High-resolution Stratigraphy, Regional Correlation, and Report of Molluscan Faunas: Colorado Group (Cenomanian-Coniacian Interval, Late Cretaceous), East-central Saskatchewan

Christopher J. Collom [1]

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1. Introduction

This report presents data resulting from joint field research during 1992, 1994, and 1995. The multidisciplinary project, informally named the "Carrot River/Pasquia Hills Project" (CRPHP), was jointly sponsored by the Canadian Museum of Nature, Ottawa (S. Cumbaa, coordinator) and the Royal Saskatchewan Museum, Regina. Aspects of CRPHP research, mostly addressing vertebrate paleontology, have been previously presented in Cumbaa *et al.* (1992), Cumbaa and Tokaryk (1993), Tokaryk *et al.* (1997), Cumbaa *et al.* (1997), Cumbaa (1999), and Cumbaa and Tokaryk (1999). Future CRPHP research will focus on systematic description of the various marine fauna, such as elasmobranch and ray teeth (Cumbaa and Stewart), teleostid fish (Stewart), marine reptiles (Wu *et al.*, in review), and molluscs and invertebrate communities (Collom). The abundant inoceramid *Mytiloides labiatus*, not illustrated herein, is the focus of a forthcoming monographic study (Collom) that will compare populations of this cosmopolitan Turonian bivalve from each of the western Canadian provinces. All specimens illustrated herein are stored at the Royal Saskatchewan Museum (Regina), the Royal Tyrrell Museum of Palaeontology (Drumheller), and the Geological Survey of Canada (Vancouver).

2. Stratigraphic Framework

Fine-grained facies of the Colorado Group in eastern Alberta, Saskatchewan, and western Manitoba have received differing degrees of attention from mappers, stratigraphers, and paleontologists since the pioneering work of MacLean during the 1910s (Kirk, 1930; McLearn and Wickenden, 1936; Bannatyne, 1970). However, studies of the Cretaceous in Saskatchewan have been hindered by: 1) rare, widely separated outcrops; 2) horizontally bedded strata (reducing the potential for thick sections in river-cut valleys); and 3) the dominance of poorly consolidated fine-grained facies that are prone to slumping upon exposure. Nonetheless, biostratigraphically important molluscan macrofossils (ammonites and inoceramid bivalves) are surprisingly common and well preserved at Carrot River, Waskwei River, and Bainbridge River in Saskatchewan. These localities are the focus of CRPHP study to date. This report supplements and partially revises the landmark contribution of McNeil and Caldwell (1981).

Five northwesterly trending upland areas form the "Manitoba Escarpment" in eastern Saskatchewan and western Manitoba: Pembina Mountain, Riding Mountain, Duck Mountain, the Porcupine Hills, and the Pasquia Hills (McNeil and Caldwell, 1981, Figure 1). The northernmost of these, the Pasquia Hills, contains exposures suitable for detailed collecting and correlation. Due to the poorly indurated nature of the fine-grained marine facies, some of the exposures described herein may not be accessible in the near future. For example, the 25 m thick Bainbridge River exposure (Figure 4-1), discovered during the 1995 field research in the area north of Hudson Bay, Saskatchewan, was probably produced by valley wall collapse during the late 1980s or early 1990s. It is close to, and possibly developed from, Sections 21 (4.7 m thick) and/or 22 (2.45 m thick) in McNeil and Caldwell (1981). Additional information regarding the Pasquia Hills area may be obtained by contacting me at *cjcollom@mtroyal.ab.ca*.

a) Lithostratigraphy and Facies

Stratigraphic formations (Figure 2) addressed in this section were initially described by Kirk (1930) and Wickenden (1945), and refined by McNeil and Caldwell (1981). Detailed formal definitions are given in Glass (1990). The Cretaceous marine strata in Saskatchewan and Manitoba are part of the "eastern calcareous facies belt" (see Figure 3, Kauffman, 1977). In Alberta and western Saskatchewan, recognition of the lateral equivalents of the units discussed here is largely facilitated by molluscs, foraminifera, calcareous nannofossils, and marine and terrestrial palynomorphs (dinoflagellates, pollen). Also important are distinctive isochronous marker beds, such as bentonites (volcanic ashes) and rare coarse-grained sandstones and conglomerates. Correlation of the Colorado Group in eastern Saskatchewan westward to the Foothills region, based on facies patterns and on gamma- and resistivity-log responses, is undependable as few facies are common to both areas. High-quality biostratigraphic data are therefore essential for

[1] Department of Earth Sciences, Mount Royal College, 4825 Richard Road, Calgary, AB T3E 6K6.

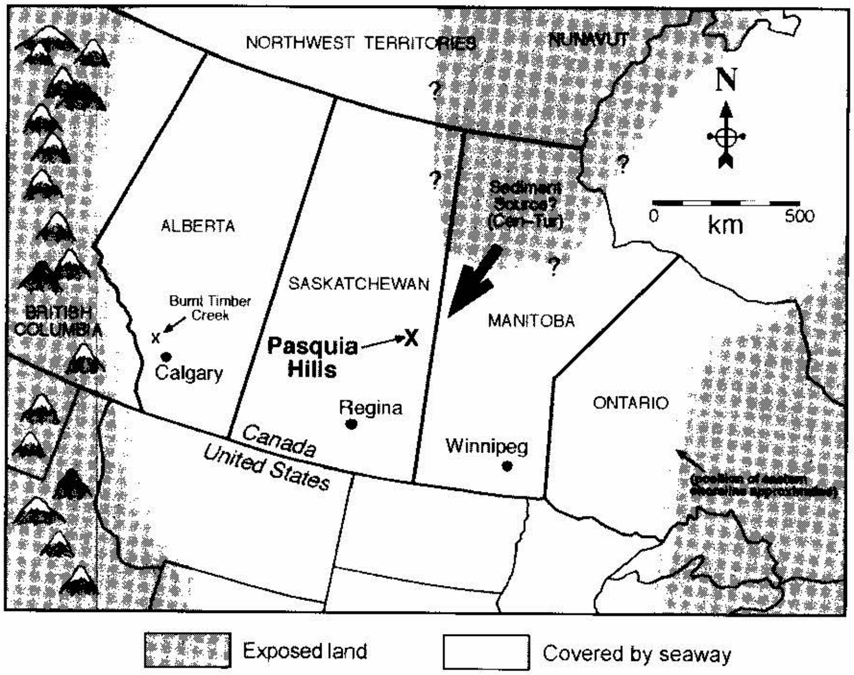

Figure 1 - Map of western and central Canada (**Mytiloides labiatus **Zone: Early Turonian), with reconstructed shorelines for the Cretaceous Western Interior Seaway, at the maximum sea-level transgression of the Greenhorn Cyclothem. Pasquia Hills and nearby Carrot River are denoted by 'X'. Large arrow indicates inferred provenance in Keewatin of siliciclastic sediments (siltstone and fine-grained sandstone) observed within the upper Ashville Formation at the Bainbridge River section. Given the considerable distance from eastern and western shorelines (~1000 km), large marine reptiles found at Carrot River (e.g. crocodiles) probably used coastal regions of this poorly documented land area for nesting and egg-laying. Migration into and emigration from the eastern portion of the seaway by species mentioned in this report may have occurred via the boreal "Hudson Arm" (connecting this region to West Greenland and northern Eurasia), rather than the "MacKenzie Arm" or Tethyan corridors.

constraining the ages of the Ashville, Favel, Morden, and Niobrara formations in the study area.

Ashville Formation

The Ashville Formation has four members (O-Y) in Saskatchewan: the Skull Creek, Newcastle, Westgate, and Belle Fourche. These are variably composed of organic-rich mudstone, siltstone, thin sandstones (quartzose), and concentrations of vertebrate and invertebrate skeletal material. Only the upper ~4.0 m of the Belle Fourche Member were observed at the Bainbridge River and Carrot River sections (Figure 3). The Belle Fourche Member is correlative to the lower Blackstone Formation (Sunkay Member) in the Rocky Mountain Foothills (Figure 2). In the subsurface of Alberta, these clastic facies are represented by offshore sandstones, the Barons Sandstone. At Bainbridge River, facies coeval to the Barons are represented by thin lenses and beds of silty to fine-grained sandstone (Figure 3) associated with accumulations of vertebrate skeletal debris, the Fish Scales Formation (Leckie *et al.*, 1992).

