Geoscience Canada

"The Burgess Shale:" Not in the Shadow of the Cathedral Escarpment

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Volume 17, Number 2, June 1990

URI: https://id.erudit.org/iderudit/geocan17_2car01

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Publisher(s)

The Geological Association of Canada

ISSN

0315-0941 (print)
1911-4850 (digital)

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Comments and Reply on "The Burgess Shale: Not in the Shadow of the Cathedral Escarpment

COMMENT: In Defense of the Escarpment near the Burgess Shale Fossil Locality [1]

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Introduction

In his article "The Burgess Shale: Not in the Shadow of the Cathedral Escarpment", Ludvigsen (1989) challenges the concept that the massive carbonate that constitutes the upper portion of the Cathedral Formation had abruptly terminated at a high, westward- (basinward-) facing escarpment at the time when the Burgess Shale Fauna was being deposited at the escarpment's base. In this reply, I defend the escarpment concept, while at the same time admit that there are complex problems surrounding the deposition of the Burgess Shale Fauna.

Ludvigsen has not only challenged the escarpment concept, but he has offered a replacement interpretation, which is that the Burgess Shale Fauna was deposited on the inner edge of a slope of moderate inclination. Before introducing his interpretation to his readers, Ludvigsen argues against the acceptance of a time line (Fritz, 1971, fig. 2) drawn down the face of the escarpment to show that it stood vertically for an unspecified (but considerable) time. This line was drawn at the boundary between the Middle Cambrian *Glossopleura* and *Bathyuriscus-Elrathina* zones (see Figure 1). It was drawn westward along the top of the Cathedral Formation to the escarpment edge (also the edge of the basin), then directed steeply downward along the face of the Cathedral Escarpment beyond the level of the adjacent ("basinal") clastics containing the Burgess Shale Fauna, and finally turned abruptly westward again. This latter segment was placed within what "appears" to be a Cathedral carbonate tongue, which has been termed the "boundary limestone" (Fritz, 1971, p. 1165).

Ludvigsen argues that my time line has served as the primary — indeed sole — reason for the acceptance of the escarpment concept. In Ludvigsen's view, the conceptual time line was drawn using an outdated and faulty "Index Model", a model based upon a single tier of zones that ignores environmental influence. To replace the "Index Model", Ludvigsen presents a "Dual Model" featuring numerous separate faunal zonations; for instance, one to reflect the trilobite succession in the basin and one to reflect trilobite evolution on the shelf, *etc.* Using his "Dual Model", Ludvigsen attempts to show that the *Glossopleura* Zone within the platform carbonate of the Cathedral Formation is equivalent to the *Bathyuriscus-Elrathina* Zone within the laterally adjacent basinal clastics of the Stephen Formation.

In a figure indicating the two zones to be more or less equivalent, Ludvigsen (1989, fig. 11) shows a time line of his own — one drawn westward from within the Cathedral Formation, curving only slightly downward as it leaves the Cathedral carbonate, and then extending horizontally into the basinal clastics of the Stephen Formation. Once into the basin, the time line continues westward through the level of the phyllopod bed in Walcott's Quarry. This time line is intended to show that the Burgess Shale Fauna was deposited at a depth only slightly greater than that on the adjacent Cathedral carbonate platform. Having demonstrated the two models, Ludvigsen dismisses the escarpment concept in favour of a gentle slope.

In summary, Ludvigsen has first raised a complex problem and then dichotomized his investigation by focussing on an "Index Model" *versus* a "Dual Model". To argue a problem within these constraints might be good entertainment, but it is not good science. Stephen Jay Gould (1987, p. 8) captured the essence of arguing a problem under similar restraints when he stated, "Any scholar immersed in the details of an intricate problem will tell you that its richness cannot be abstracted as a dichotomy, a conflict between two opposing interpretations. Yet, for reasons that I do not begin to understand, the human mind loves to dichotomize...". In this case, Ludvigsen has restricted the approach to a correlation problem by offering only two models in order to present two clearly defined choices. Forced to make a judgement based on Ludvigsen's data and the models at hand, the reader might choose the "Dual Model" and agree with Ludvigsen's conclusion that the use of the "Index Model" is responsible for a misguided (faulty) escarpment concept. However, I suspect many readers of Cambrian literature do not accept Ludvigsen's view that an "Index Model" is at the heart of the escarpment concept, and that they are aware that many of the ideas incorporated into the "new" "Dual Model" (Ludvigsen *et al.*, 1986) have been in use for some time, following their publication by Lochman-Balk and Wilson (1958). As an aid to the solution of the escarpment problem, I submit that neither model is applicable, and I will briefly explain why. I will then give my reasons for favouring the escarpment concept by using a less structured approach.

In this paper, I will restrict the definition of the Burgess Shale Fauna to the fossils of the "phyllopod bed" in Walcott's Quarry. I thereby avoid confusing this main source of the Burgess Shale Fauna with the numerous important, but smaller, finds (Collins *et al.*, 1983) of Burgess fossils from other stratigraphic locations within the area.

Problems with the "Index Model" and "Dual Model"

Ludvigsen (1989, p. 53) names Rasetti (1951), Lochman-Balk and Wilson (1958) and Fritz (1971) as proponents of the "Index Model". However, Rasetti is not renowned for forcing single zones through various facies, but rather for working on trilobite faunas in boulders from the St. Lawrence Lowland. The faunas were conservatively recorded according to the boulder in which each was found. Rasetti hesitated to erect new zones with these fossils, nor did he correlate many of them with the various zones in use at that time. In fact, he stated (1948, p. 317) "It is clear that the boulders from the St. Lawrence valley belong to several distinct horizons, but it is at present impossible to state how many." Zones that he did erect, such as the *Pseudolisania* Zone (Rasetti, 1944, p. 231) and the *Austinvillia* Zone (Rasetti, 1945, p. 307), were neither forced through other environments nor used to replace existing zones. It is clear from Rasetti's work that he was well aware that the St. Lawrence trilobites represent a special environment, and that he did not expect to find them everywhere in rocks of the same age.

In the Burgess area and nearby Rocky Mountains, Rasetti (1951) demonstrated the vertical position of various trilobites, proposed two new zones and refined four others. His work was located mainly on the shelf (middle carbonate belt) and on the inner edge of the adjacent basin (slope deposits). In his Rocky Mountains work, Rasetti emphasized faunas rather than zones, recalling his work along the St. Lawrence in which he emphasized boulder associations rather than zones. In short, Rasetti was not working with an "Index Model". His Rocky Mountains work was within a transitional area, and not two areas that can be neatly separated into shelf and basinal environments as in Ludvigsen's (1989, fig. 9) illustration of his "Dual Model".

[1] Geological Survey of Canada Contribution No. 42589

Ludvigsen has cited Lochman-Balk and Wilson (1958) as proponents of the "Index Model". This seems unreasonable, because Lochman-Balk and Wilson's concepts not only do not fit into the "Index Model" concept, but have been incorporated by Ludvigsen and others into their "Dual Model". Lochman-Balk and Wilson recognized that the distribution and ranges of trilobite genera strongly reflected their environments. They recognized three biofacies realms located in concentric belts around Laurentia: the shallow shelf, intermediate, and euxinic basin. These realms more or less coincide with the restricted shelf, carbonate platform and the basin. The shallow shelf and intermediate realms generally contain enough taxa in common to permit the use of one zone in both realms. The euxinic basin realm requires a totally different set of zones. Even with these insights, Lochman-Balk and Wilson (1958, fig. 14) questioned fitting some of Rasetti's trilobites from the St. Lawrence boulders into a common zonal scheme for the first two realms. Their reluctance to force a correlation is further evidence that they should not be branded as proponents of an "Index Model". The Lochman-Balk and Wilson paper cannot be dismissed as an obscure release or overlooked because of an opaque presentation. It was awarded best paper published in the *Journal of Paleontology* in 1958, it is still widely acclaimed, and it anticipated the widely cited concept on Middle (Palmer, 1960) and Upper (Robison, 1960) Cambrian concentric belts of sedimentation around Laurentia. The Palmer and Robison adaptations focus on an inner detrital (shallow shelf) belt, middle carbonate (intermediate) belt and outer detrital (slope and euxinic basin) belt.

It is ironic that in 1971, while at the same time giving Ney (1954) credit for the escarpment concept, I (Fritz, 1971, p. 1160) stated, "At Ney's writing, however, there was an unstated alternative that the carbonate "reef" grew at only a slight elevation above adjacent mud to the southwest." This alternative concept, that had been entertained and dropped by me, is the one now proclaimed by Ludvigsen under his "Dual Model". Ludvigsen could have embraced the alternative concept in 1971, rather than accepting the escarpment concept as "irresistible" and exploiting "this theme yearly for lectures on Cambrian historical geology, stratigraphy and paleontology..." (Ludvigsen, 1989, p. 58).

While writing my 1971 paper, I had not been working with an "Index Model" and I had already tried to apply the basics of the "Dual Model". By then I had enough data from other disciplines to indicate that biostratigraphic models brought in from outside did not fit the problem at hand. The pertinent components of those data, and some new data as well, are discussed below. As the escarpment problem revolves mainly around the relationship between the "thick" (carbonate) Cathedral Formation and the "thick" (clastic) Stephen Formation, these formations and their faunas will be emphasized.

