Evidence of Syn-Sedimentary Tectonism in the Burgess Shale and Other Middle Cambrian Units, British Columbia, Canada

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Abstract

The thick Cambrian stratigraphic succession of Western Laurentia were deposited along a quasi-active rifted margin, a remnant of the Proterozoic fragmentation of the supercontinent Rodinia. The fossiliferous Burgess Shale (Middle Cambrian) bears evidence of this ancient rift, as do the older Gog and Mt Whyte formations (Early Cambrian), and younger Eldon-Pika Formations and Duchesnay Shale. Shallow buried normal fault-bounded horsts and grabens of the underlying Kicking Horse Rim (KHR) likely played a central role in propagation of seismicity leading to the destabilization of marginal platform and basinal facies. Discovery that both the near-vertical Cathedral and Eldon-Pika escarpments were formed by hydrothermal and tectonic mass wasting processes linked to the KHR (Stewart et al., 1993) is perhaps the most dramatic manifestation of syn-sedimentary tectonism during this dynamic period of the Early Paleozoic. Evidence is presented here for other manifestations of tectonism in the basinal deposits adjacent to the Middle Cambrian carbonate platform escarpments that post-date formation of these submarine cliffs.

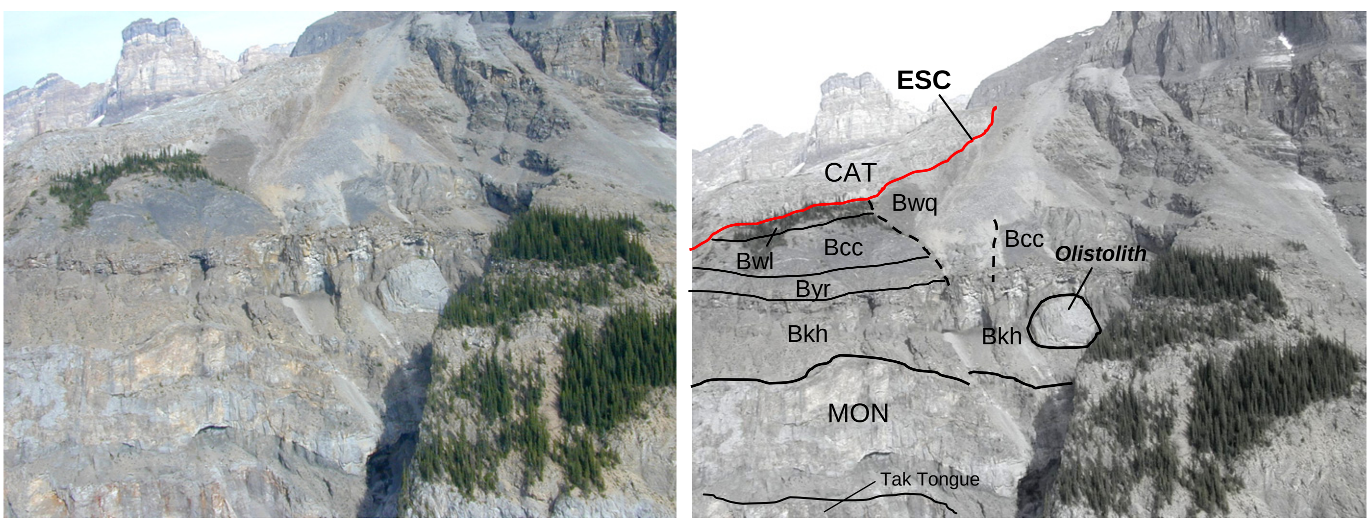

Figure 1: Northwest ridge of Mt. Stephen. Olistolith (arrow) either shed prior to or during development of half-graben faults (dashed lines) that juxtapose Yoho River and Campsite Cliff members against Walcott Quarry shales. Long axis of well-bedded Cathedral Fmn carbonate olistolith >50 m. ESC – Cathedral Escarpment. Cathedral Mountain visible in distance, upper left. Width of outcrop in photo = ±1.0 KM.