The boundary between the Ashville Formation and overlying Favel Formation represents a short hiatus, with silty, non-calcareous mudstones below and calcareous laminated mudstones above. The contact zone includes sparse, thin (<2 cm), silty to very fine-grained sandy beds deposited near the centre of the Western Interior Seaway during the Middle to Late Cenomanian transition. Neither the Cordilleran hinterland, some 1000 km to the west, nor the poorly known eastern shoreline, a comparable distance to the east, can be logically invoked as source regions. Because many of the quartz grains in these beds are angular to subrounded in shape, it is unlikely that they were transported such vast distances. I therefore suggest the existence of a more proximal sediment supply.

The Arctic region of Keewatin has been depicted as an exposed land area in most paleogeographic reconstructions of the Western Interior Seaway since the 1970s (Figure 1). This landmass separated the "MacKenzie Arm" of the seaway directly north of Alberta from the "Hudson Arm" of northwest Ontario and Hudson Bay. As a result of Pleistocene glacial activity, Phanerozoic strata on the Canadian Shield have been eroded away. If there was an upland during the Cretaceous flooding of North America, then sediments would have been transported from it to the seaway by normal fluvial processes. The Keewatin landmass is envisioned as the provenance for siliciclastics in the upper Ashville Formation at the Bainbridge River Section (middle Colorado Group). Marine facies in the Sverdrup Basin correlative with the Ashville and Favel formations (Christopher Formation and Hassel Formation: MacRae, 1992; Nuñez-Betelu, 1994) also contain anomalous quartz-rich sands that thicken towards Keewatin. As with the much thinner siltstones and sandstones in Saskatchewan and Manitoba, the Sverdrup Basin clastics were most likely derived from the otherwise unknown landmass between the Hudson and MacKenzie arms.

In the Crowsnest Pass area of southern Alberta, at the contact of the Blairmore and Alberta groups, >100 m of volcaniclastic rock of Early Cenomanian age are present and are thought to be coeval to the Fish Scales Formation, an easily recognized gamma-log marker in subsurface wireline data (Leckie *et al.*, 1992). Massive concretions up to 1.5 m in diameter and consisting

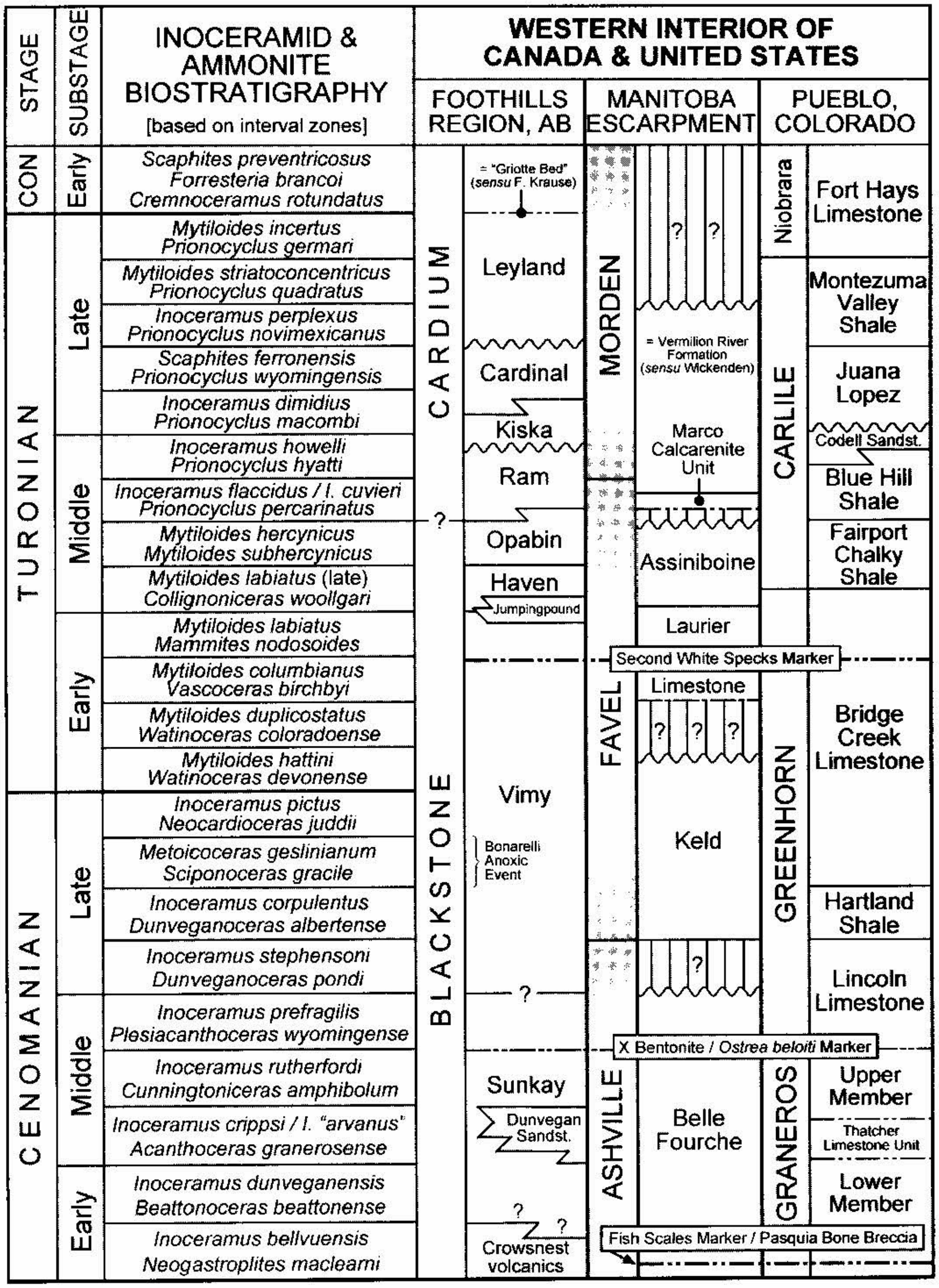

Figure 2 - Biostratigraphy and lithostratigraphy for the Early Cenomanian to Early Coniacian interval (mid- to Late Cretaceous), Western Interior of Canada and the United States. Members of the Blackstone Formation from Stott (1961), based on the newly designated WCSB reference section at Burnt Timber Creek, Alberta (see Figure 4-2). Vertical lines indicate disconformities and depositional lacunas. Contemporary ammonite and inoceramid-based interval zones modified from Cobban and Scott (1972) to accommodate new information (e.g. Collom, 1991; Kirkland, 1996). The *Sciponoceras gracile/Metoicoceras geslinianum* ***Zone represents a globally recognized anoxic interval ("Bonarelli Event"), equal to the Keld Member throughout the Manitoba Escarpment (marker beds B3 to B6, Figure 3). Both the*** *I. pictus* ***and*** *M. labiatus* ***zones are associated with the*** *Hedbergella loetterlei* ***Assemblage Zone (foraminifera), which straddles the Cenomanian-Turonian boundary. Disconformity within the Keld Member not well constrained, based on the absence of*** *M. duplicostatus* ***and*** *W. coloradoense* ***at all sections collected. The Laurier Limestone Beds (Keld Member, Early Turonian) represent the highest relative sea level of the Phanerozoic. Pueblo, Colorado section designated by Pratt*** *et al.* ***(1985) as the Western Interior reference section for the Cenomanian and Turonian stages, and the GSSP (Global Boundary Stratotype Section and Point) for the base of the Turonian (Bengtson, 1996).***

almost entirely of calcite-cemented teleost bones and selachian teeth were found by the CRPHP in the Pasquia Hills at a stratigraphic level comparable to the Fish Scales, in the upper part of the Ashville Formation (Figures 4 and 5, in Cumbaa and Tokaryk, 1999). This remarkable bioconglomeratic unit is herein named the Pasquia Bone Breccia (PBB).

Debate continues regarding the origin of the Fish Scales beds (Leckie *et al.*, 1992; Bloch *et al.*, 1993). Most investigators agree that one or more volcanically driven mass mortalities, primarily affecting fish, sharks, and certain plankton over a short time span, combined with sediment starvation resulting from sea-level rise, are the main causal mechanisms. The role of the Crowsnest Volcanics in formation of the Fish Scales Marker(s) is not established, but available biostratigraphy and geochronology support their penecontemporaneous age.

