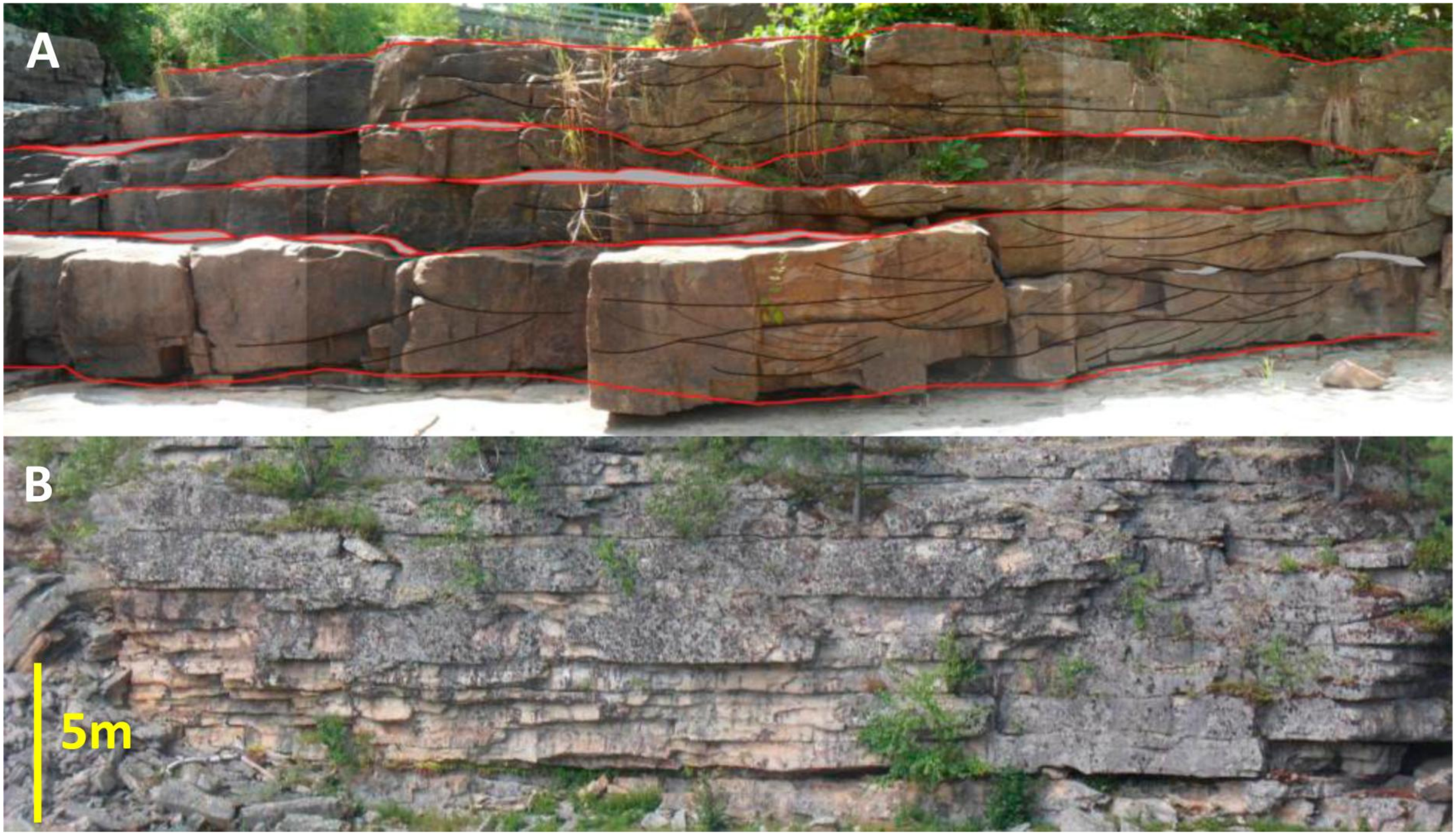

Figure 5: (A) close up view of the stratal archetecture of E2, comprising 3D dune cross-strata bounded in tabular coset beds. Thin discontinuous mudstone/siltstone layers are present (in grey) between these coset beds. Location is near Peru, NY. (B) This stratal archetecture is very continuous laterally and vertically, as shown by this escarpment at Flat Rock State Forest in New York.

Figure 6: Unconformity between W1 and W2 (shown in red). The unconformity is angular and truncates folded strata of W1. Also outlined above the contact are sandstone lithic clasts derived from W1. Location is near Lyndhurst, ON.