Despite nearly a century of investigation, a regional understanding of the Cathedral and Eldon-Pika escarpments is just beginning to develop. Results here are derived from research during summer field investigations from 1998-2003. Hypotheses being tested have relied to an extent on present-day geological analogs. The KHR is only vaguely understood, but detailed structural research is ongoing (Kubli and Simony, 1994; Lickorish and Simony, 1995). As a relic of the extensional rifting that ultimately separated Laurentia from East Antarctica and Australia, the KHR and it's various salients (horsts, grabens) play a central role in any discussion of Cambrian tectonism and it's stratigraphic expression. These stair step half-grabens, characteristic of extensional regimes, are thought to resemble those of the Triassic-Recent Atlantic Basin in style, if not in scale. Normal faults in such settings are episodically reactivated for relatively long periods of time, exceeding 200 million years in both examples cited herein. The nearly 2,000 m high face of Mt Stephen that towers above the hamlet of Field, BC is one of very few places that large shed fragments (olistoliths) of the Cathedral Formation can be found embedded in basinal deposits of the Burgess Shale (Figure 1). The ~50 m long olistolith seen near the northwest ridge of Mt Stephen is below a fault-bounded slump feature in the Burgess Shale that juxtaposes Walcott Quarry Member Shale against older Yoho River Limestone and Campsite Cliff Shale members. This is interpreted to have resulted from a slump that occurred shortly after Yoho River Limestone deposition (four mud mounds found in this layer here), but prior to filling of this scarp with mudstones containing abundant Walcott Quarry soft-bodied fossils. Interfingered with these fine-grained clastics are innumerable fingers of magnesian exhalite (Powell et al., 2004), these being most common directly adjacent to the Cathedral Escarpment (red line in all figures herein). Thus, the shedding of the olistolith was considerably earlier than the slump within the basinal sediments, but both clearly post-date tectonic-driven collapse of the Cathedral margin.

The Cathedral and Eldon escarpments were demonstrably irregular and embayed along their >40 KM trends, and to a greater extent in certain areas than others. Two of these larger collapse-formed scallops are known as the Cathedral Embayment (near Field) and the Natalco Embayment, farther to the southeast. Between Natalco Lake and Mummy Lake, BC a premier exposure of the Cathedral Escarpment is revealed on the northeast-facing side of the ridge above Natalco Lake (Figure 2). What makes this site unusual is that the glacial valley to the west has Cathedral Platform facies rising high on *both* sides, where Burgess Shale mudstone facies should be expected on at least one. The westward perspective in Fig. 2 suggests the viewer is looking off the Cambrian carbonate platform into the deep basin. Yet, a NW-SE oriented "spur" of Cathedral unexpectedly exists here, with escarpments of essentially the same azimuth. Not far to the south, an abundantly fossiliferous exposure of the Cathedral-Burgess contact occurs along an east-west trending section of outcrop. A Recent analog for this unique configuration of otherwise well-documented Middle Cambrian formations is represented by Tongue-Of-The-Ocean (TOTO) on the Bahamas Platform. Although nearly ten times the depth and length of this ancient example in the Canadian Rockies, TOTO re-oriented 180 degrees from normal map perspective does match all the criteria of the Natalco Lake area. Typical thicknesses of exhalite near the Cathedral Escarpment can usually be measured on the scale of centimeters to a few metres, but within this embayment accumulations of >30 m of bedded exhalite were measured. These anomalously thick occurrence of exhalite, ore for the Red Mountain Mine for several decades here, can be observed just off the left side of the outcrop photo in Fig. 2. Shafts from the mine, dug near the middle of the talc-rich succession, penetrate into the mountain for 80 metres or more. These precipitated deposits are interpreted to have formed within a silled sub-embayment, one that had some form of obstruction near the narrow entrance that allowed brines to pool and collect on a scale not present elsewhere. Whether the northward extension of the Natalco Embayment described here was formed by margin collapse processes (Stewart et al., 1993), hydrothermal dissolution, prolonged tectonism, or some combination of these factors isn't yet fully understood. Because brine flow has been tied to faults and circulating fluids traveling along those surfaces (Powell et al., 2006), it may well be the case that both embayment formation and thick exhalite accumulation resulted from the same tectonic processes.