An as yet unnamed regressive-transgressive sequence in the lower Blackstone Formation (within the Sunkay Member) represents approximately the same stratigraphic horizon as the middle of the Belle Fourche Member. In northern Alberta, the zones of *I. dunveganensis* and *I. crippsi* correspond to the Shaftesbury Formation and Dunvegan Formation, situated between the Fish Scales and the "X Bentonite" markers (Figure 3). *Cunningtoniceras* sp. has been collected near the X Bentonite level at Burnt Timber Creek (Figure 4-2), but *Cunningtoniceras* or *Dunveganoceras* have yet to be found in Saskatchewan. Available data suggest the sandstone unit in the Sunkay Member is coeval to the Dunvegan Formation, and these in turn are correlative to <2.0 m of fine-grained sediment in the Pasquia Hills. Until additional evidence is found, it is concluded that a major progradation of the western shoreline of the WCSB occurred during the early Middle Cenomanian (*I. crippsi/A. granerosense* Zone) that is not easily recognized in the Pasquia Hills, and a hiatus is present at the Ashville-Favel formational contact (*I. stephensoni/D. pondi* Zone: early Late Cenomanian) that has no apparent analog in Alberta.

Biota

The relatively thin exposure (<1.5 m±) of the uppermost Ashville at the DH-3 site on Carrot River has yielded well preserved pneumatic bones representative of the oldest avifauna known from the Western Interior (Cumbaa and Tokaryk, 1999). No age-diagnostic molluscs were collected at this site, but marine dinoflagellates from near DH-3 corroborate a Middle to Late Cenomanian age for the lowest exposed strata on Carrot River (D. Jarzen, pers. comm., 1996). Nicholls *et al.* (1990), describing remains of marine protostegid turtles, provisionally assigned a Coniacian age to isolated outcrops of the upper Belle Fourche Member (e.g. near DH-3, see Figure 3 in Cumbaa and Tokaryk, 1999). Subsequent identification of the diagnostic foraminifera *Verneuilinoides perplexus* (D. McNeil, pers. comm., 1992) and marine dinoflagellates (D. Jarzen, pers. comm., 1994) from this level provides a reliable Middle Cenomanian age for this lower bioclastic bone unit. These correlations suggest that this concretionary bone layer (SMNH 63E03-0001 in Cumbaa and Tokaryk, 1999) may be laterally equivalent to the PBB (at SMNH 63E09-0003), although few, if any, upper Ashville exposures are present in the 115 km distance between Carrot and Bainbridge rivers.

Favel Formation

The Favel Formation consists of two members: the Keld and overlying Assiniboine (Figure 3). The formation is composed predominantly of laminated, dark grey to black, marine mudstone and ten bentonite beds, ranging in thickness from <1.0 cm to ~10 cm. The thickest bentonite, herein referred to as B7 (numbering consecutively from the contact with the Belle Fourche below), occurs *between* the two prominent, argillaceous limestone layers of the Laurier Limestone Beds regional marker unit (McNeil and Caldwell, 1981). The Laurier Limestone Beds, at the top of the Keld Member, are ~20 to 30 cm thick and are the only well indurated sedimentary unit within the Favel Formation in the Pasquia Hills.

The Favel Formation is exposed at each of the four sections investigated (the base of the Laurier Limestone Beds is used as datum for correlation in Figure 3), but the lower and upper contacts were observed only at the Bainbridge River locality. This is the most complete section of the Favel Formation in the Pasquia Hills and perhaps in the entire Manitoba Escarpment. The Keld Member is almost entirely Late Cenomanian (*Inoceramus corpulentus, I. pictus* zones) in age, whereas the Assiniboine is Middle Turonian (*Mytiloides hercynicus* Zone). The cosmopolitan guide fossil *Watinoceras* is apparently absent in the Favel Formation. This is the index ammonite for recognition of the basal Turonian (*W. devonense*) in Western Canada.

The most spectacular vertebrate found by CRPHP investigators is a 6.5 m long specimen of the crocodylomorph *Terminonaris* (identified as *Teleorhinus* in previous reports, but this is a preoccupied name) on Carrot River. Bones of this 95 percent complete individual were collected from marine mudstones immediately below the Laurier Limestone Beds (Figure 3). This large marine reptile is, therefore, most likely of Early Turonian age (*Watinoceras* spp. Zone). Its excavation was started by Tokaryk in 1991. A complete description of the reptile is forthcoming (Wu *et al.*, in review). The skull is nearly 1.25 m in length and boasts at least two re-healed injuries presumably from duels with other members of its species. The death of this otherwise healthy individual probably resulted from an attack by another *Terminonaris* (Tokaryk, pers. comm., 1994). Despite abundant shark teeth within and immediately adjacent to the Laurier Limestone Beds at both Carrot River localities, the *Terminonaris* shows little evidence of post-mortem scavenging. The articulated nature of the skeleton attests to the low oxygen and low current

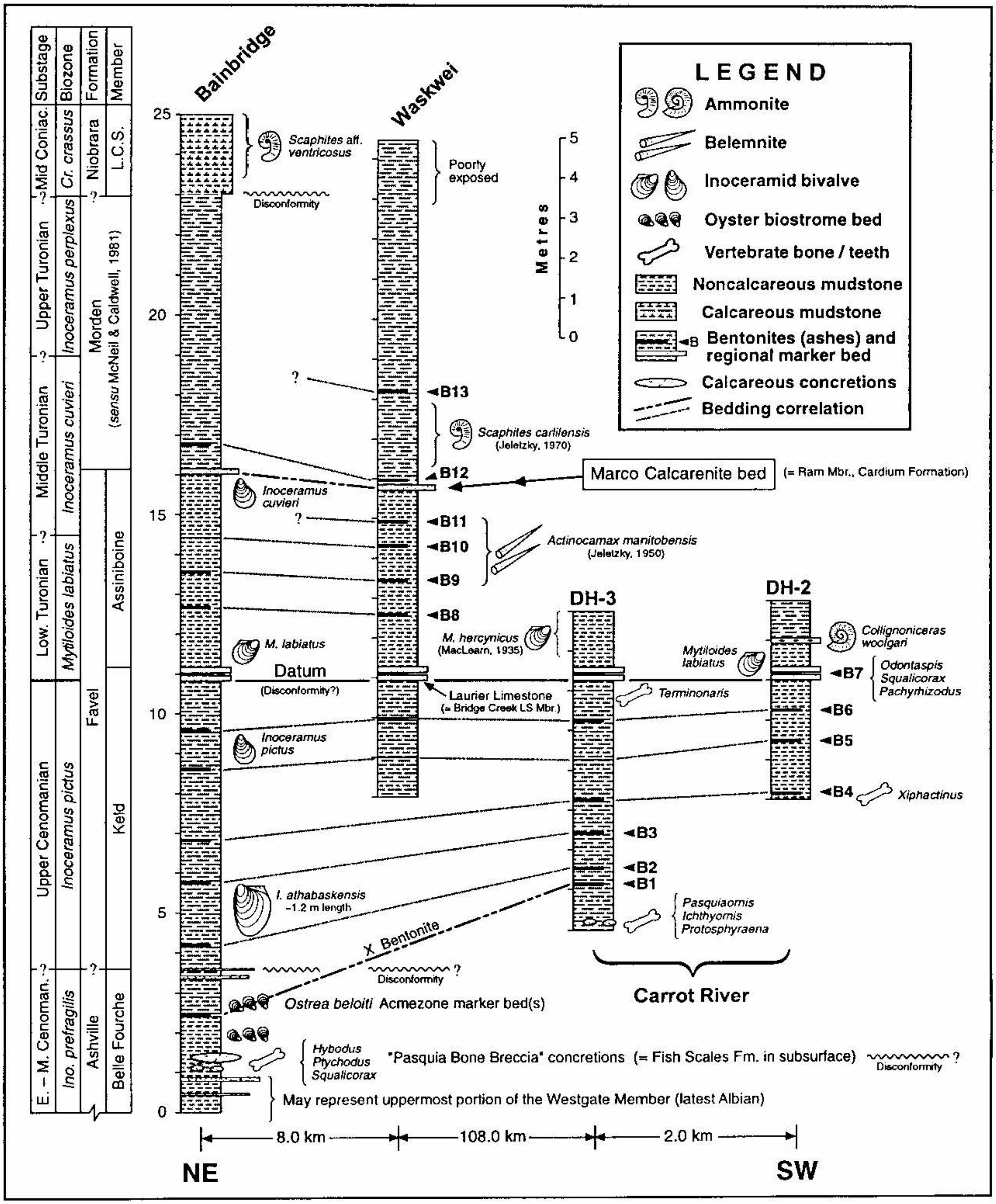

Figure 3 - High-resolution correlation of the four surface outcrops described in this report. Datum is the regionally persistent limestone bed couplet of the Laurier Limestone Beds (Keld Member), encompassing marker bentonite B7 (~10 cm thick). Stratigraphic occurrences of important vertebrate and molluscan fossils are indicated. The Bainbridge River section (Cumbaa et al., 1997) is designated as the reference section for the Favel Formation in the Pasquia Hills region. The Pasquia Bone Breccia Unit (PBB) has only been confirmed at Bainbridge River, the northeastern part of the study area, but may be represented by a thinner, concretionary bioclastic layer at the DH-3 section. X Bentonite and Ostrea beloiti biostrome, event beds having been traced throughout the Western Interior, were initially correlated across the Manitoba Escarpment by McNeil and Caldwell (1981). Not depicted are the decimetre-thick bedding rhythms representing the precessional cycle (~21 Kyr), best developed in the Favel and Niobrara formations.

energy conditions on the Early and Middle Turonian seafloor.