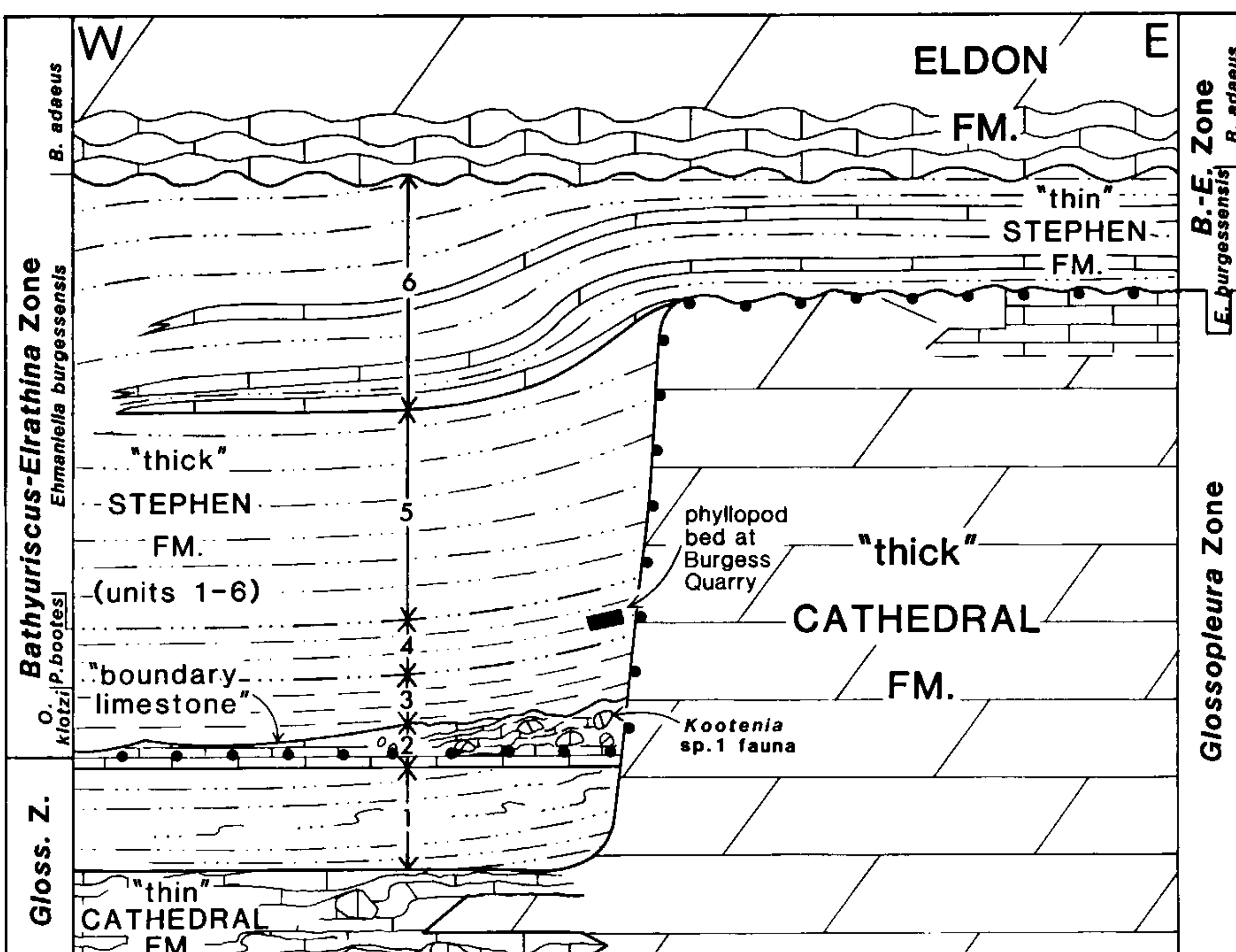

Figure 1 *Schematic cross-section showing Middle Cambrian stratigraphy in the Burgess area, Yoho National Park, British Columbia. The heavy dotted lines mark the boundary (time line) between the* Glossopleura *Zone and the* Bathyuriscus-Elrathina *Zone. Stratigraphic units in terms of Aitken's (1989) nomenclature are: units 1-5 = Amiski Member, unit 6 = Waputik Member, "thin Stephen" overlying Cathedral Formation on Mt. Field and Mt. Stephen = Wapta Member.*

"Thick" Cathedral Formation

The lateral juxtaposition of upper "thick" Cathedral Formation to the east against the "thick" Stephen Formation immediately to the west (Figure 1) is well displayed on Mount Field and Mount Stephen, and most geologists would agree that the two lithologies represent different depositional environments and at least some degree of faunal change. McIlreath (1977a) has presented copious data to show that the "thick" Cathedral Formation was deposited in shallow water under near optimum conditions for carbonate deposition.

The difference between the concept expressed in Ludvigsen's paper and that expressed here revolves around the age of the carbonate as compared with that of the juxtaposed clastics, which in part (but not wholly) hinges on an evaluation of the faunas. The age of the "thick" Cathedral Formation as a whole presents a major problem for those engaged in a local faunal analysis, because dolomitization has mainly altered its fossils beyond recognition. Limestone at the base has produced *Plagiura-Poliella* Zone fossils (Rasetti, 1951, 1957). The middle and upper parts are dated by physical correlations to the east, where westward pinching inner detrital tongues contain fossils of the *Albertella* Zone and the *Glossopleura* Zone (Aitken, 1989). Of particular importance is a measured section (Fritz, 1971, fig. 4) 1.5 km east of the escarpment. There, *Glossopleura* occurs 3 m below the top of the "thick" Cathedral Formation and *Ehmaniella burgessensis* Rasetti and *Pagetia walcotti* Rasetti of the *Bathyuriscus-Elrathina* Zone occur 3 m above in the "thin" Stephen Formation. These two collections were used to draw the boundary between the *Glossopleura* and the *Bathyuriscus-Elrathina* zones at the contact between the two formations on this part of the shelf. Deiss (1940), Rasetti (1951), Fritz (1971) and McIlreath (1977a) have placed a disconformity at this contact.

"Thick" Stephen Formation

The "thick" Stephen Formation in the area of concern is not considered by me to contain typical basinal deposits or faunas, nor would this be expected because of its location immediately adjacent to platform deposits of the Cathedral Formation. I believe that the lower and lower medial "thick" Stephen Formation strata represent a medial slope environment, except for the anomalous "boundary limestone". The upper medial and upper "thick" Stephen Formation is believed to represent a medial and high slope environment.

The "thick" Stephen Formation in the Burgess area is the type area for the lower two-thirds of the *Bathyuriscus-Elrathina* Zone (Rasetti, 1951). Rasetti recognized four faunas within the "thick" Stephen Formation. Fritz (1971) combined two of these faunas and added a basal fauna of his own. Rasetti's faunal succession, as restructured by Fritz (1971), and the enclosing strata will be briefly described below in ascending order as seen in a section located on Mount Stephen (Figure 1; Fritz, 1971, fig. 6) approximately 1 km west of the escarpment. Considerable attention will also be given to the underlying *Glossopleura*-bearing strata in the upper part of the "thin" Cathedral Formation.

In the "thin" Cathedral Formation, *Glossopleura* is present in dark grey platy limestone displaying basinward directed slump structures. Some light-coloured blocks have fallen from the "thick" Cathedral Formation into these strata (Rasetti, 1951). The presence of *Glossopleura* within these high slope deposits testifies to the ability of the genus to penetrate the slope environment. The intertonguing relationship between the "thin" and "thick" Cathedral Formation is, as might be expected, at a "normal" transition from the outer edge of the middle carbonate belt into the innermost edge of the slope. This intertonguing is an intercalation of thick, platform-like beds and thin, platy slope beds, as shown in photographs by Ney (1954), Fritz (1971) and Aitken and McIlreath (1984). Ludvigsen (1989) also shows an intertonguing relationship (less gradual) at this level between the lower Cathedral Formation and Stephen Formation clastics in his figure 11.

In his figure 12 (upper diagram), Ludvigsen (1989) deals with the overlying strata at the escarpment level. To demonstrate the "Index Model", he has faithfully reproduced a figure from Conway Morris and Whittington (1985, fig. 2) showing no carbonate interbeds extending into the basin. To even a casual observer, the lack of interbeds at the escarpment level would serve as a strong argument against shallow, upper slope sedimentation west of the escarpment position. The lack of interbeds at this level, as opposed to the abundant interbeds at the lower, "thick" Cathedral-"thin" Cathedral level, is what caught Ney's eye in 1954 and led to the escarpment concept. The need for interbeds to support his gentle slope concept must have occurred to Ludvigsen when he drew his lower (Dual Model) diagram in figure 12 (see also his fig. 11) because, despite their absence at the outcrop, he drew them into his diagram at the escarpment level without comment.

Immediately above the "thin" Cathedral Formation in a stratigraphic section on the northeast slopes of Mount Stephen is a 45 m thick basal unit of the "thick" Stephen Formation. A nearby outcrop (west of the Fossil Gully Fault) of this unit has produced the spectacular new find of Burgess Shale-like fossils which are associated with *Glossopleura* (Briggs and Collins, 1988, p. 780). The unit is composed of medium- to dark-grey mudstone that weathers light brownish grey, and therefore matches the average lithology of the "thick" Stephen Formation as a whole. The presence of *Glossopleura* here and within the slumped limestone beds of the underlying "thin" Cathedral Formation testifies to the capacity of the genus to live within more than one bottom condition in a basin-edge (slope) environment.