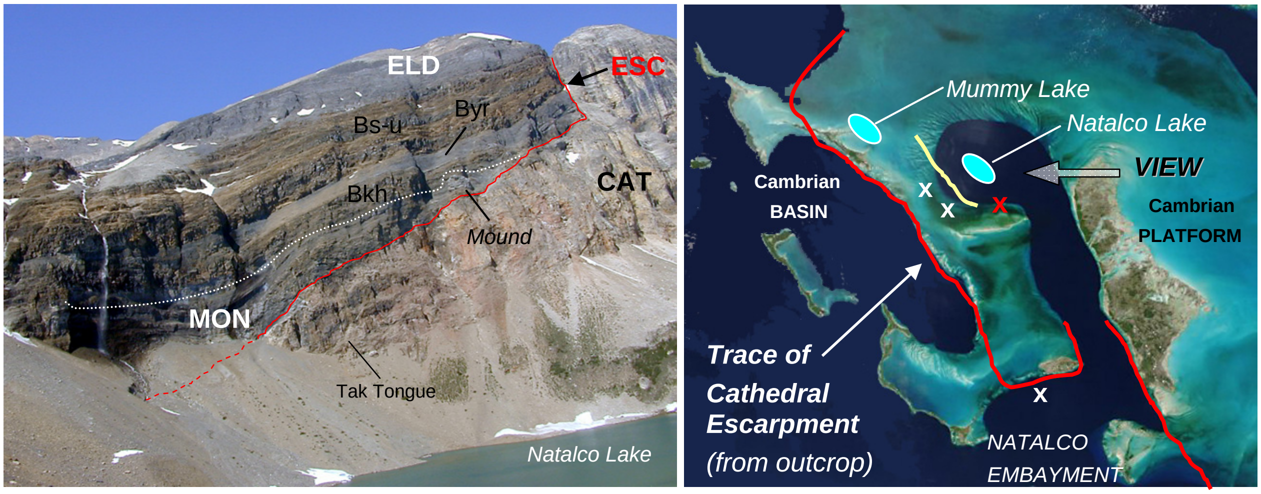

Figure 2: West face of Natalco Lake Cirque, British Columbia. Cathedral Escarpment indicated in both photos, satellite photo of the Bahamas Bank at Tongue-Of-The-Ocean from NASA public archives. North in Bahamas photo is towards bottom. Outcrop photo is looking to west, shown by arrow on right. Exposure seen on vertical face on left indicated by yellow line west of Natalco Lake in photo on right. Abbreviations as in Fig. 1; Bs-u is Burgess Shale undivided (above the Yoho River Limestone Mbr). White x's are outcrops studied, red X denotes location of the Red Mtn Talc Mine. Width of outcrop in photo = ±1.2 KM.

Although on a smaller scale than the embayment at Natalco Lake, grabens filled with dark coloured, bedded Mg/Ba-enriched exhalite have also been documented at Hawk Creek Cirque, BC. The north face of the ridge separating this valley (Figure 3) from Verdant Cirque to the south displays in spectacular relief no less than three basinward-descending horsts and grabens in the topmost Eldon-Pika platform slope succession. Verification of the exhalite facies in the graben closest to the escarpment (farthest on left in photos) was undertaken by roped technical ascent to obtain samples. Here, the sharp contact between the graben-filling exhalite and adjacent bedded carbonates can be observed both vertically (along side walls), and parallel to bedding (along the graben floor). Draping of basinal mudstones and carbonate mound units over the horsts can clearly be seen in the Vermilion and Duchesnay units above. The relation between faulted Eldon-Pika platform and slope facies and those of the younger basin-fill strongly support these being syn-sedimentary features and not products of Laramide orogenic activity.

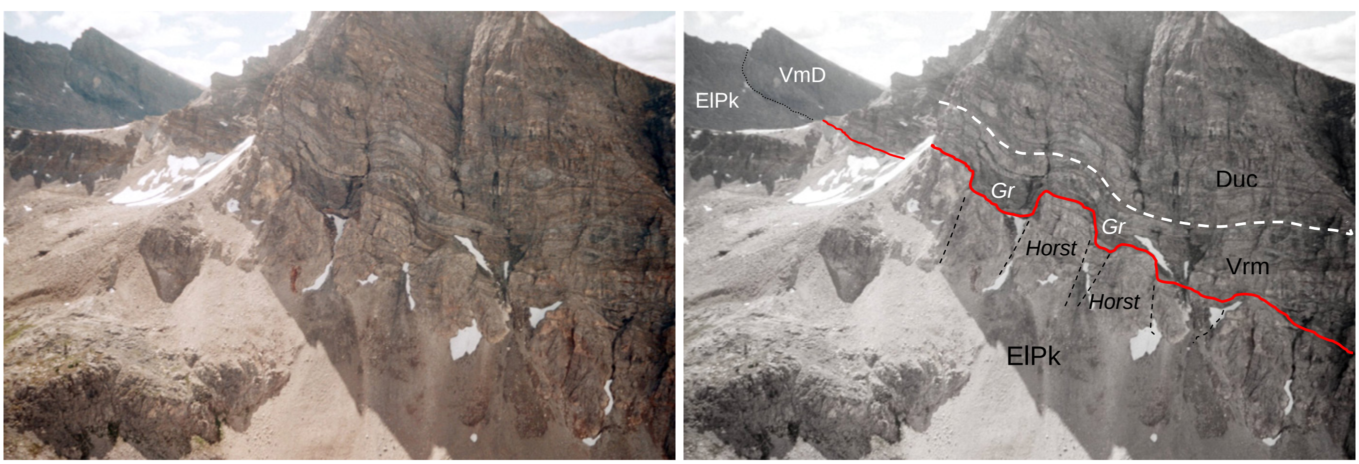

Figure 3: South face of Hawk Creek Cirque, British Columbia. Gr = grabens formed between horsts within the Eldon-Pika and coeval Tokumm slope facies. Relief on central horst is 30 m. In distance, outcrop of Eldon-Pika (ElPk) and Vermilion-Duchesnay (VmD) visible on south face of Verdant Cirque. Width of outcrop in photo = ±1.0 KM.