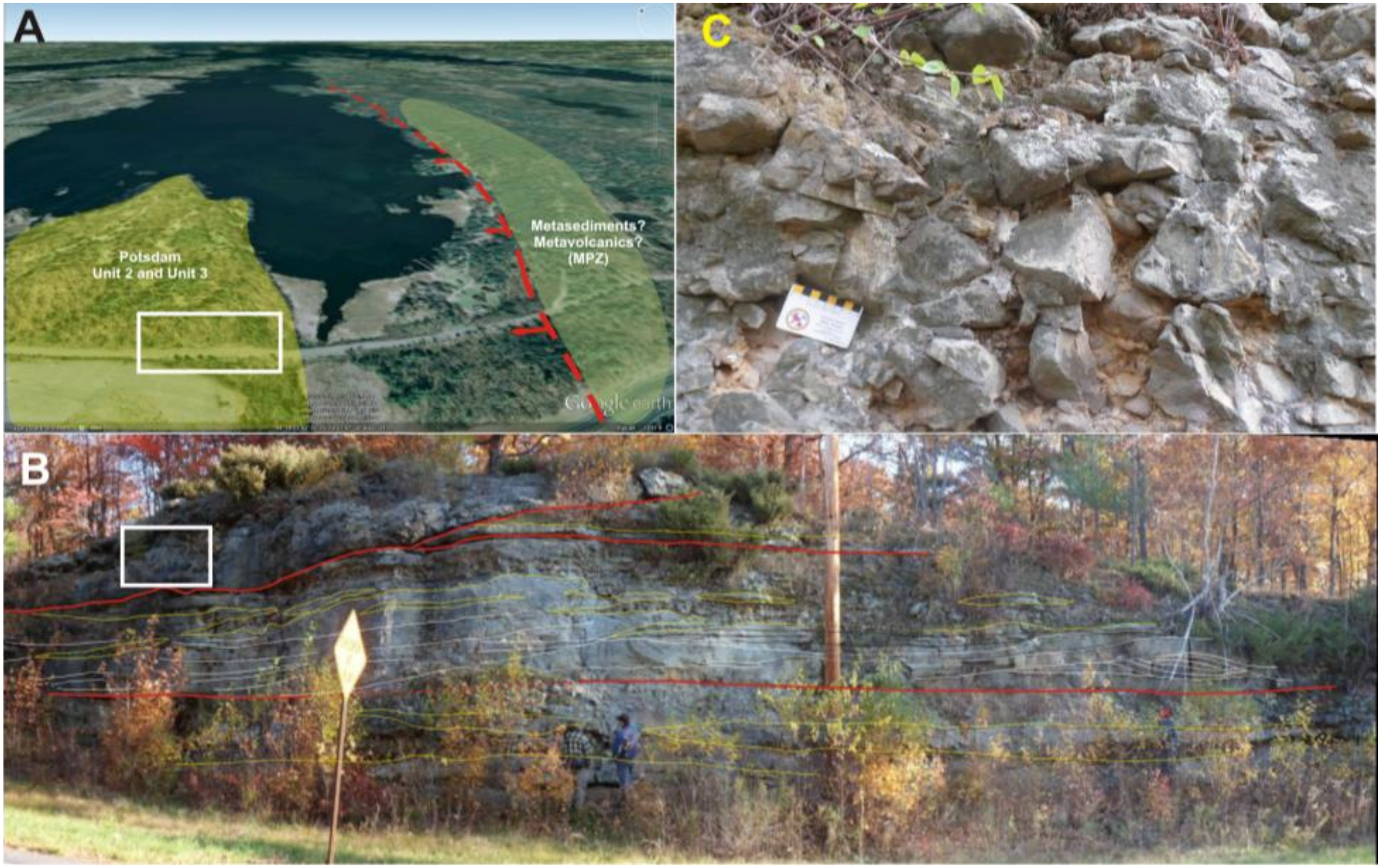

Figure 7: Example of a boulder sediment-gravity flow deposit adjacent to a normal fault, location is Wellesley Island, NY. The general relationship is shown in (A) - Potsdam strata are located adjacent to a mapped normal fault. The strata are interbedded sandstones and conglomerates (B). The texture of the uppermost bed in (B) is shown in (C)- an unsorted boulder conglomerate lacking any fabric.