The second unit within the Stephen Formation in the Mt. Stephen section is the 19.2 m thick "boundary limestone", which is composed of platy to irregular thin- to medium-bedded limestone with some light-coloured blocks of *Epiphyton*-bearing limestone. McIlreath (1977b) found the unit to be in part composed of a proximal bench averaging 100 m thick at its position against the escarpment. The bench is composed of a "heterogeneously mixed bioclastic peloidal wackestone to grainstone interbedded with uniformly thin-bedded, dark-grey, basinal lime mudstone..." that grades basinward into the unit's second part, which is composed of lime mudstone extending over 3 km basinward. The "boundary limestone" is not a true tongue of the "thick" Cathedral Formation as drawn by Ludvigsen (1989, fig. 11), but instead is locally composed of clasts stacked against the carbonate escarpment as rubble with blocks up to small boulder size (McIlreath, 1977b, p. 119 and fig. 8). Shallow water features are present in the blocks, reflecting a platform origin. The carbonate clasts display no evidence of having been reworked while in their basinal position.

Glossopleura, Polypleuraspis and *Oryctocephalus* are present just above the basal contact of the "boundary limestone", where they constitute the highest *Glossopleura* Zone fauna yet found in the "thick" Stephen Formation (Fritz, 1971, fig. 6). *Oryctocephalus* is a genus that is not found in shallow water strata in North America. Near the middle of the "boundary limestone" is a fauna consisting of *Kootenia* sp. 1, *Olenoides* and *Stenothecoides*. This assemblage is considered to be the lowest local fauna within the *Bathyuriscus-Elrathina* Zone (Fritz, 1971).

The presence of *Glossopleura* (including some whole specimens) in various lithologies within the "thin" Cathedral and "thick" Stephen formations, combined with its abrupt termination below a new fauna, is considered valid evidence for placing the boundary between the *Glossopleura* Zone and the *Bathyuriscus-Elrathina* Zone within the "boundary limestone". It is difficult to argue that *Glossopleura* continued to live on the shelf after its extinction in the basin. This is because the abraded fragments that constitute the post-*Glossopleura Kootenia* sp. 1 fauna in the "thick" Stephen Formation probably came from the shelf along with the allochthonous carbonate clasts in the matrix surrounding these fossils. A scenario suggesting that local platform carbonate containing the *Kootenia* sp. 1 fauna was completely removed by erosion is presented below under "Interpretation of "thick" Stephen Formation units".

Above the "boundary limestone" is a 28.3 m interval containing light grey to light brownish grey weathering shale that is dark grey on fresh surface. Within this finest grained unit in the Stephen Formation section, the partings are thin (averaging 0.5 cm in thickness), and the rock is softer and more recessive. Found here are *Bathyuriscus rotundatus* (Rominger), *Elrathina cordillerae* (Rominger), *Bathyuriscus*? sp. and *Ehmaniella waptaensis* Rasetti. The first two species suggest correlation of this interval with the *Ogygopsis klotzi* fauna, although the species in common are less abundant and there is far less variety than at the type area for that fauna, located only a short distance to the southwest.

The fourth Stephen Formation unit (25.3 m) comprises light tan to light grey weathering, medium-grey mudstone of average resistance. At the base is a thick (0.6 m), resistant marker bed of orange weathering mudstone. Within this unit are the sponges *Protospongia* sp., cf. *Pirania muricata* Walcott and the trilobites *Peronopsis montis* (Matthew), *Pagetia bootes* Walcott, *Zacanthoides romingeri*? Resser, *Kootenia burgessensis* Resser, *Olenoides serratus* (Rominger) and *Elrathina* sp. Numerous soft-bodied fossils, such as *Canadaspis* sp. and *Anomalocaris canadensis* Whiteaves are present, but only small fragments could be obtained without extensive quarrying. The only *Scenella* sp. within this "thick" Stephen Formation section came from this unit. The unit shows a strong correlation to the type area for the *Pagetia bootes* fauna, which includes the phyllopod bed at Walcott's Quarry. At the quarry there is a local high abundance of *Scenella*.

The fifth unit (96.0 m) contains light brownish grey weathering, medium-grey mudstone that has a thin (10.7 m), recessive interval of shale at the base and is overlain by the lowest of a series of light orange weathering, medium-grey limestone interbeds. Fossils are rare within this member. *Pagetia bootes* occurs up to nearly the halfway point and *Ehmaniella burgessensis* Rasetti and *Spencella* sp. were found in the upper third. Both this unit and the overlying unit are considered as being within the domain of the *Ehmaniella burgessensis* fauna, as *E. burgessensis* is known in a section on Mount Field (Fritz, 1971, fig. 5) to extend to the base of this unit and even into the unit below. *Spencella* also extends down to near the base in the latter section.

The uppermost unit, unit six (100 m), closely resembles unit five, except for sparse, but distinctive, orange weathering, medium-dark grey, thin- and medium-bedded limestone interbeds. These interbeds can be traced eastward into the "thin" Stephen Formation, where they locally occur as a subordinate, but distinctive, lithology throughout that formation. These interbeds contain *Ehmaniella burgessensis*, *Spencella* and echinoderm fragments in a coquina. Immediately above unit six are the basal, blue-grey weathering nodular beds of the lower Eldon Formation, which contain the *Bathyuriscus adaeus* fauna.

Interpretation of "thick" Stephen Formation units

The first two stratigraphic units (1, 2) within the "thick" Stephen Formation are interpreted as follows (see summary for alternative interpretation). The basal mudstone unit is judged to be a basinal extension of a mudstone blanket that once smothered the "thick" Cathedral Formation carbonate and was later eroded on the platform. The basal mudstone was deposited as the first unit of clastics to lie against the Cathedral escarpment. The second basinal unit ("boundary limestone") is believed to record an on-shelf provenance of algal patch reefs that existed when a brief transgression permitted the local shelf waters to clear. During this time, reef-generated carbonate clasts of all sizes were carried over the escarpment, the coarser fraction landing against the escarpment and a portion of the finer particles carried to the outer part of a local carbonate apron.

On the shelf, patch reefs were in turn smothered by fine, siliceous clastics, some of which passed over the escarpment and were deposited at a slow rate over the floor of the adjacent basin (units 3, 4). The Burgess Shale Fauna was deposited during this time. Then, with increased bypassing and associated erosion over the shelf, the pace of basinal siliciclastic deposition increased, and the local basinal area was quickly filled (unit 5). During this phase, erosion locally removed all of the strata above the "thick" Cathedral Formation. Finally, widespread deposition took place over the platform ("thin" Stephen Formation) and over the adjacent part of the basin (unit 6). Deposition was in a relatively high-energy environment, as is indicated by worn fragments of *Ehmaniella burgessensis* and *Spencella* and echinoderm parts in the limestone interbeds. The physical extension of these interbeds over the escarpment and into unit 6 (Figure 1) indicates the burying of the escarpment during the time of unit 6 deposition.

Deposition of the "thin" and "thick" Stephen Formation ended with a rapid transgression reflected by the basal, nodular limestone of the overlying Eldon Formation. At the contact between the Stephen and Eldon formations, there is almost no displacement above the buried escarpment. Trilobite genera of the *Bathyuriscus adaeus* fauna in the basal, nodular limestones of the Eldon Formation that are not found in shallow water deposits of the Cordillera are *Pagetia*, *Peronopsis* and *Tonkinella*.

Facies and zones in the Burgess area and elsewhere

The phyllopod bed with its Burgess Shale Fauna presents a striking contrast in facies when compared to the barren, massive carbonates of the Cathedral Formation only a few metres away. The phyllopod bed comprises mudstone in dark, thin, finely laminated beds with no evidence of bioturbation. How does one reconcile the close proximity of these clastics to the massive carbonate representing a shallow, well-aerated environment? Furthermore, how does one explain the medium to lower slope-inhabiting trilobites *Oryctocephalus* and *Pagetia* in the phyllopod bed, and, even more puzzling, the deeper basinal trilobites *Peronopsis* and *Ptychagnostus*? The sponge *Protospongia* is also present yet, in the Richardson Trough and Selwyn Basin, this genus occurs almost exclusively in deep-water strata. There is also an enigmatic abundance of limpet-like shells of *Scenella amii* (Matthew). This genus would be expected near local relief (see Babcock and Robison, 1988, for an alternative, cnidarian, interpretation of *S. amii*). Taken together, the above observations favour the escarpment concept as a method of explaining this rapid change of facies.

Viewing only the phyllopod bed, I can at least agree with Ludvigsen's (1989, fig. 10) placing it in the basinal *Ptychagnostus praecurrens* Zone. However, this bed and its enclosed fauna occupies only two vertical metres within the "thick" Stephen Formation, and it is impossible to say how much more of the Formation lies within the zone. Since there is no evidence whatsoever that the *P. praecurrens* Zone correlates with the *Glossopleura* Zone, there is good reason to at least question Ludvigsen's time line (1989, fig. 11) extending through the phyllopod bed into the middle of the *Glossopleura* Zone within the upper "thick" Cathedral Formation. In fact, one might even question the wisdom of attempting a time line from a true basinal fauna into the "thick" Cathedral environment before embarking on an intermediate approach, which is from the slope environment into the shelf environment. To be fair, Ludvigsen does consider one "intermediate" zone, the *Oryctocephalus* Zone of Robison (1976), but since this zone occupies the whole lower half of the Middle Cambrian, it is simply too broad to be of use in this discussion.

If, as argued above, the "thick" Stephen Formation is considered to be mainly a slope deposit, then a comparison with other *Glossopleura*-bearing slope deposits from elsewhere might provide a further idea as to how the genus has intermixed with deeper water taxa, and thus give some practical hints for correlation. This exercise provides at least a partial test in the Burgess area of my impression that the boundary (time line) between the *Glossopleura* and the *Bathyuriscus-Elrathina* zones in the immediate basin is not environmentally displaced relative to the upper boundary drawn on the adjacent platform. It is an independent test of the escarpment concept.