A notable exception to this general condition of quiet water deposition is the Marco Calcarenite in the uppermost Favel (McNeil and Caldwell, 1981, p36). This unit is made up of micritic, calcite-cemented, fine-grained quartz sandstone and siltstone. Bioclasts are predominantly fragmented cryptodontid bivalves (*I. cuvieri* Sowerby; Middle Turonian). This marker has been recognized at the Bainbridge and Waskwei sections (Figure 4-4). At the DH-2 locality (Carrot River), a ~10 cm thick argillaceous limestone bed 1.0 m above the base of the Laurier Limestone Beds contains the early Middle Turonian guide fossil *Collignoniceras woollgari* (Mantell). It probably does not represent the Marco Calcarenite (Figures 2 and 3).

Biota

Case *et al.* (1990) reported a Coniacian age for the elasmobranch fauna of the Laurier Limestone Beds and adjacent facies of the middle Favel. As implied by Cumbaa and Tokaryk (1999, p60), this age assignment is now considered to be inaccurate as *in situ* specimens of inoceramid bivalves and key ammonite species, present at both the Western Interior reference section (Pueblo) and throughout western Europe (Kauffman, 1977), were collected from these strata during CRPHP field work. The presence of the cryptodont *Inoceramus prefragilis* Stephenson and *I. athabaskensis* McLearn in the basal 2 m of the Keld Member restricts the oldest portion of the Favel Formation to the Middle Cenomanian. Numerous specimens of *Mytiloides labiatus* (Schlotheim) with disarticulated and paired valves have been recovered from the Laurier Limestone Beds and the lowest part of the Assiniboine Member, indicating that the Cenomanian-Turonian boundary is within otherwise homogenous calcareous mudstones of the upper Keld Member (the *Whiteinella aprica* Subzone). Therefore, the uppermost portion of the Keld Member is not younger than late Early Turonian.

Upper Cenomanian basinal mudstones worldwide record an unfossiliferous interval of dramatically heightened organic carbon storage, the Bonarelli Global Anoxic Event (GAE) (Jenkyns *et al.*, 1994). Although causal explanations vary, in several Euramerican localities this event appears to have either initiated, or was associated with, accelerated background extinction rates of benthic and pelagic marine organisms. In the WCSB, the Bonarelli GAE is recognized within the Vimy Member, Blackstone Formation (Alberta), and the Keld Member in Saskatchewan. No obvious mortality events are known from these intervals in Western Canada, but there are few invertebrates within certain 5 to 10 m thick portions of the Blackstone Formation that are interpreted to have been deposited during this anoxic event. Dark grey to black shales with potentially high TOC content (>5.0 wt%) in the lower Vimy Member may be evidence of the Bonarelli GAE. Geochemical samples of the Favel Formation were not collected, but these may be forthcoming from other workers in the Pasquia Hills (e.g. Schröder-Adams *et al.*, 1999).

Morden Formation

The dark grey to black, laminated, generally non-calcareous mudstones of the Morden Formation are one of the more distinctive facies in the Manitoba Escarpment. Resting unconformably(?) on the Marco Calcarenite (Favel Formation), these middle and upper Turonian fine-grained sediments display little bioturbation (rare *Chondrites* and *Planolites*), and contain far fewer inoceramid bivalves and ammonites than the older Favel Formation and younger Niobrara Formation calcareous facies.

Biota

Characterization of the Morden Formation is best accomplished by foraminifera and calcareous nannofossils, which are relatively plentiful. McNeil and Caldwell (1981) documented *Pseudoclavulina* sp., *Trochammina ribstonensis* Wickenden, and *Hedbergella loetterlei* (Nauss), indicating a Middle Turonian age. The ammonite *Prionocyclus hyatti* (Stanton) was reported by Jeletzky (1970) but its locality was not indicated and efforts towards finding this specimen within the collections of the Geological Survey of Canada in Ottawa have not been successful. This biostratigraphic tie-point, therefore, remains unconfirmed. Erosional removal or non-deposition of facies recording the Turonian-Coniacian boundary make it difficult to determine the youngest age for the Morden Formation, but it may be as high as the middle Late Turonian (e.g. *P. wyomingensis/S. ferronensis* Zone).

Niobrara Formation

The Niobrara Formation (Vermilion River Formation in Kirk, 1930) has two informal members in the Manitoba Escarpment region, the Calcareous Shale unit ("Lower Chalk Speckled Member" in McNeil and Caldwell, 1981, Figure 44) and the overlying Chalky unit ("Upper Chalky Member" in McNeil and Caldwell, 1981, Figure 44). As with the older Favel Formation, the facies of the Niobrara Formation are light to dark grey, laminated calcareous mudstone to marlstone. The poorly accessible cliff exposure at Bainbridge River is the single locality at which this formation crops out. A float specimen of *Scaphites* aff. *ventricosus* Meek and Hayden (Figure 6-1) was found not far downstream, indicating that the upper <2.0 m of exposed strata (Calcareous Shale Unit) are at least Middle Coniacian (*Cremnoceramus crassus* Zone, Figure 3).

b) Regional Correlation

The most comprehensive description and intra-regional correlation of facies along the Manitoba Escarpment is McNeil and Caldwell (1981). More than 100 sections were sampled for benthic and planktonic foraminifera,

