Permophiles

International Commission on Stratigraphy
International Union of Geological Sciences

ICOS 2009
ROCKY MOUNTAIN FIELDTRIP

Fieldtrip Leaders:

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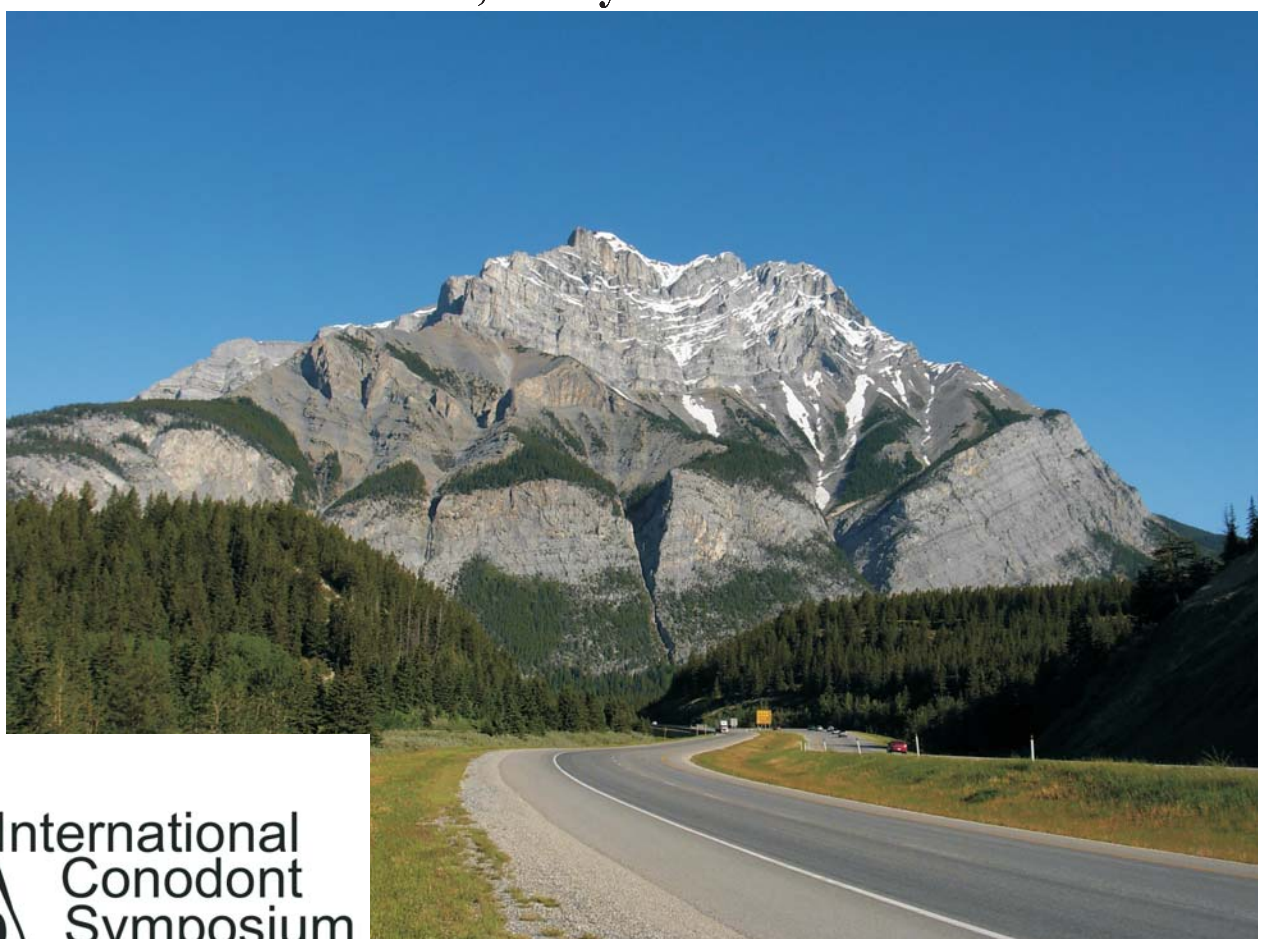

U. Devonian and Mississippian rocks, Cascade Mountain, Banff

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Day 1: Leave University of Calgary bound for Banff Centre via Highway #1, Highway 40 south, and the Spray Lakes road.

During the four days we will travel about 1150 km during which we will see some of the best mountain scenery anywhere in the world with a fascinating geologic history.

Introduction

The route you are traveling heading west out of the city will take you past Canada Olympic Park, once called Paskapoo after the rock formation underlying it. Canada Olympic Park, or COP, was the site of the 1988 Olympic Winter Games ski jump, bobsled, luge, and demonstration freestyle skiing.