In the Bear Mountains in Idaho, the Spence Tongue of the Lead Bell Shale is an off-shelf deposit which is highly fossiliferous and contains, amongst other fossils, *Athabaskia sp.*, *Amecephalus punctatum* (Resser), *Chancia coriacea* (Resser), *Bathyuriscus atossa* Walcott, *Bythicheilus typicum* Resser, *Glossopleura*, *Pagetia fossula* Resser, *Peronopsis bonnerensis* (Resser) and *Oryctocare* (Resser, 1939; Fritz *in* Oriel and Armstrong, 1971). Near Pend Oreille Lake in Idaho (Resser, 1938), elements of the same fauna are found with *Amecephalus, Athabaskia, Glossopleura, Pagetia fossula* Resser and *Peronopsis bonnerensis* in common. In the Northern Egan Range in Nevada (Fritz, 1968), *Glossopleura* and *Athabaskia* occur together, and several distinctive pagetiid species are present a short distance below (basal *Glossopleura* Zone?).

In a comparison of the *Glossopleura*-associated faunas of the Great Basin slope deposits with the slope fauna in the "thick" Stephen Formation, similarities that might be expected from Ludvigsen's correlation are lacking. *Amecephalus* and *Athabaskia* that are so commonly associated with *Glossopleura* in the Great Basin are not seen in the upper part of unit 2 and overlying units 3 to 6. This part of the "thick" Stephen Formation does contain two species of *Pagetia, P. bootes* Walcott in the lower part and *P. walcotti* Rasetti in the upper part, and one species of *Peronopsis, P. montis* (Matthew), in the lower part. However, in slope deposits, it is the species of pagetiids and agnostids that are important. *Glossopleura*-associated Great Basin taxa are *Pagetia fossula* and *Peronopsis bonnerensis*. I therefore argue that the absence of the above mentioned Great Basin taxa in the upper part of unit 2 and units 3 to 6 of the "thick" Stephen Formation is due to their younger age, and not due to facies.

Summary

The escarpment concept in my view remains as the most probable explanation for the remarkable distribution of facies and faunas in the Burgess area. McIlreath's studies of the carbonates bolsters this concept. The composition of six units within the "thick" Stephen Formation suggests that this succession was deposited mainly under slope conditions at various depths. The interpretation of the units given here needs rigorous testing. For instance, it cannot be proven that the clastics in unit 1 are related to clastics that supposedly covered the local Cathedral Formation carbonates, for they may have passed through channels within, or have skirted around, uncovered Cathedral carbonates. The concept of a patch reef provenance for the "boundary limestone" needs testing against the possibility that the provenance was instead the upper part of the Cathedral reef.

The *Bathyuriscus-Elrathina* Zone, as defined by Rasetti and modified by Fritz, contains a few basinal taxa, some slope taxa, and some shelf taxa, depending on the vertical position within the type area (Burgess area) for the zone. A comparison of these taxa with *Glossopleura*-associated taxa in slope deposits within the Great Basin does not show the needed overlap of key taxa necessary to substantiate Ludvigsen's statement that the two zones are equivalent. It is more likely that the former taxa postdate the latter and that the time line drawn down the face of the escarpment (Fritz, 1971) is correct. The biostratigraphic and stratigraphic data collected thus far remain consistent with the escarpment interpretation.

Acknowledgements

The manuscript for this paper has been read by J.D. Aitken, C. Collins, C. Lochman-Balk, I.A. McIlreath, W.D. Stewart, E.L. Yochelson and H.B. Whittington. I am indebted to each for helpful comments, but retain full responsibility for views, presentation of data and emphasis, which are not necessarily those of the colleagues mentioned.

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COMMENT

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Summary
The sedimentological model that places the Burgess Shale and its unique fauna "in the shadow of the Cathedral Escarpment" has been attacked on the basis that the escarpment was conceived solely on the basis of misinterpreted paleontology. We review here the stratigraphic and structural basis on which the escarpment was originally recognized without benefit of paleontology, and show that the "ramp model" conceived to replace the "escarpment model" is without foundation. The attack on the layers of the Burgess Shale as turbidites is better founded; we present a new model involving deposition by fallout from storm return interflows.

Introduction
We thank Rolf Ludvigsen for his flattering assessment of the beauty of the model, published by ourselves and others, that places the Burgess Shale and its marvelous fossils "in the shadow of the Cathedral Escarpment". At the same time, we welcome his publication of an alternative model that does away with the escarpment. We have been aware of opposition to the escarpment model (*e.g.*, Beales *et al.*, 1986), and indeed have discussed the question with Frank Beales and urged him to publish, but lacked a text to which to respond.

Upon examining Ludvigsen's (1989) paper, we are made aware that, perhaps blinded by our experience of having stood upon the escarpment, we have, in our published work, neglected to insist upon some obvious relationships that prove its existence. It is true also that few sedimentological "data" have been published, although these are provided in detail in McIlreath's (1977a) Ph.D. thesis, which is not cited by Ludvigsen. Our colleague, W.H. Fritz, has responded to Ludvigsen's attack on his interpretation of the chronostratigraphic significance of relevant trilobite assemblages (Fritz, this volume, p. 104-108). Our purpose here is to reiterate and emphasize the significance of structural relationships and lithofacies. We intend to demonstrate again the existence of an escarpment of shallow-water carbonate rocks abutted by younger, siliciclastic sediments deposited in deeper water. Our models for the escarpment and the Burgess Shale have undergone subtle modifications since last presented, however (Aitken and McIlreath, 1984). The timing and mode of basin filling ("thick Stephen Formation") are now seen more clearly than previously, and will be discussed. Finally, we see some justice in Ludvigsen's attack on the "accepted" interpretation of the layers of the Burgess Shale as turbidites, at least as typical turbidites, and will commment thereon. Our preferred interpretation of events through the period of Burgess Shale deposition differs in detail from that of Fritz (this volume); this is evidence that the last word has not been written.

We will also be at pains to falsify several specific claims made by Ludvigsen:
(a) The Cathedral Escarpment " ... is a Cambrian bathymetric feature that has been defined [solely] by trilobite biostratigraphy".
(b) Fritz (1971) "used the distribution of mid-Cambrian trilobite zones ... to define a local depositional feature that he named the Cathedral Escarpment."
(c) "The evidence ... did not come, as one might expect, from paleoenvironmental analysis of lithofacies or from study of paleobathymetric indicators such as sedimentary structures, trace fossils, ... or even from consideration of depositional models."
(d) "The sedimentologic evidence that supports the Cathedral Escarpment can be itemized succinctly. None exists!"

The Escarpment Recognized and Defined "on the Basis of Biostratigraphy"
Ludvigsen's repeated claim that the escarpment concept rests entirely upon the interpretation of collections of trilobite fossils denies history. Charles Ney (1954, quoted by Fritz (1971) and Aitken and McIlreath (1984)), a hard-headed economic geologist reporting on the Monarch and Kicking Horse Mines in Mount Stephen and Mount Field, clearly recognized the escarpment on the basis of exposed relationships between rocks of markedly different character. Aitken and Fritz together rediscovered those relationships in ignorance of Ney's work, and immediately visualized the escarpment essentially as portrayed in the current "escarpment model". Their discovery of the "step" in the boundary between *Glossopleura* and *Bathyuriscus-Elrathina* zones came later in the same field season (Aitken and Fritz, 1968), and was welcomed as confirmatory evidence for a model that was expected to encounter scepticism.

The abruptness of the near-vertical contact between pale, coarsely crystalline dolomite and dark, laminated, unburrowed shale (Figure 1) cannot be overemphasized. A tall man can very nearly stand with one foot on platform-margin dolomite and the other on deep-water shale. There is absolutely no intertonguing of escarpment carbonates and slope siliciclastics [the "Boundary limestone" is an exception only under Ludvigsen's (1989) "ramp" model and his denial of the temporal significance of the "step" in the boundary between faunizones mentioned above]. Ludvigsen has established a reputation as a perceptive and thorough observer; the fact that he has been able to imagine a facies change, however abrupt, between shale and dolomite, indicates that he has not visited a good exposure of the escarpment. The contact is so sharp that early manuscripts of the modern maps (Cook, 1975; Price *et al.*, 1980) showed the escarpment as a fault. Each investigator in turn — Ney, Aitken, Fritz, McIlreath — separately and individually was at pains to disprove such a fault on the southeast face of Mount Field and the northwest lower cliffs of Mount Stephen, before proceeding. On the Mount Stephen side, this can be verified by careful observation from the highway. The "impression" that this abrupt, near-planar contact is a fault is so persuasive that some time passed after recognition of the escarpment on Mount Field before it was recognized that the "obvious" fault between Walcott's Burgess Shale quarry and the Cathedral Formation dolomites to the north (Figure 2) was in fact another exposure of the escarpment. Ludvigsen's analysis ignores the bipartite character of the "thick" or basinal Stephen Formation, recognized in turn by Aitken, Fritz, and McIlreath. The upper part (Wapta Member of Aitken, in press) contains a high proportion of limestone beds that are, in large part, grainstones and packstones, siltstone beds with ripple marks, and abundant evidence of burrowing. It is continuous with the upper member of the "thin" or platformal Stephen Formation and lithologically similar. Because it postdates the Cathedral Escarpment on lithostratigraphic, structural and biostratigraphic (Fritz, 1971, this volume) evidence, it does not impinge on the problems of interest here, other than to conclusively demonstrate termination of the deep-water environment in front of the escarpment. The lower part (Amiskwi Member of Aitken, in press) is strikingly different, being nearly devoid of limestone and completely unburrowed. At a section on Mount Field, 500 m in front of the escarpment, the section above the limestones of the "thin Cathedral" Formation (Takakkaw Tongue of Aitken, in press) that project westward beneath the basinal Stephen Formation (Figure 1), is as follows:

Basal unit of upper (Wapta) member: 60% shale, 40% limestone in thin and medium beds (trilobite-echinoderm grainstone/packstone, with oncoids).