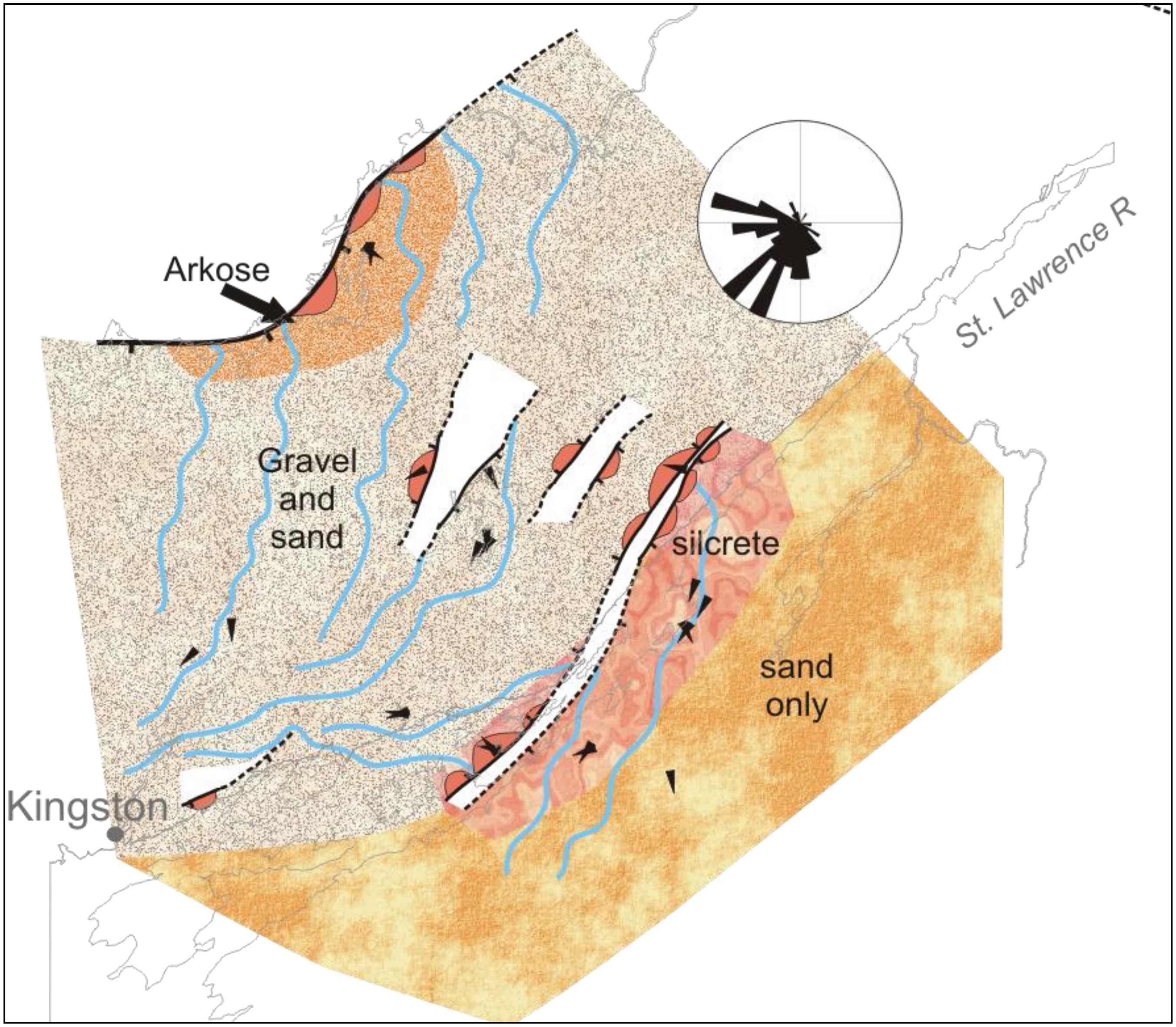

Figure 8: Paleogeographic reconstruction of W2 in the vicinity of Kingston. Here, the distribution of numerous fault scarps and associated boulder debris flows, such as in Figure 7, are shown. Black triangles as well as the rose diagram represent paleoflow measurements. Paleoflow and differences in the occurrence of coarse clastics indicate a paleodrainage divide existed in the vicinity of the St. Lawrence River. Arkoses occur along a major bounding fault, which is also the northern limit of W2 deposits.

Figure 9: Unconformity between W2 and W3, north of Portland, ON. An erosional surface is shown by the red line. This is overlain by a ~40cm- thick transgressive gravel and then an onlap surface, shown here in yellow. Deposits above the onlap surface are fully marine strata of W3 with robust vertical burrows.