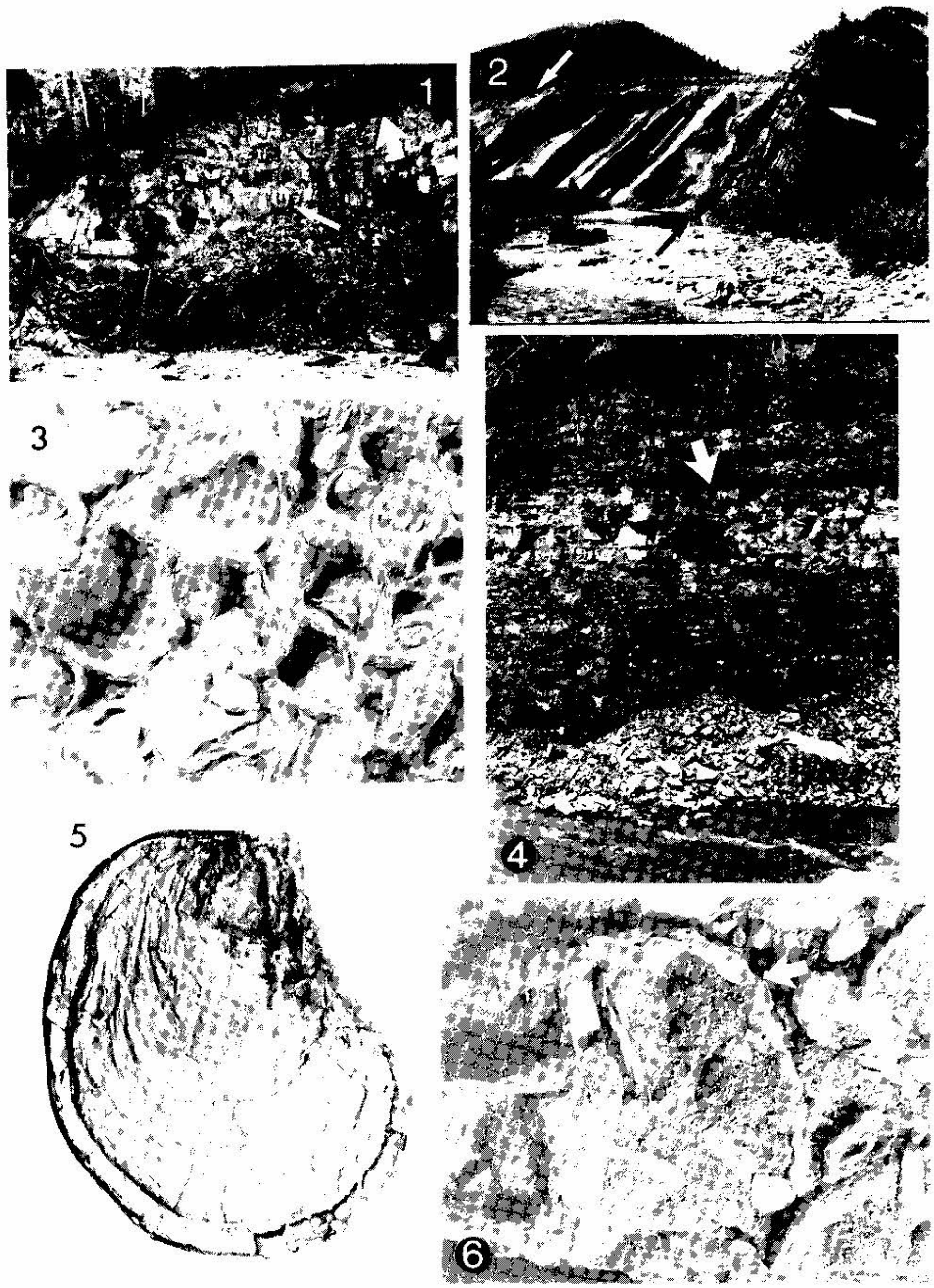

***Figure 4** - (1) The highly condensed Bainbridge River section, representing fine-grained marine facies from the latest Albian?/earliest Cenomanian to Middle? Coniacian (~15 Myr in 25 m of strata); smaller arrow points to person for scale; (2) Sunkay Member, Blackstone Formation at Burnt Timber Creek, Alberta: coeval to Belle Fourche Member and lower Keld Member in Saskatchewan, note four consecutive parasequences (in shadows): black arrow to person (for scale), white arrow on right at position of 3rd-order sequence boundary capping shallowing-upwards interval: white arrow at left denotes position of the X Bentonite (Middle Cenomanian);(3) Pseudoperna bentonensis Logan - TMP 98.32.1 (x1.16), coquina slab of inter-cemented individuals, representing more than two generations of encrustation: Favel Formation, Bainbridge River; (4) Waskwei River section, containing upper Keld Member to upper? Morden Formation strata: debris fan at base of exposure has produced abundant vertebrates (shark teeth, bony fish, marine turtle), arrow indicates the Favel-Morden formational contact (person at lower left for scale);(5) Inoceramus prefragilis Stephenson (x0.77), lateral view of right valve (not collected): note preservation of original prismatic shell material: upper Belle Fourche Member, Bainbridge River; and (6) Ostrea beloiti Logan - TMP 98.32.2 (x0.96), view of numerous closely packed individuals in various states of disarticulation (arrow to near-complete left valve: note anachomata along ventral margin): upper Belle Fourche Member, Bainbridge River.*

from the Skull Creek Member, Ashville Formation (Late Albian, *Haplophragmoides gigas*) to the Odanah Member, Pierre Formation (Late Campanian, *Haplophragmoides fraseri* Zone). Ten foraminifera-based zones were recognized and defined for this ~30 Myr interval. No advances were made, however, for co-occurring molluscan biozones. These were partially reported by Jeletzky (1970), although an investigation of Colorado Group macrofauna from the Manitoba Escarpment comparable in scope to McNeil and Caldwell's foraminiferal study is still lacking. Gill and Cobban (1965) reported on the ammonites and associated macroinvertebrates of the Colorado Group at nearby Pembina Mountain, North Dakota. Combined with later contributions (e.g. Obradovich and Cobban, 1975), no fewer than 40 zones, based on eight well documented ammonite lineages, have been established for the same time interval, with an average zone duration of <400 Ka.

Upon recognition of the established Western Interior molluscan biozones, and their corroboration with contemporary microfossils (foraminifera, dinoflagellates, calcareous nannofossils, and terrestrial palynomorphs), well guided observations can be made regarding depositional rates in different regions of the Cretaceous seaway. The Blackstone Formation of Alberta is coeval to the Belle Fourche, Keld, and Assiniboine members, as demonstrated by the equivalence of their macroinvertebrate faunas. At Bainbridge River, the thickest and most complete section of this interval in the Pasquia Hills, the Favel Formation is ~12.5 m thick (Figure 3). This is half the height of the Bainbridge exposure (25 m), which, in addition to the Favel, includes the uppermost part of the Ashville Formation, the Morden Formation, and possibly a portion of the "Lower Chalk Speckled" unit of the Niobrara Formation. Comparisons with Western Interior geochronology (Obradovich, 1993) indicate that nearly 15 million years are represented by this relatively thin interval. In the Foothills region of Alberta, the Bainbridge River equivalents include the Blackstone Formation (four members), Cardium Formation (five members), and at least the lower two members of the Wapiabi Formation (Muskiki and Marshybank)(Figure 2). Their total thickness is considerably greater than their counterparts in the east.

Of the many exposures of the Alberta Group (Blackstone, Cardium, Wapiabi), perhaps the most complete is at Burnt Timber Creek, northwest of Calgary. Here the marine and nearshore strata equivalent to those in the Bainbridge River section crop out in an essentially continuous river-cut exposure, and are approximately 1200 m thick. Thus, for every 1.0 m of deposition in Alberta, a scant ~2.0 cm accumulated on the shallow eastern platform of the WCSB. Furthermore, a composite section of the thickest Blackstone Formation (at Thistle Creek, Alberta), Cardium Formation (at Ram River, Alberta), and Wapiabi Formation (at Thistle Creek, Alberta) exposures would be ~1550 m thick (Stott, 1963; Collom, unpubl. data). The so-called foredeep, resulting from Sevier/Cordilleran overthrusting associated with terrane accretion along the western margin of North America, accounts for the considerably greater accommodation space in Alberta and British Columbia. These relationships bring to light the extreme condensation and sediment starvation that persisted in the eastern basin during the Late Cretaceous.

c) Correlation with Pueblo Reference Section

The above described Cenomanian and Turonian zones, illustrated in Figure 2, are known to a greater level of stratigraphic resolution than any other of Cretaceous age in North America. Research at Rock Canyon Anticline, south-central Colorado by the University of Colorado, Boulder campus (primarily graduate students of Erle Kauffman) has precisely constrained the biozone contacts of *Inoceramus pictus, Mytiloides hattini,* and *M. labiatus* to individual limestone beds within the Hartland and Bridge Creek members of the Greenhorn Formation (Elder, 1987; Kirkland, 1990; Harries, 1993). The bluffs and railroad cuts at Pueblo Reservoir, Colorado, were chosen as the reference section for the Cenomanian and Turonian stages in North America (Pratt *et al.*, 1985). This site will be referred to as the "WIRS", or Western Interior Reference Section.

The Second International Symposium on Cretaceous Stage Boundaries (Brussels, Belgium, Sept. 1995) went a step further by recommending that Pueblo be designated the international GSSP for the base of the Turonian (Bengtson *et al.*, 1996). Although the invertebrate fauna from the WIRS have more Tethyan and Euramerican affinities than Canadian equivalents with more Boreal and Indo-Pacific elements, the biostratigraphically important ammonite families and epifaunal bivalves are present in most Late Cretaceous marine realms (Kauffman, 1975). Comparisons between the WCSB and the Colorado-Kansas region were initially made by McNeil and Caldwell (1981, Figure 44) and McNeil (1984, Figure 13). Adjustments to those schemes are presented herein.

The uppermost Belle Fourche beds at Bainbridge and Carrot rivers are most likely Middle Cenomanian (*I. prefragilis/V. perplexus* Zone), and are correlative with the Sunkay Member of the Blackstone Formation in Alberta (Figure 2). This silty mudstone, above the Dunvegan Formation deltaic deposits of the Peace River Arch region, is coeval with the lowermost Kaskapau Formation. Presence of the widespread *O. beloiti*/ X Bentonite marker beds (Middle Cenomanian) allow comparison with the upper Graneros Formation and lower Lincoln Member of the Greenhorn Formation in Colorado. The Ashville-Favel contact is traceable into the lower part of the Vimy Member (*I. stephensoni* Zone/*C. simplex* Subzone), which is essentially the same level as the base of the Hartland Member at the WIRS. The second zone of the Late Cenomanian (*D. albertense* Zone) contains both *I. corpulentus* McLearn and *I. flavus* Sornay, but the former species is more abundant in the WCSB.