Amiskwi Member

4. 6 m Silty shale as below, with rare thin lenses of oolitic, trilobite-echinoderm grainstone/packstone.

3. 116 m Shale, dark brown, partly silty, fossiliferous, with a single, 1-metre bed of laminated lime mudstone, 48 m above the base.

2. 25 m "Boundary limestone", mainly lime wackestone-mudstone, minor debris-flow breccia.

1. 26 m Shale, grey, calcareous, partly silty. (On Mount Stephen, but not Mount Field, this unit is much broken by penecontemporaneous slide-surfaces.)

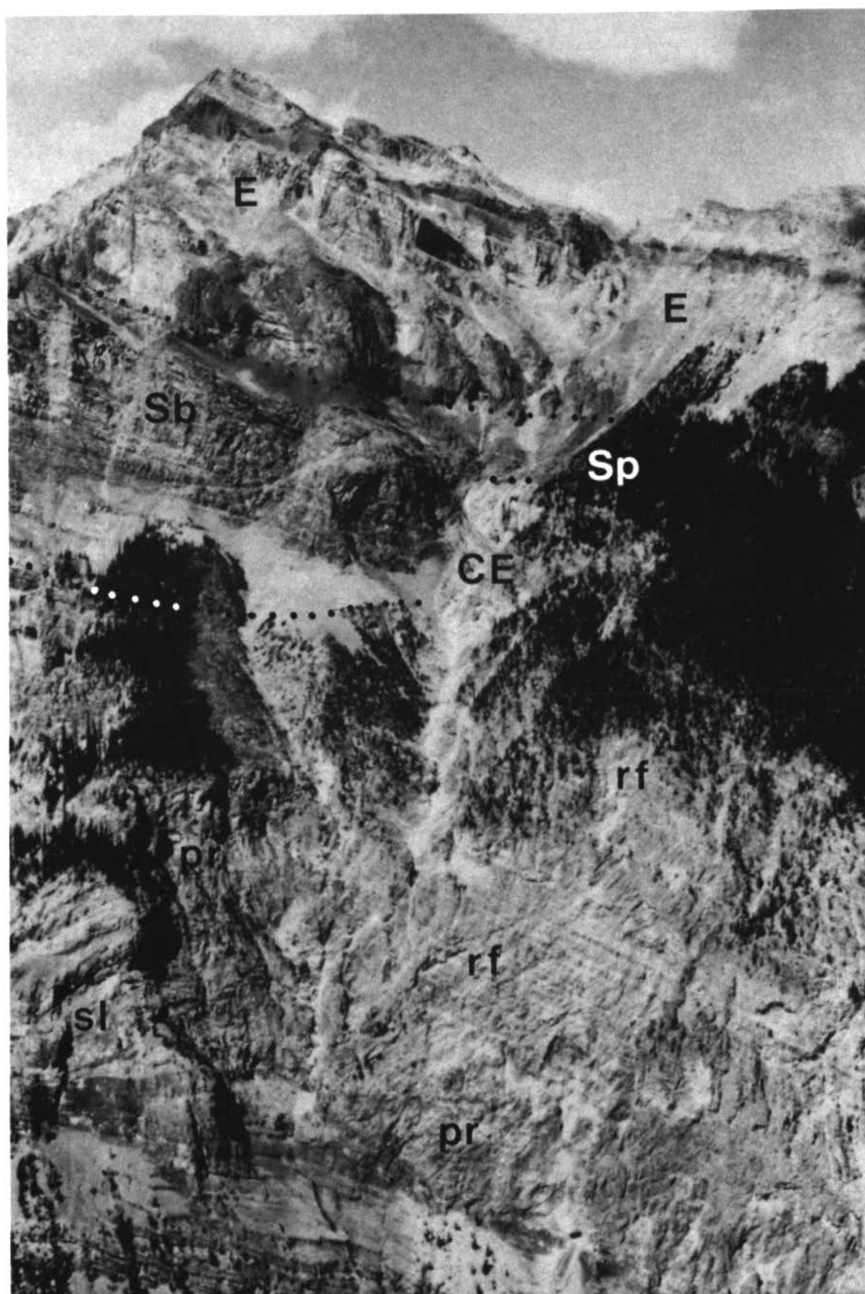

Figure 1 *The Cathedral Escarpment (**CE**) on the south face of Mount Field. Note the complete absence of carbonate tongues extending into the abutting mudrocks at the level of the escarpment, in contrast with the obvious intertonguing at the level(s) of the earlier, prograding reef (**pr**). Other facies of the Cathedral Formation: **rf**, well-bedded reef-flat facies; **sl**, reef foreslope facies; **Sp**, platformal ("thin") Stephen Formation; **Sb**, basinal ("thick") Stephen Formation; **E**, Eldon Formation.*

Measurement of a continuous section closer to the scarp face is hampered by cliffs and patches of talus, but the stratigraphy just described can be traced to the escarpment, the sole change noted being scarp-ward thickening of the "Boundary limestone" and pinchout of the shale beneath it. The same lithologic succession is recognized at Walcott's Burgess Shale quarry, a few tens of metres in front of the escarpment (Figure 2; see also Fritz, 1971, fig. 5). According to Ludvigsen's suggestion, this shale-dominated section, and the unbroken dolomites of the upper Cathedral Formation that abruptly limit it eastward, are part of an integrated depositional system, an "ocean-facing, muddy ramp." Ludvigsen has provided the effective phrasing: "... the sedimentological evidence for the ramp model can be summarized succinctly" — none has been presented!

Problems with the Escarpment Model

On present knowledge, interpretation of the escarpment as a true reef remains attractive. The distinctive, well-bedded, shallow-water, cyclical reef-flat facies, unique to this setting, passes westward into massive, coarse, featureless dolomite like that of the less contentious, prograding reef beneath (Figure 1; fig. 2 of Aitken and McIlreath, 1984).

We assume that the main stumbling block for most doubters of the escarpment model, and Ludvigsen in particular, is the paucity of reef-talus at the toe of the putative escarpment. This certainly gave pause to the writers, and led to attempts at non-escarpment models, all of which foundered on the evidence. Yes, coarse, reef-derived debris is to be expected. Yes, there is little of it, but this in itself is not strong evidence against the escarpment model. For example, some of the Devonian reefs of Alberta have shed copious sand- to megablock-sized debris, while others have shed none at all (R.H. Workum, personal communication, 1990). Beauchamp *et al.* (1988, especially p. 598) have illustrated Upper Paleozoic buildups of high relief that also have shed little or no identifiable debris.

Ludvigsen explicitly does not quarrel with our current model for the earlier, pre-escarpment, prograding Cathedral reef (Figure 1) that indeed shed much coarse material onto an obvious fore-reef slope, where the debris is intertongued with black, ribbon-bedded limestone. Progradation of that reef ended with a step-back of some 200m (shown in Aitken and McIlreath, 1984; fig. 2, but not fig. 3), followed by a radical change in reef style to vertical (non-progradational) growth. The change to vertical growth coincides with virtual cessation of transport of particulate carbonate to the adjoining slope. These changes may reflect an increase in the rate of relative rise of sea level, accompanied by a reversal of dominant water movement from off-platform to on-platform. These changes would cut off supply of carbonate debris to the slope, inhibit progradation, conducive to rapid cementation of new reef material, and cause the upwelling that may be one of the keys to the taphonomy of the Burgess Shale.

The possibility remains that the Cathedral Escarpment is, instead of a reef, one of the "truncation surfaces" (headwall scarps of large-scale slides) at the margins of the Cathedral and Eldon carbonate platforms, recently shown to us by W.D. Stewart. We think not, but this alternative has not been rigorously tested at the outcrop.

Sedimentology of the Burgess Shale — Turbidites, Tempestites, or Both?