The Paskapoo slopes area is ecologically interesting and has been the site of many battles between developers wishing to build new houses in suburbia, and environmentalists wanting to preserve the area as a wildlife corridor. You will notice that despite years of legal battles, the developers seem to be winning.

On your right, you can see old terraces cut into the hills as a sign that the current-day Bow River was once much larger and much higher. This is when Glacial Lake Calgary had formed as a result of glacial melt water. Many of the new communities in the northwest are built on a deep layer of gravel as a result of this process through the last ten thousand years.

Calgary is in an ecological zone known as the aspen parkland. In this zone, aspen trees share dominance with wild grasses from the prairies. Soils in this area are dark chernozems, ideal for grasses, and you will find many farms and ranches here. As you head west, you will gradually enter a new zone where spruce is the dominant vegetation.

As you head west, you are entering the foothills region, where the rock layers are starting to uplift. The most defined expression of uplift is finally found as you enter the front ranges of the Rocky Mountains about 45 minutes out of the city (Fig. 1).

Although most people refer to any of the mountains between Calgary and the west coast (Vancouver) as the Rockies, they are actually composed of many different ranges. The first range is actually the Rockies; the Front Ranges were known to the aboriginals in the area as Nahihi, which translated means Rocky. Some of the other ranges you would pass through should you drive to Vancouver are the Rocky Mountain Main Ranges, the Selkirks, the Purcells, the Monashees, and the Coast Ranges.

35 km; Road cuts start to show deformation in the form of minor thrust faults and west dipping strata associated with the mountain building to the west. This deformation marks the transition from the Alberta Plains to the Foothills.

48 km; Scott Lake Hill – Scott Lake Hill is really rather unremarkable as you drive past it. However, it has many of the characteristics of a high alpine meadow. If you drive from