Earthquakes and other seismic events during the Middle Cambrian, perhaps on a scale not often historically witnessed (Richter Magnitude 8 to 9) resulted in several modifications of the basinal sediements near the Cathedral and Eldon escarpments. Soft sediment deformation, synsedimentary folds and fractures, and debris-flows are relatively common in the Burgess Shale, and particularly the Vermilion and Duchesnay units. At Verdant Cirque, BC two distinct mud mound layers are clearly present on the spectacular north face shown in Figure 4. The lower mound layer caps the Vermilion Sub-Unit (informal), and the upper is within the relatively thick succession of basinal mudstones of the Duchesnay Unit. Mounds within both of these horizons are uncannily similar to those of the Yoho River Limestone and Wash Limestone members of the Burgess Shale. These are flat-bottomed microbial carbonate mounds, lacking biological framework-building organisms. Their proximity to the Eldon-PIka Escarpment suggests they, like the exhalite, may have an origin tied to seepage from faults along this quasi-linear trend. The author noted in the field that these mound layers are diachronous, rising several metres of section towards the Escarpment. Bedding surfaces below the mounds closest to the Eldon-Pika can be followed basinward to where they terminate against the mound layer. This stratigraphic relationship is interpreted to represent downslope migration of mounds resulting from periodic seismic events. The nucleation area for the mounds is almost directly adjacent to the Escarpment, but during tectonic shaking these begin to slide away from this area along inclined bedding surfaces. Each successive dislodging of a newly-formed mound causes that group to move down until they come to rest against the previously-formed group. The process is repeated some 20 to 30 times, or until the mass of the accumulated mounds is so great that even the largest quake cannot cause the 'logjam' of mounds to move farther downslope. As a result, the last formed mounds can grow for a longer interval than their ~5 m high (avg) predecessors. In fact, the largest such mound, appropriately nicknamed the "Emperor Mound" is nearly 50 metres in height. (see lower white arrow on right side of right photo in Fig. 4) Diachroneity of mound layers was not observed for the older mounds of the Monarch and Burgess shale formations – although all of those also show evidence of seismic activity and lateral movement on bedding surfaces. Such movement usually results in deformation of underlying beds. Ongoing research continues to documents these characteristic aspects of the Middle Cambrian in Western Canada.

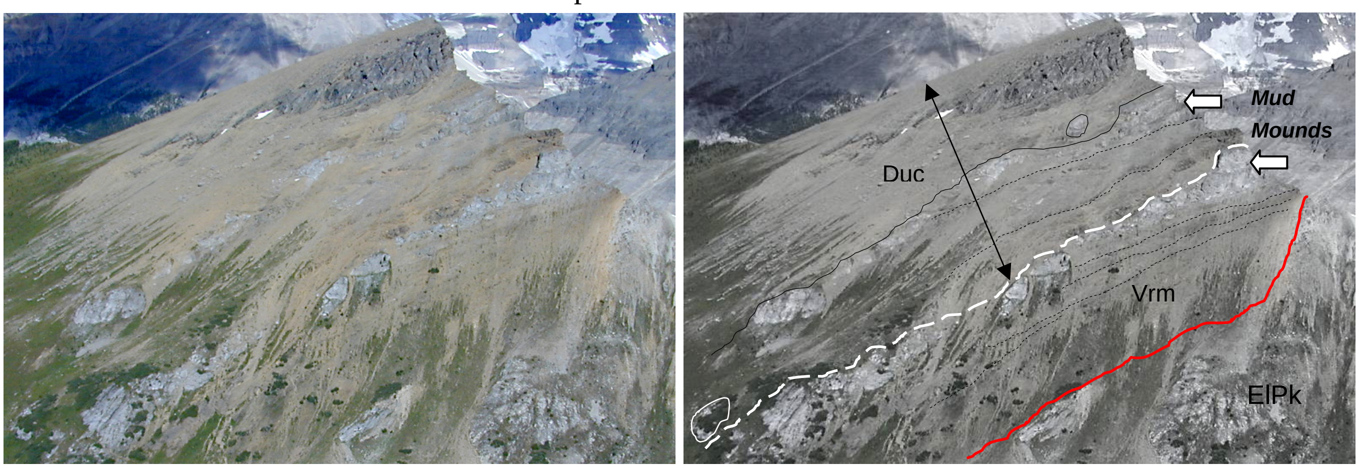

Figure 4: North face of Verdant Cirque, British Columbia. Eldon escarpment at lower right (red line). Basinal facies include the Vermilion Subunit (Vrm) and Duchesnay Unit (Dsc). Both consist of a sequence of mudstone-dominated facies with interbedded ooidal packstones, interpreted as regressive deposits, overlain by transgressive limestone mud-mound dominated intervals. The mounds are diachronous; becoming younger towards the escarpment, to the right. Width of outcrop in photo = ±1.0 KM.

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