Ludvigsen (1989) touches a nerve with his attack (arising directly from the "ramp" model) on the interpretation of the thin beds of the Burgess Shale as turbidites (Piper, 1972). We have accepted that interpretation previously in a general way. Piper's derivation of the sediment from the escarpment itself (Figure 3a) is, however, inconsistent with the escarpment model and the siliciclastic lithology of the beds. In his scenario, the Burgess Shale was deposited in front of an actively growing reef. This is inconsistent with Fritz's (1971, this volume) view of the temporal significance of the critical faunal

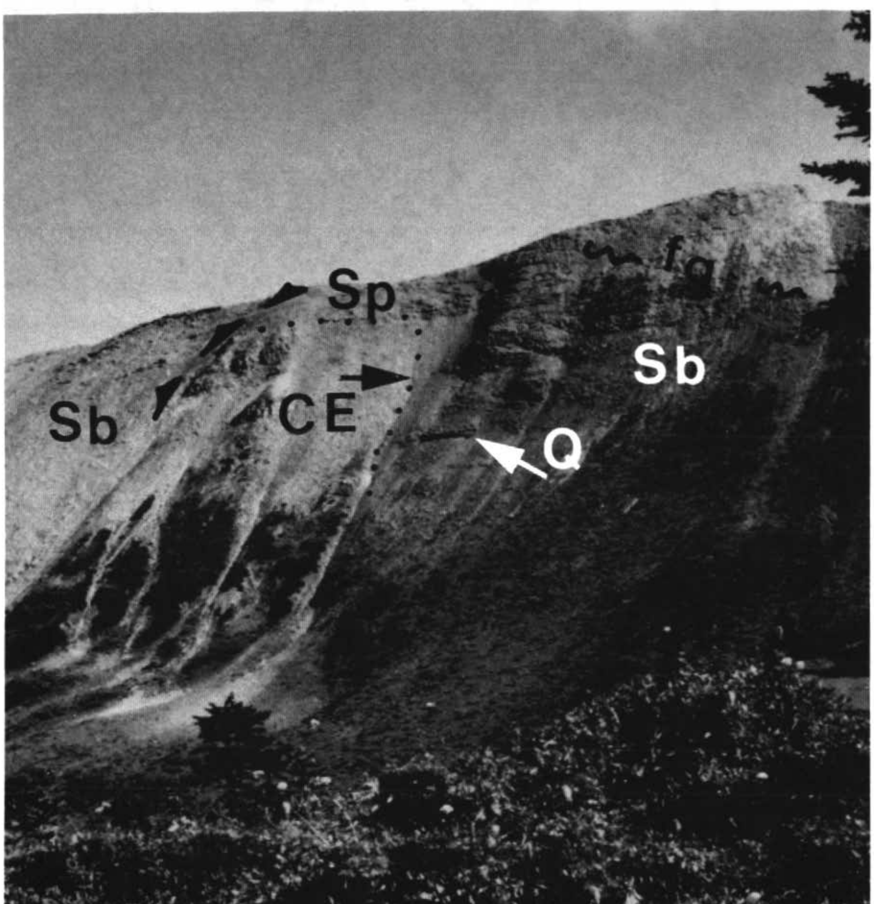

Figure 2 *The Cathedral Escarpment near Walcott's Burgess Shale quarry (**Q**) on the west side of the ridge connecting Mount Field with Wapta Mountain, viewed from the trail through Burgess Pass. Because the ridge trends north, and the escarpment northwest, the escarpment passes behind the quarry, and is even closer to it than this view suggests. Note the complete absence of carbonate tongues extending from the carbonate platform into the abutting mudrocks. The Wapta Mountain thrust fault, at left, places basinal Stephen strata on platformal Cathedral and Stephen strata. Annotation as for Figure 1, plus **fg**, Fossil Gully fault.*

boundary, but is reconcilable with Ludvigsen's (1989) view. It troubled us initially that these "turbidites" are found within a few tens of metres of the escarpment, but that relationship by itself does not falsify the turbidite model. If the Burgess Shale is part of a deep-water fan (*i.e.*, cone) abutting an escarpment, some of the fan-building turbidity currents or overbank flows must have flowed parallel to the escarpment. The great subaerial fans abutting the fault-line scarps of the Basin and Range Province provide familiar examples. Fans require point sources, however, and no such point source, *i.e.*, a gap or pass through the top of the escarpment, has been identified anywhere. The exposures do not permit the mapping of a fan, if one exists; does a line source, rather than a point source, fit the facts?

The biostratigraphy *of the platform* (Rasetti, 1951; Aitken and Fritz, 1968; Fritz, 1971; Aitken, 1989, in press), which is not in dispute, tells us that the outer edge of the Cathedral carbonate platform aggraded well into *Glossopleura* time, and perhaps until its end (or slightly later, see below), and that the carbonate platform was extinct when the oldest preserved fossils of the *Bathyuriscus-Elrathina* Zone were laid

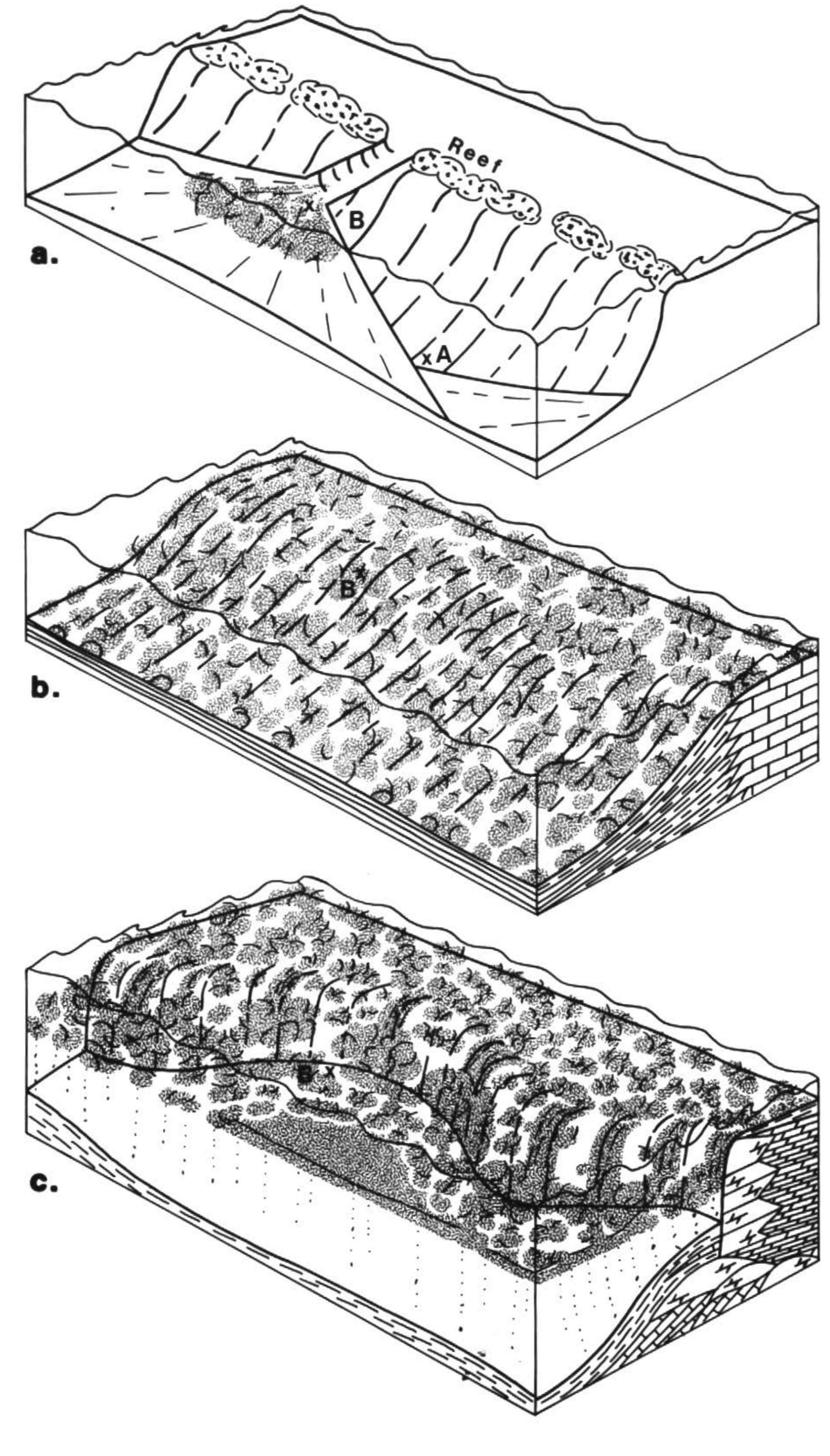

Figure 3 *Cartoons illustrating suggested modes of emplacement of the strata of the Burgess Shale "Phyllopod Bed".*
(a) *Turbidites/deep-sea fan outboard of a growing reef (Piper, 1972).* ***"A"*** *and* ***"B"*** *are possible sites of the Burgess Shale quarry. Mechanism for initiation of turbidite flow was not specified.*
(b) *Storm deposition on an actively aggrading ramp (Ludvigsen, 1989).* ***"B"*** *is inferred site of Burgess Shale quarry.*
(c) *Storm deposition outboard of a dead (smothered) reef-escarpment, with deposition by fallout from a muddy interflow (this paper).* ***"B"*** *is inferred site of Burgess Shale quarry.*

down on it. Note that neither the platform stratigraphy (Aitken, 1981, 1989, in press), nor the sedimentology of the basinal sediments, including the "Boundary limestone", allows for any significant erosional break between the youngest fossils of the *Glossopleura* Zone and the oldest fossils of the *Bathyuriscus-Elrathina* Zone. Because no unit of inner-detrital mudrocks belonging to the Cathedral Formation or the lower (Narao) member of the platformal Stephen Formation crosses the margin of the carbonate platform, two scenarios for a source of the oldest (pre-"Boundary limestone") mudrocks of the basinal Stephen Formation are possible: (a) they were inner detrital muds bypassed across the top of the uppermost limestones of the lower member of the platformal Stephen Formation and its Cathedral equivalent at the rim; or (b) they were brought in from a source other than the adjacent platform while the carbonate margin continued to aggrade (the Field Member of the Eldon Formation, a tongue of outer-detrital mudrock and limestone, proves that such a source existed during at least part of the Middle Cambrian). The latter scenario is the more attractive if the faunal boundary within the "Boundary limestone" corresponds in a temporal sense with the faunal boundary on the platform (which may be a disconformity), as maintained by Fritz (1971, this volume) and disputed by Ludvigsen (1989). In this case, materials of the "Boundary limestone" were derived from a shallow platform that had not yet been smothered by siliciclastic mud, and persisted into earliest *Bathyuriscus-Elrathina* Zone time as a source, but not a resting-place, for carbonate particles.