The precise stratigraphic position of the Cenomanian-Turonian stage boundary (C-T) is not known for the

Manitoba Escarpment and is only approximated in the Rocky Mountain Foothills within the well studied Blackstone Formation. McNeil and Caldwell (1981, Figure 31) placed the C-T boundary a few metres above the base of the Keld Member, based largely upon the diagnostic foraminifera *Clavihedbergella simplex* and inferences "from common associates of zonal indices." As such, most of the Keld Member is Turonian. CRPHP collections indicate that there are no *M. labiatus* (late Early Turonian) from below the Laurier Limestone Beds, but there may be an earliest Turonian fauna within the upper part of the Keld Member. In contrast, the C-T boundary is restricted to a level fewer than 10 cm above marker limestone bed #86 (LS-7 of Elder, 1987) of the Bridge Creek Member, Greenhorn Formation, at the WIRS (Figure 5-5). This precisely defined, isochronous boundary is defined by the First Appearance Datum (FAD) of *M. hattini* and *Watinoceras* spp. Neither fossil has been found in the Pasquia Hills, suggesting that there may be a hiatus associated with the basal contact of the Laurier Limestone Beds.

A Late Cenomanian age for most of the Keld Member is confirmed by the presence of the cryptodont *Inoceramus athabaskensis* near the base and *I. pictus* near the top of the calcareous mudstone. *Inoceramus pictus* Sowerby is common within the lower six limestone and shale beds of the Bridge Creek Member at the WIRS. Peak transgression of the Greenhorn Cyclothem (2nd order sequence) during the Early Turonian facilitated the deposition of bedded limestone farther north than at any other time during the ~40 million year history of the Cretaceous seaway in North America. Along the Manitoba Escarpment this carbonate depositional episode is reflected in the Laurier Limestone Beds of the Keld Member. Calcareous concretion horizons within the upper half of the Vimy Member, Blackstone Formation, are a western equivalent of the Laurier Limestone Beds, as is the Bridge Creek Member (Figure 2). Nearly all continents with Turonian-age marine strata record moderately to very fossiliferous, carbonate-dominated beds during *Watinoceras* to *Mammites* time (~93 Ma BP).

The Assiniboine Member of the Favel Formation (Middle Turonian: *M. hercynicus* Zone) appears to be correlative with the Haven and Opabin members of the Blackstone Formation, although the silty and sandy facies of the Haven is not represented in Saskatchewan. The base of the Assiniboine Member is at the approximate level of the Greenhorn-Carlile contact (base of Fairport Member). The Marco Calcarenite, capping bed of the Favel Formation, shares faunal similarities with the Blue Hill Member of the Carlile Formation at the Pueblo WIRS, as both contain *I. cuvieri*. The relationship of the Marco Calcarenite to the Blackstone-Cardium transition is less clearly understood. The Marco Calcarenite may contain elements of the *I. howelli/P. hyatti* Zone (latest Middle Turonian), and therefore be partially correlative with the Ram Member (Cardium Formation) and Codell Member (Carlile Formation). These sandstone-dominated regressive units both have transitional, diachronous basal contacts and relatively sharp upper contacts. The Ram and Codell (and Marco Calcarenite?) appear to record a major shoreline progradational event that affected the entire Western Interior Seaway and was therefore probably not a reflection of local tectonism.

The Morden Formation was correlated by McNeil and Caldwell (1981) with the Blue Hill Member of the Carlile Formation based on *Heterohelix* cf. *reussi* (foraminifera) and *Prionocyclus hyatti*. This collignonicerid ammonite ranges up into the Codell Member of the WIRS, but only overlaps with the heteromorph *Scaphites carlilensis* Morrow in the lower half of the *I. howelli* Zone. It occurs with *I. costellatus* and *I. securiformis* in the Denver Basin, Colorado. Jeletzky (1970, Plate 26, Figures 7a and 7b) illustrated a *S. carlilensis* from the Morden Formation in Manitoba. No scaphitids have been collected from below the Niobrara Formation in the study area, but the relative position of Jeletzky's specimen is shown in the Waskwei River section in Figure 3. Nevertheless, the Morden Shale likely represents deposition into the Late Turonian to at least the *I. perplexus* Zone. Late Turonian representatives of the Carlile Formation (Juana Lopez and Montezuma Valley members) are well known (Collom, unpubl. data), and are correlative of the Cardinal Sandstone and lower Leyland Shale in Alberta (see Hall *et al.*, 1994). It seems that this *M. incertus* Zone is missing in the Pasquia Hills, but, is represented by a significant lacuna between the Morden Formation and the overlying Niobrara Formation. No macrofauna of certain early Coniacian affinities (e.g. *Cremnoceramus deformis* Zone) are known from Saskatchewan, but evidence is beginning to accumulate for the identification of Middle Coniacian strata (*C. crassus* Zone at the location shown in Figure 6-1).

3. Sequence Biostratigraphy

Establishment of regionally correlative Cretaceous molluscan biozones in marine successions of the Western Interior began in both Canada (McLearn, 1920) and the United States (Cobban, 1951) early in the 20th century. Concepts and applications of these zones, however, have changed considerably. The biozones used herein are *interval* zones (North American Commission on Stratigraphic Nomenclature, 1983, see Article 50), based on the first appearance datum (FAD) of the name-bearing taxa. High-resolution correlation of the fine-grained facies of the Colorado Group in Saskatchewan and Manitoba with the sandier and thicker successions in Alberta are lacking, but comparisons have been made (McNeil and Caldwell, 1981) based on micro- and macrofaunal occurrences. In terms of sequence stratigraphy, no fewer than four sequence boundaries (third-order level) are present. These are at the base of the Favel Formation, the base of the Marco Calcarenite, the base of the Morden Formation, and the base of the Niobrara Formation. A possible fifth unconformity may exist at or near the base of the Laurier Limestone Beds (Keld Member).