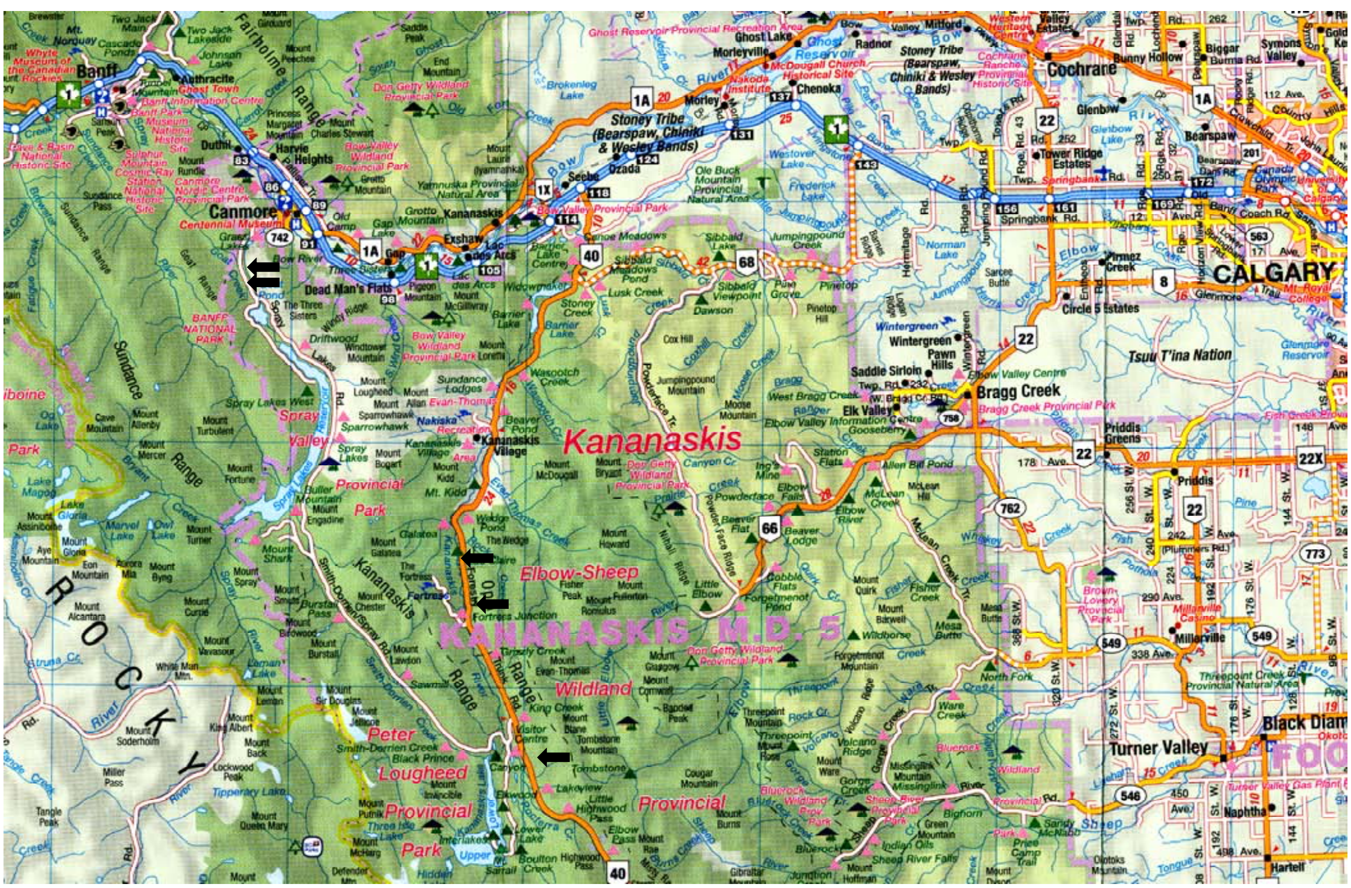


Figure 1. Map view of route.

Calgary to Vancouver, even though you will cross the Rogers Pass and the Coquihalla, both known as high mountain roads, neither is as high in elevation as Scott Lake Hill. The peak of the Coquihalla is at just over 1200 metres, while Scott Lake Hill tops 1410 metres.

54 - 65 km; Morley Flats with a classic glacial landscape including drumlins and eskers that resulted from the last glacial advance (Wisconsin), which was at its peak about 18,000 years ago with the major part of the retreat completed 11,000 years ago. This area would have been covered with one kilometre of ice only 18 millennia ago. You will start to notice that as you are heading west the vegetation is changing. Spruce is coming in, as are some lodgepole pines and a very few limber pine (interestingly, limber pine tends to follow outcrops of the Paskapoo Formation). Lodgepole pine got its name because this was the tree the aboriginals used as the centre pole in their dwellings, or lodges. They chose it preferentially because of its tendency to be very straight. Willow, silver berry, and buffalo berry dominate the bush or shrub level. Also, the vegetation will soon start to come in "waves", cresting the tops and sides of the hills. This is due to the influence of the chinook winds.

The chinook is a warm wind formed as air descends from the mountains. As it comes down, it warms adiabatically at a certain steady rate. This then flows over the foothills, and can take the temperature from minus 20 degrees Celsius to plus 15 Celsius in about one hour. This effect is most noticeable in the winter, and is defined by the chinook "arch". The arch is formed by clouds, typically with a large area of blue sky behind it where the air is descending to the plains. As it lowers, it dives under the clouds, forming the arch. Winds similar to the chinook are known throughout the world, such as the Santa Annas in California and the North African sirocco.

Much of the land the highway passes through is native reserve. Closer to the city, the Tsuu t'ina nation is predominant. As we go further west, the land you pass through belongs to the Siksika nation or Stoney First Nation Reserve.

69 km; Turn south on #40. We turn onto Highway 40, also known as the Kananaskis Trail. Kananaskis is Calgary's mountain playground. As a Provincial park, it is open to multiple uses, including hiking, rafting, limited development, grazing, skiing, mountain biking, and forestry. Many of the mountains here are named for warships in the first and second World Wars, especially the battle of Jutland, including Mounts Indefatigable, Invincible, Nestor, and Warspite.

Kananaskis is full of wildlife. It is the location of a golden eagle migration route that sees upwards of 5,500 eagles pass through each year. To celebrate this event, each year The Festival of Eagles is held in either Banff or Canmore.

Mount Yamnuska (the mountain that looks like a sailback reptile) marks the first landmark outcrop of the Rockies (Fig. 2). At its foot is Bow Valley Provincial Park, a small park noteworthy for the rare orchids that grow beside some of the springs there as well as our first stop. It is also noteworthy for the number of deer the area attracts, and for the geologically interesting esker that snakes through the park.

You can see Mt. Yamnuska to the right and behind us as we turn. he resistant grey cliffs of Middle Cambrian limestone towering above the wooded and black lower slopes of Mount Yamnuska have been thrust about 40 km northeastward over the non-marine mudstones and sandstones of the Belly River Formation (Upper Cretaceous) along the McConnell Thrust. This flat thrust fault was first described by R.G. McConnell of the Geological Survey of Canada in 1887. In this area, the McConnell Thrust marks the physiographic and structural boundary between the Foothills to the east and the Front Ranges to the west; the latter are defined by Paleozoic carbonates brought to the surface.