Physical relationships demonstrate that, when its growth was ended, the platform-margin escarpment stood well above the basin slope to the west. Its height can be estimated only with resort to the disputed bio- and chronostratigraphy. For purposes of sedimentological analysis, however, the precise timing of subsequent events is not critical. Following the disappearance of *Glossopleura* and its allies "from the record preserved on the platform", and their replacement by *Bathyuriscus, Elrathina et al.*, the lower, limestone-dominated (Narao) member of the platformal Stephen Formation was covered by the shale-dominated upper (Waputik) member. At the Cathedral platform margin, conditions during any hiatus were either (a) emergence (no evidence); (b) sediment bypassing [suggested by the absence of equivalents of three faunules of the *Bathyuriscus-Elrathina* Zone (Rasetti, 1951; Fritz, 1971)]; or (c) deposition of metre-scale, mud-based, shale-limestone cycles (upper member of platformal Stephen). Only in case (a) is a source of siliciclastic mud other than the platform required. In cases (b) and (c), storms and storm return flows could mobilize platformal siliciclastic muds newly introduced onto the platform, and sweep them into the basin.

Words tied to scientific concepts can have the effect of mental blinkers. Who can use the word "turbidite" without visualizing a slope? Are we dealing with a slope in this storm return flow scenario? No, we are dealing with a cliff. A turbid storm return flow, pouring off the platform and carrying with it abandoned skeletons and living animals, both hard- and soft-bodied, would not hug the near-vertical escarpment. We must picture instead a dense, muddy, submarine Niagara, and the kind of billowing turbulence seen in cataracts and snow-avalanches on cliff-faces. The muddy cloud would expand into the basin (possibly becoming perched on a layer of colder water as an interflow), dropping first the coarser shells, then the tumbled, disoriented and mud-choked animals (perhaps debilitated by their cold plunge), and finally the mud fraction (Figure 3c), producing the tripartite layers described by Piper (1972). "Turbidites"? "Tempestites"? Both, actually, and neither typical of its kind. The idea of settlement from a perched mass of muddy water is attractive in that it allows anaerobic conditions to persist at the bottom, uninterrupted by ventilation by aerated water. Arrival of a settling cloud containing the fine fraction at the gently sloping sediment surface might set up a secondary turbidity current there, and account for the "tumbled" orientations of the corpses (Whittington, 1971).

One important corollary of this model is the source of the fossils. The model requires that this be mainly the relatively shallow, muddy platform represented by the upper, Waputik Member of the platformal Stephen Formation, with presumably minor contributions from the fauna adapted to life on the escarpment and an admixture of forms endemic to the colder, deeper, off-platform waters. A second corollary is that representatives of the taxa on which the platformal zonal scheme is based should be found in synchronous deep-water deposits near the escarpment, to provide a basis for the kind of platform-to-basin chronocorrelation that has been made by Fritz (1971, this volume) in support of the "escarpment model".

Conclusion

Ludvigsen (1989) has attacked the sedimentological model that explains both deposition and preservation of the Burgess Shale and its fauna by placing them "in the shadow of the Cathedral Escarpment". His attack is based on false assumptions and unjustified statements, namely, that the escarpment was conceived solely on the basis of assumptions about the chronostratigraphic significance of trilobite fossils, and that no sedimentological evidence for the escarpment exists.

Quite to the contrary, the escarpment was discovered twice on the basis of lithostratigraphy and structural relationships, prior to acquisition of any biostratigraphic knowledge bearing on its existence. Furthermore, a wealth of sedimentological data was in the hands of the proponents of the escarpment model, although little of it has been published. Ludvigsen offers a "ramp model" that does away with the escarpment, but presents no new sedimentological data. The "ramp model" is totally incompatible with well-exposed stratigraphic and structural relationships in the area of interest.

Ludvigsen is on slightly firmer ground in criticizing the categorization of the layers of the Burgess Shale as turbidites, and suggests that they are, instead, tempestites. Like many deposits, the Burgess beds may be both. A new look at the paleogeography of Burgess Shale time suggests that the Burgess beds may indeed be tempestites, but, if so, were laid down by a process previously undescribed. This new insight has important implications concerning the living-sites of the animals now found in the Burgess Shale, and conditions at their site of entombment.

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REPLY

To Comments by Fritz *and* Aitken and McIlreath

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Introduction

For the past 20 years, the Cathedral Escarpment has stood over the fauna of the Burgess Shale, not because this interpretation was a compelling synthesis of diverse stratigraphic, sedimentologic and paleontologic data and not because this interpretation was the best of a number of competing depositional models. No, according to claims, the existence of the escarpment was obviously the only possible explanation: consideration of others was unnecessary. The escarpment model quickly became reified as a geographic feature that seemed as factual and as incontrovertible as Mount Field itself. Indeed, the only proof considered necessary was a steep line on the flanks of Mount Field on a figure, labelled "Cathedral Escarpment".

None of the numerous publications on the Burgess Shale that were printed during the 1970s and 1980s mentioned the possibility of other, non-escarpment explanations. Perhaps if the intellectual gnashing-of-teeth (alluded to by Aitken and McIlreath in their discussion) about attempts at non-escarpment models prompted by the absence of reef talus had been presented in print, the escarpment would have been seen for what it is - an explanation, but not **the** explanation, for an abrupt juxtaposition of two distinct Cambrian lithofacies in Yoho National Park.

My paper on the setting of the Burgess Shale was written, not to provide **the** correct answer, but to present a plausible alternative to the escarpment and turbidite models. That alternative was a model involving tempestite deposition on a muddy, ocean-facing ramp.

In their responses to the points raised in my paper, Fritz and Aitken and McIlreath promise a bit more than they deliver. Fritz claims that neither the Index Model nor the Dual Model of biostratigraphy is applicable, and promises a "less structured approach" to the escarpment question. Nonetheless, he returns to an undiminished Index Model which requires a succession of zones in open-shelf shales identical to that in restricted-shelf carbonates. Aitken and McIlreath promise to document the presence of the escarpment by stratigraphic, sedimentologic and structural criteria. In the end, they fail to demonstrate that one lithofacies towered over the other at the time of deposition. They do, however, relent on the turbidites.

Below, I respond to specific points raised by my critics, and speculate on the possible role of diagenesis in influencing the lithofacies in the vicinity of the Cathedral margin.

Eureka - The Escarpment!

Large-scale depositional features such as deltas, barrier bars, barrier reefs and submarine escarpments do not **exist** in the rock record in the same manner as do minerals, fossils, rocks or sedimentary structures. Hence, their discovery is not a matter of "Eureka!". Rather, it involves interpretation of data within the framework of depositional models. In order for a vertical juncture of two lithofacies to be interpreted as an escarpment, various data (either sedimentologic, or biostratigraphic, or both) must be presented to show that one facies stood above the other when they were deposited.

So, who first discovered or recognized the Cathedral Escarpment? Charles Ney (1954) supplied the "Eureka!", but otherwise contributed little more than a statement of conviction and a steep line on a figure. The stratigraphic discussion in Aitken and Fritz (1968) provided much the same. The definition of the escarpment as an interpretive feature came from Fritz (1971). His conclusions were based on biostratigraphic data analyzed within an implicit biostratigraphic model and, therefore, his interpretation could be tested. That is what I did in my paper.

Science *versus* Entertainment

Fritz claims that I sacrificed science for entertainment by dichotomizing a complex correlation problem by "offering only two models in order to present two clearly defined choices". However, this does seem to be an improvement over the previous attempt (Fritz, 1971) in which correlations were treated as inevitable consequences of the distribution of generically defined trilobite zones. As I said in my original paper: "Assumptions made about the nature of the [biostratigraphic] units will inevitably influence which strata are correlated. More often than not, the assumptions are left unstated and the resulting correlations tend to be treated as biostratigraphic **fact** when actually they are contingent on the validity of a particular biostratigraphic **model**". I emphasized the critical role of models, made the assumptions of each model explicit, and showed how these assumptions influence the correlations. This is hardly a non-scientific approach.

Fritz also criticizes my characterization of Lochman-Balk and Wilson (1958) as proponents of the Index Model, and claims that these authors anticipated the major features of the Dual Model more than 30 years ago. Their paper was clearly important — it was one of the first papers I read when I started working on trilobites. Even though Lochman-Balk and Wilson recognized the presence of three concentric biofacies realms in North America, they applied the same zonation of trilobite genus-range zones to all but the "outer euxinic biofacies " — a belt that is now known to comprise largely accreted terranes. The claim that the same zone can be applied to all strata regardless of facies is the hallmark of index fossil biostratigraphy. Without giving it a name, and without acknowledging that it was a model, Lochman-Balk and Wilson were clearly using, and promoting, what I call the Index Model.

Most Cambrian trilobite biostratigraphers in North America have recognized the need to establish separate zonal sequences for separate biofacies and, over the past 15 years, many such zones have been erected — either supplanting the zones of the "standard" sequence or restricting their use to a single biofacies (Palmer and Taylor, 1976; Robison, 1976; Palmer and Halley, 1979; Briggs and Robison, 1984; Westrop, 1986; Ludvigsen, Pratt and Westrop, 1990; Pratt, in press). The continent-wide "standard" of Cambrian trilobite genus-range zones is clearly being phased out.