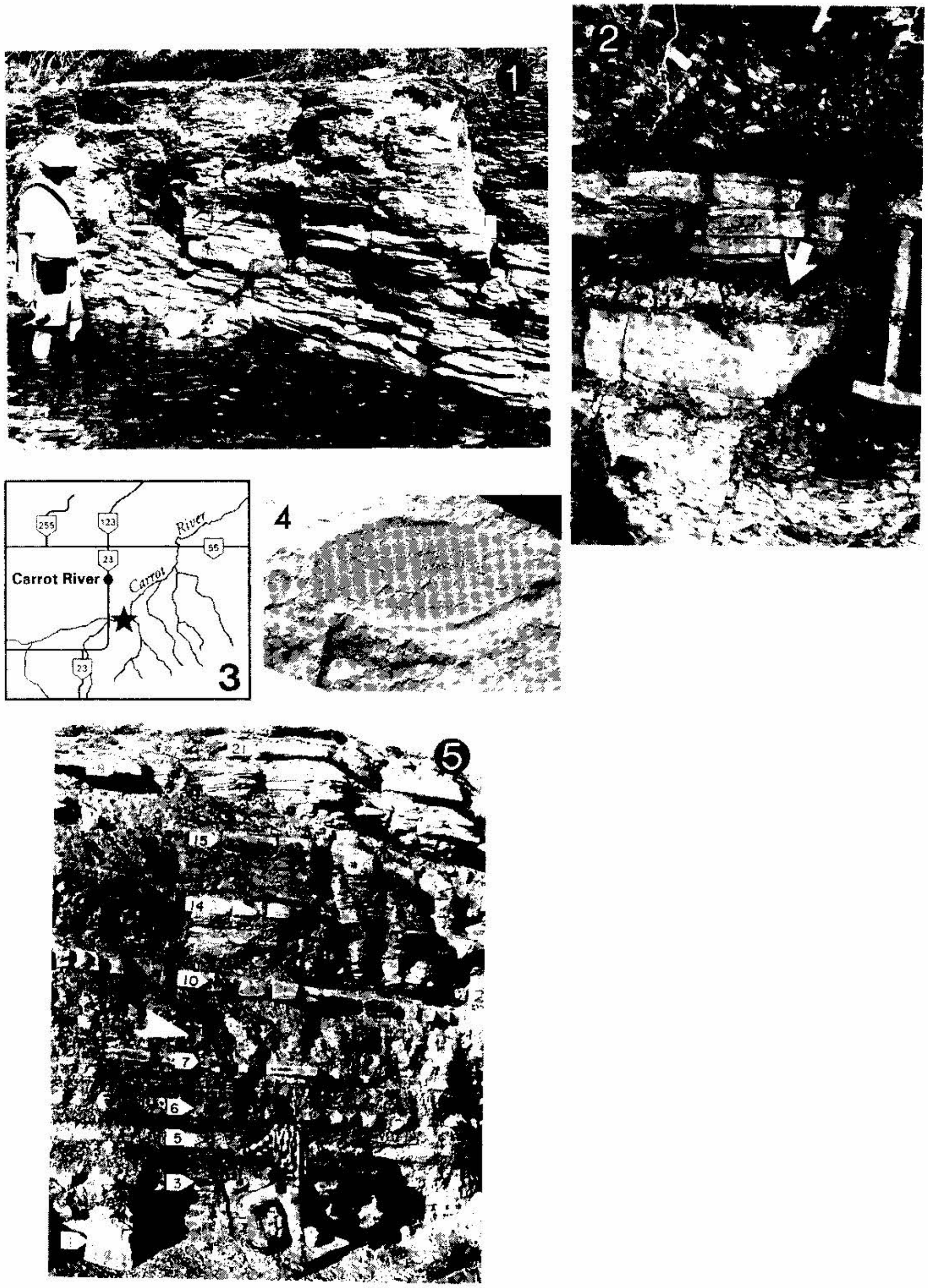

Figure 5 - (1) Cyclically interbedded laminated mudstone and marlstone facies of the Keld Member, Favel Formation: DH-2 locality, Carrot River; (2) Laurier Limestone Beds, uppermost Keld Member with marker bentonite B-7 between indurated beds (at arrow): DH-2 locality, Carrot River; (3) map of Carrot River region: DH-2 and DH-3 sites (river-cut exposures; location shown by star) are separated by only 2.0 km; (4) Xiphactinus *sp. - P2413.1a (x0.85), latex peel of large isolated scale: DH-2 locality, Carrot River; and (5) The Western Interior Reference Section (Pueblo, Colorado), shown are the basal ~11 regionally correlative limestone beds of the Bridge Creek Member, Greenhorn Formation (equivalent to upper Keld Member and lower Assiniboine Member in WCSB): Cenomanian-Turonian stage boundary indicated by white arrow (W. Elder for scale).*

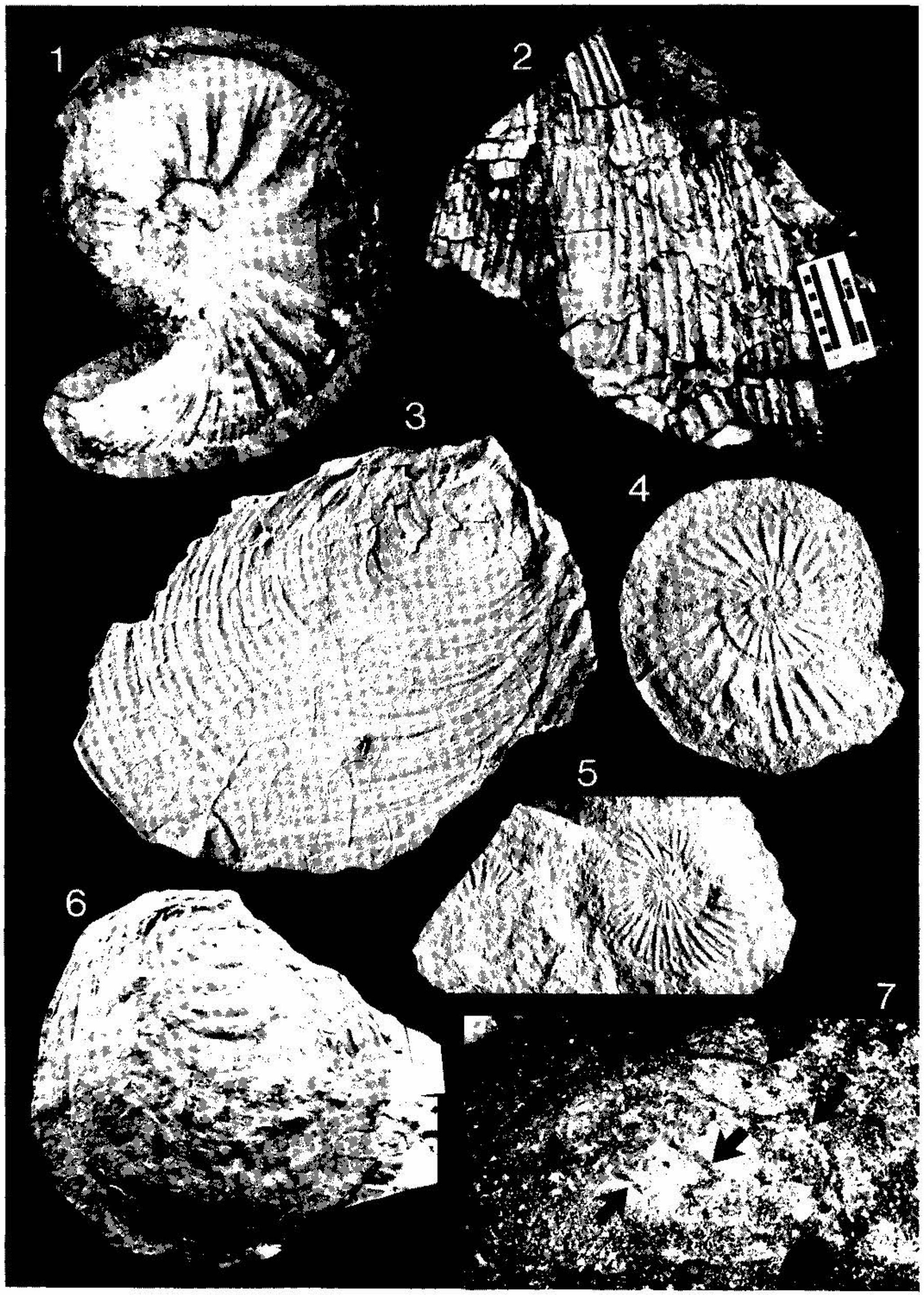

Figure 6 - (1) *Scaphites* **aff.** *ventricosus* ***Meek and Hayden (x0.84), macroconch?: Niobrara Formation float, Bainbridge River; (2)*** *Inoceramus* **aff.** *athabaskensis* ***McLearn, fragment of very large left valve (?), numerous epibionts are the encrusting oyster Pseudoperna: lower Favel Formation, Bainbridge River; (3)*** *Mytiloides hercynicus* ***(Petrascheck) - GSC 9297 (x0.84), lateral view of right valve, internal mold: Assiniboine Member, Carrot River (collected by F.H. McLearn, August 1935); (4)*** *Collignoniceras woollgari* ***(Mantell) - TMP 98.33.1 (x0.84), lateral view of adult macroconch (?), latex peel; (5)*** *C. woollgari* ***- TMP 98.33.2 (x0.84), lateral view of two adult specimens, latex peel: (4) and (5) are both from DH-2 locality (~1.0 m above Laurier Limestone Beds), Carrot River; (6)*** *Inoceramus* **aff.** *prefragilis* ***Stephenson (x0.0.17), lateral view of large right valve with protruding anterior margin: Bainbridge River?; and (7)*** *Thalassinoides*, ***ichnofossils (arrows) within marker bentonite B-7, between prominent limestones of the Laurier Limestone Beds, Favel Formation: Carrot River, camera lens cap for scale.***

The Belle Fourche Member represents an overall third-order transgression (transgressive system tract), culminating with progradational facies being irregularly deposited during the latest Cenomanian throughout the WCSB. The Cruiser Formation and "Fish Scales Sandstone" are examples of these discontinuous sand bodies. The lower Keld *S. gracile* Zone is characterized by low-oxygen facies (black shale), and may represent either an unrecognized sequence boundary or a maximum flooding interval. The Laurier Limestone Beds were deposited during maximum flooding and relative sea-level rise. Subsequent regression and shoreline progradation resulted in deposition of the thin (<5 to 7 m) Jumpingpound Sandstone (*C. woollgari*: Figure 2) in Alberta. Although unmarked by a silty or sandy facies, the contact between the Keld and Assiniboine members occurs at this horizon in Saskatchewan.