Meaning of the *Glossopleura/Bathyuriscus-Elrathina* "Zonal" Boundary

Fritz and I agree that the boundary between *Glossopleura* assemblages and overlying *Bathyuriscus-Elrathina* assemblages extends from the Boundary Limestone in the basin vertically up the carbonate margin to the top of the thick Cathedral Formation. What is in dispute is the nature and the meaning of these biostratigraphic units. Fritz maintains that a collection of *Polypleuraspis* sp., *Glossopleura*? and *Oryctocephalus* cf. *reynoldsi* from the Boundary Limestone is correlative to one of *Polypleuraspis* sp. and *Glossopleura* sp. from limestones at the top of the thick Cathedral Formation. Because both collections contain the name bearer (even if tentatively identified), they both belong to the *Glossopleura* Zone, which is separated from the overlying *Bathyuriscus-Elrathina* Zone by a time line. By contrast, I suggest that the chief significance of these two collections is that they belong to a low diversity *Glossopleura* biofacies from shallow water carbonates which is largely equivalent to a high diversity *Bathyuriscus-Elrathina* biofacies from deeper water shales. The boundary between these biofacies is markedly diachronous over a short distance.

Closely similar litho- and biofacies occur in the Great Basin of Nevada and Utah and it is useful to see how different biostratigraphers have handled the correlations that are disputed by Fritz and myself. Briggs and Robison, neither of whom is a stranger to Cambrian biostratigraphy or to Burgess Shale fossils, made the following assessment of Great Basin Middle Cambrian faunas and their implications for the Burgess Shale (1984, p. 3-4, references omitted):

> "A general marine transgression during the Middle Cambrian widely superimposed a diverse open-shelf trilobite fauna containing *Bathyuriscus* and *Elrathina* above a restricted-shelf fauna dominated by *Glossopleura*. These faunas have traditionally been assigned to different zones. Nevertheless, total stratigraphic ranges of both *Bathyuriscus* and *Elrathina* have been observed to overlap completely the range of *Glossopleura*. In the Spence Shale of the Wellsville Mountains [of Utah] species of *Bathyuriscus, Elrathina* and *Glossopleura* are associated in the same beds. These distribution patterns are part of the basis for proposed abandonment of *Bathyuriscus-Elrathina* as a zone name. The patterns also are important with regard to interpretations that have been made about the depositional setting of the Burgess Shale in British Columbia. The Burgess shale has been determined to represent a part of a sediment apron that accumulated adjacent to a near-vertical submarine escarpment. Using the uppermost occurrences of *Glossopleura* as a time surface, Fritz calculated that minimum water depths at the front of the escarpment exceeded 200 metres. Based on observed distribution patterns of faunas containing *Glossopleura* and *Bathyuriscus-Elrathina*, we suggest that the boundary between these faunas may have greater ecological than temporal significance and inferred water depths during Burgess shale deposition may be exaggerated."

Briggs and Robison recognized the profound facies control on those trilobite assemblages that Fritz considered to be temporally correlative and concluded that, based on trilobite biostratigraphy, the thick Stephen Formation and the thick Cathedral Formation are, at least in part, correlative. Therefore, Fritz' crucial evidence — the time line that defines the escarpment — has now evaporated.

Biofacies and zones of the Stephen Formation

Fritz argues that the occurrence of *Oryctocephalus, Pagetia, Peronopsis* and *Ptychagnostus* in the Burgess Shale demonstrates a deep-water setting in front of the escarpment because the first two are "medium to lower slope" and the latter two are "deeper basinal". The presence of the last three genera along with the oryctocephalid *Tonkiella* in the same collection from the Cow Head Group of Newfoundland (Young and Ludvigsen, 1989) cautions against using individual genera as depth indicators. Collectively, such genera indicate open-shelf biofacies (Robison, 1976), and nothing more. The Cow Head collection occurs in light brown grainstone and packstone with abundant spar — hardly a deep water lithofacies.

It is difficult to respond to Fritz' discussion of the temporal significance of the trilobite collections from Nevada, Idaho and British Columbia, because his tacit assumption is that they belong to the same biostratigraphic entity by virtue of including perhaps only a single specimen of *Glossopleura*. Meaningful correlations of Cambrian strata must be based on shared species — not just in slope deposits and not just with pagetiids and agnostids as Fritz suggests, but in all settings and with all trilobites.

Absence of a Debris Apron

Aitken and McIlreath pass quickly over "the paucity of reef-talus at the toe of the putative escarpment" by admitting that there is little of it. In fact, there is less than a little — there is none! This is all the more difficult to understand because the Cathedral Escarpment above the Boundary Limestone was one of three ancient examples of a by-pass margin with a reef that were cited by McIlreath and James (1984, fig. 14) in their excellent paper on facies models of carbonate slopes. In this setting, the reef caps the escarpment and, therefore, "the most characteristic and spectacular style of accumulation is the wedge of peri-platform talus" (McIlreath and James, 1984, p. 254). Because a debris apron is an integral and necessary part of the depositional system across a carbonate submarine cliff, the thick Stephen Formation adjacent to the carbonate bank **must** contain considerable amounts of carbonate talus if the escarpment stood 200 m high. The facies model approach of McIlreath and James (1984) is informative in this regard because it makes predictions (p. 254-255) which then become the basis for confirmation or falsification. If judged on the sedimentologic evidence from the thick Stephen Formation in front of the Cathedral margin, the Escarpment Model clearly fails according to the criteria presented by McIlreath and James.

Sedimentologic Evidence for the Cathedral Escarpment

Aitken and McIlreath repeatedly emphasize the sharp nature of the dolostone - shale contact at the Cathedral margin. They note that the lower Stephen Formation is different from the upper Stephen, and that the style of reef growth in the lower Cathedral Formation is different from that in the upper Cathedral. Neither of these relationships demonstrated that the outer edge of the carbonate platform stood vertically above the muddy basin during deposition of the Burgess Shale. Thus, evidence of the Escarpment Model is still wanting.

Source of Burgess Shale Faunas and Sediments

A reader who has been following the general interest publications on the fauna and environment of the Burgess Shale (for example, Conway Morris and Whittington, 1985) may be startled to realize that Aitken and McIlreath have now moved the animals from their familiar deep and dark living position on the mud in the shadow of the Cathedral Escarpment to shallow and lit settings on top of the platform. According to them, an infrequent storm would throw sediment and animals into suspension as a turbid flow which would then cascade down the 200 m precipice to drop its load as a tempestite *cum* turbidite at the base of the cliff. Before this interesting scenario can be evaluated, convincing evidence for the existence of an escarpment must be presented and that, as has been seen, has been elusive. Published work on the ecology and taphonomy of the Burgess biota (Whittington, 1971; Conway Morris, 1986), however, does not support this type of transport, and there is no evidence that the trilobites of the thick Stephen Formation belong to anything other than normal open-shelf biofacies that occupied positions seaward of the carbonate bank. That is, there is no mixing of trilobite biofacies in the Burgess Shale.

Diagenesis of Strata near the Cathedral Margin

Sharp facies changes from shallow water carbonates to deeper water calcareous shales are fairly common in Paleozoic rocks of the Cordillera. For example, in Lower Devonian strata of the Mackenzie Mountains, Noble and Ferguson (1971, p. 586, fig. 10) showed 170 m of coarsely crystalline dolostone of the Manetoe Formation passing abruptly into 150 m of calcareous shale of the Funeral Formation over a few metres with "little or no intertonguing".

However, nowhere in western Canada is a facies change as planar as that of the Cathedral margin exposed in Yoho National Park, and nowhere else do carbonates pass into non-calcareous shales such as those of the thick Stephen Formation. My suggestion that the Cathedral Formation carbonates and the Stephen Formation shales were part of a single depositional system on a muddy calcareous ramp is, at first glance, difficult to reconcile with the preserved rock record. However, post-depositional alteration may well be responsible for at least some of these features — in particular, the abrupt, planar nature of the facies change and the largely non-calcareous nature of the shales of the thick Stephen Formation.

The western margin of the Cathedral Formation could well be the plane at which dolomitization stopped, rather than the position where carbonate deposition ceased. It is quite conceivable that dolomitization could terminate with a sharp boundary at some plane across a gradual limestone — shale transition as carbonate content and porosity/permeability fell below critical levels. This boundary would, in any case, be sharpened and straightened by movement on minor faults as a result of differential compaction (Aitken and Fritz, 1968), as evidenced by slickensides at the dolostone - shale contact.

The thick Stephen Formation now consists largely of non-calcareous shales and mudstones, but it may originally have comprised calcareous muds deposited on a ramp in front of an actively accreting carbonate bank. That diagenetic processes played a significant role in decalcifying these muds is suggested by the complete replacement of the calcium carbonate exoskeleton of the Burgess Shale trilobite *Olenoides* by chlorite and illite (Whittington, 1980). The soft parts of the Burgess faunas are preserved as aluminosilicate films with reflective areas composed of muscovite (Conway Morris, 1986). The timing of the diagenesis is uncertain. It may have occurred during compaction, accompanied by elevated temperatures and pressures (Conway Morris, 1986). Was the replacement restricted to calcitic shells, or was it more pervasive among disseminated bits of calcite within the mudstones? The degree to which the clay minerals of the thick Stephen Formation are diagenetic alteration products after calcite has not yet been explored.

The critical factor responsible for the outstanding preservation of the Burgess Shale biota may well be diagenesis of calcareous muds located close to a carbonate bank.

Conclusion

Notwithstanding the lengthy comments on my paper of last year by Fritz and by Aitken and McIlreath, the quality of the evidence for an escarpment has not improved. The biostratigraphic data cannot be resolved into the required time line, and the sedimentologic data are equivocal with regards to the presence of an escarpment. I maintain that a ramp model is better than an escarpment model, but cheerfully acknowledge that the documentation for this model is permissive rather than compelling.

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