The Marco Calcarenite may be genetically related to other late Middle Turonian "clastic wedges", such as the Ram Member of the Cardium Formation. Considering the observed degree of sediment bypass and starvation in the Pasquia Hills, it may be that the Marco Calcarenite records consecutive regressive (RST) and transgressive (TST) events. Its disarticulated and broken bivalve shell debris attests to high energy and, possibly, bottom-scouring waves inferring relatively shallow waters at time of deposition. The Morden Formation was probably deposited during the same interval when the two major progradations of the Ram and Cardinal members of the Cardium Formation occurred in the western shoreline facies belt. The dark organic-rich mudstones of the Morden Formation however, show no obvious evidence of clastic influx from the inferred Keewatin source area. Shared occurrences of molluscan index taxa have been the main guide for making onshore-offshore sequence stratigraphic correlations in the Western Interior. Much work remains in determining the precise stratigraphic positions of important erosional surfaces and the TST and RST between them.

a) Origin of Bentonites and Pasquia Bone Breccia

Two episodes of dramatic volcanism are known from the Albian-Cenomanian boundary interval in western Canada: emplacement of ultramafic diatremes of the Fort-à-la-Corne kimberlite swarm, associated with the Molanosa "highlands" of Saskatchewan (101 to 96 Ma BP, Kjarsgaard *et al.*, 1999), and eruption of the Crowsnest Volcanics (98 to 96 Ma BP) in southern Alberta. As such, the Westgate–Belle Fourche interval represents an active period of volcanism. At the Bainbridge River section, calcite crystal-lined "vugs" 4 to 8 cm in diameter were observed within concretionary bodies of the Pasquia Bone Breccia (Cumbaa and Tokaryk, 1999, Figure 4). Some of these cavities contained clumps of bentonitic material identical to the smectitic clays associated with the thicker marker bentonites, such as B7 in the Laurier Limestone Beds (Figure 6-7). These are interpreted to be remnants of volcanic ash erupted either to the north (Keewatin) or from the distant western cordillera. Elevated volcanic activity during the mid-Cretaceous has been attributed to higher oceanic spreading rates and a possible "superplume" event within the upper mantle (Larson, 1991).

Several hypotheses have been advanced to explain the distinctive bioclastic facies within the Pasquia Bone Breccia marker bed (Cumbaa and Tokaryk, 1999; Schröder-Adams *et al.*, 1999). Massive volcanic activity over the course of several months to years could have poisoned the Western Interior Seaway (via ash airfall on open water) to a level where most of its vertebrate inhabitants perished. Thick ash layers observed in cores of the Joli Fou and Viking formations from eastern Alberta (Cenomanian) may be additional evidence of such violent eruptions that changed adjacent epicontinental marine environments at a rate far exceeding that of the ability of teleost and elasmobranch populations to adapt.

In addition, if the X Bentonite, normally proximal to the *Ostrea beloiti* oyster biostrome, is present at the Bainbridge and Carrot River (DH-3) sections then it is the most widespread Cretaceous ash bed in North America. Moreover, if the X Bentonite represents a single eruptive event, then this episode of explosive volcanism is clearly greater than any recorded during human history. Basin-wide accumulations of the epifaunal oyster *O. beloiti* immediately above the X Bentonite may represent colonization by the so-called "disaster species" of Kauffman *et al.* (1991). They hypothesize that the oysters, gastropods, inoceramid bivalves, and other epifaunal organisms immediately above some Cretaceous ash layers imply that the ash itself provided a nutrient-rich substrate on which these animals could thrive, perhaps to a greater degree than under normal dysaerobic benthic conditions. Extensive networks of *Glossifungites* ichnofacies within bentonite B7 (Laurier Limestone Beds) indicate that burrowing organisms of that type were not significantly affected by large-scale volcanic events. In fact, the absence of *Thalassinoides* and *Psilonichnus* below and above this level at Carrot and Bainbridge rivers supports the possibility that volcanic ashes brought both death and opportunities for new life to the seafloor.

b) Gilbert Bedding Cycles

Decimetre-thick, cyclically bedded hemipelagic marlstone and organic-rich mudstone were initially recognized in Colorado and Kansas by Gilbert (1895, p121) as "regular alterations of strata" corresponding to "an astronomical cycle of known period". Gilbert used them to try to "deduce from this correlation an estimate in years of a portion of Cretaceous time." These time intervals are presently interpreted as Milankovitch cycles, representing the eccentricity (~100 to 126 Ka) and precession (~21 Ka) of Earth's orbital parameters (Fischer, 1980; Laferriere *et al.*, 1987). Nearly all formations within the Colorado Group exhibit such bedding (McNeil and Caldwell, 1981, Plate 5(D) and Plate 6(B); Schröder-Adams *et al.*, 1999, Figure 4A; and Figures 4-2 and 5-5 herein).

Individual limestone-shale couplets, reflecting the precessional cycle, have been correlated throughout Colorado and Kansas for the Cenomanian-Turonian Bridge Creek Limestone (Hattin, 1985; Elder *et al.*, 1994), and Turonian-Coniacian Fort Hays Limestone (Collom, 1991). Despite a relatively greater argillaceous component in the Colorado Group of Saskatchewan, such repetitive bedding can be observed in the field provided the rocks are not too weathered.

As outlined by Kauffman *et al.* (1991) and demonstrated by Elder *et al.* (1994), these Cretaceous mid-basinal couplets can be confidently correlated as 5th-order shoaling-upwards parasequences within the clastic-dominated shoreline facies belt of the Rocky Mountain Foothills. These are best observed in progradational regressive systems tracts (e.g. Dunvegan Formation), but are locally preserved in transgressive system tracts, such as the upper part of the Sunkay Member (Figure 4-2). Additional research may make it possible to correlate each of the bedding cycles ("parasequences") of the Keld and Assiniboine members to their counterparts in the Bridge Creek Limestone reference section in Colorado. Sufficient outcrop exists to undertake such ambitious correlations, but would require a closely spaced sampling program (5 to 10 cm intervals) and complete elemental and carbon/oxygen/TOC analyses.

4. Discussion and Conclusions

In the absence of stromatolites, rudistid bivalves, corals, or other phototrophic organisms, it is difficult to provide water depths of the Western Interior Seaway at given locations, particularly the Pasquia Hills. Cumbaa *et al.* (1992) and Cumbaa (1999) have argued that, in this area, bone beds, certain terrestrial palynomorph assemblages, storm-tolerant oyster species, and tidal-like bedding are suggestive of a nearshore position for parts of the Ashville Formation. Re-examination of facies and ostreiid communities, however, provide less conclusive results. The Colorado Group above the Westgate Member of the Ashville Formation in Saskatchewan appears to have been deposited at least 100 km from shore. Taking into consideration the typical benthic association (inoceramid bivalves and rare oysters) of these fine-grained, laminated non-rippled sediments, the presence of *Glossifungites* and *Zoophycos*-type ichnofacies, the dominance of planktonic foraminifera, and the nature of shark and ray faunas, it is estimated that the depth of the seaway was 60 m to 80 m maximum and 30 m to 40 m minimum.

In summary, outcrops in the Manitoba Escarpment of east-central Saskatchewan of the Keld and Assiniboine members (Favel Formation) have produced the oldest Cretaceous birds, turtles, large bony fish (*Xiphactinus*), and marine crocodylomorph (*Terminonaris*) known from North America. The undisturbed skeletons and molluscs suggest stable, quiet water depositional environments. Regional correlation using diagnostic marker beds, 12 bentonites (volcanic ash beds), and molluscan biozone index taxa (inoceramid bivalves and ammonites) allows comparison with coeval fine-grained marine deposits of the Blackstone Formation, Alberta Foothills, and with the Pueblo Western Interior reference section.

The thin, discontinuous, silty, fine-grained sandstone beds within the upper Ashville Formation (early Cenomanian) are believed to have been derived from an unknown upland to the north (presently exposed Precambrian Shield). It is considered unlikely that these clastics were derived and transported ~1000 km from the actively overthrusting western hinterland. Fewer than 5.0 m above this interval, near the Ashville-Favel contact, a prominent concretionary "bone conglomerate" layer of shark and fish bones, scales, and teeth is correlated with the Fish Scales Formation of the more proximal portion of the Western Canada Sedimentary Basin in Alberta. The origin of this highly condensed interval may represent a combination of mass mortality resulting from submarine/nearshore volcanism, and/or eustatic changes.

Biostratigraphic control of Colorado Group strata in the Pasquia Hills by means of molluscan macroinvertebrates is based on the distribution of numerous inoceramid bivalves and planispiral and scaphitid ammonites. The Ashville-Morden interval spans the Cenomanian and Turonian stages of the mid-Cretaceous, a period of ~9.0 Ma (97.0 to 88.0 Ma BP). Relative rates of sediment accumulation between the Alberta foredeep (Rocky Mountain Foothills region) and Saskatchewan were approximately 48:1. Thus the Colorado Group along the Manitoba Escarpment is constituted of highly condensed marine hemipelagic and pelagic facies.

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