The panel of resistant carbonate above the McConnell Thrust (footwall) is referred to the Middle Cambrian Eldon Formation (about 505 Ma). We will see this formation again

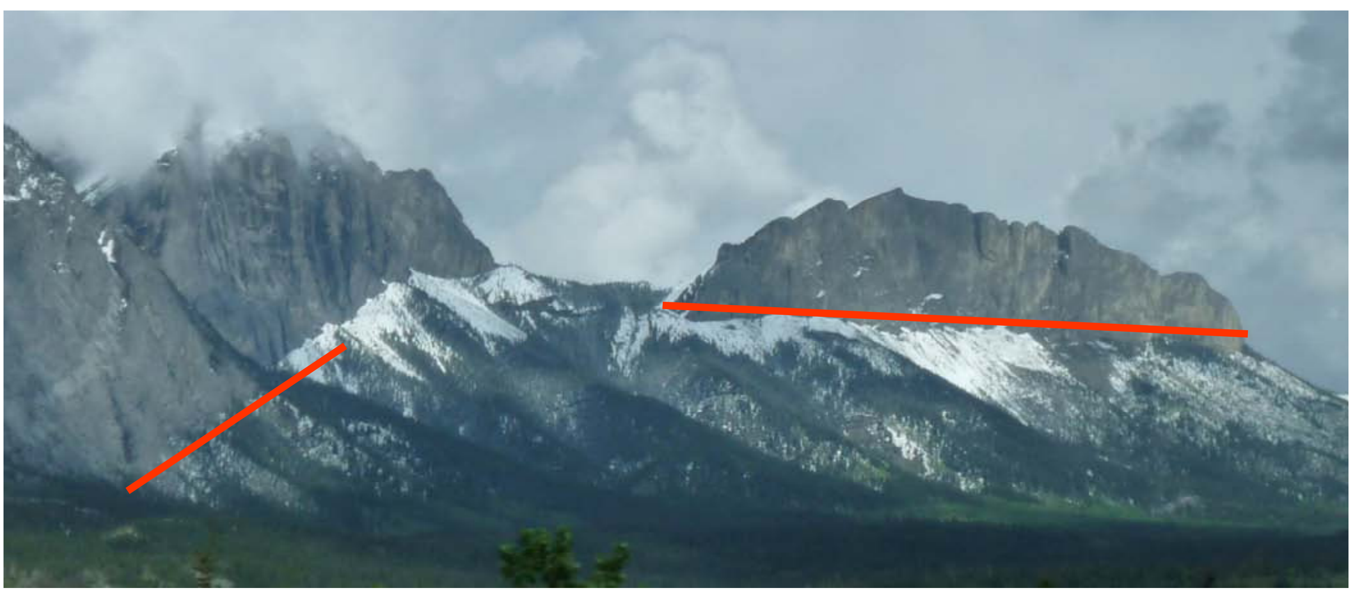


Figure 2. Mt. Yamnuska (red lines are the McConnell Thrust).

at Castle Mountain, Mount Stephen, and Mount Field where the Eldon conformably overlies the Stephen or Burgess Shale formations. However, at Mount Yamnuska they structurally overlie the non-marine to marginal marine siliciclastics of the Upper Cretaceous Belly River Formation (about 80 Ma).

To the west, the McConnell thrust assumes its more normal west dipping profile. Overlying the Eldon Formation is the Middle Cambrian Pika and Arctomys formations that include shale, carbonate, and minor red beds and evaporites. The surface at the top of this Middle Cambrian succession is a major unconformity where much of the Lower Paleozoic succession has been removed prior to deposition of the overlying Upper Devonian Fairholme Group including the Cairn and Southesk formations. The Fairholme Group will be the subject of stop 2-5.

Geologic Setting

The Canadian Rocky Mountains are a world renowned classic example of a fold and thrust belt. Decades of detailed surface and subsurface mapping by government agencies, university researchers and the petroleum industry have provided a good understanding of the geology and structural style of this type of compressional regime and its relationship to the foreland basin.

Four main sequences of rocks comprise the Rocky Mountains:

1.At the base is the 30 –50 kilometre thick North American cratonic plate, which consists of granite and gneisses more than 1500 Ma old; these are called the "basement" because they are not involved in the folding or thrust faulting of this region.

2.An old, Hadrynian to Lower Cambrian (770 – 540 Ma), about 10 km thick sequence of clastic and minor carbonate rocks were deposited on top of the crystalline basement. The rock particles were eroded from the Canadian Shield in the east and carried downstream, westward, to the ocean where Alberta and B.C. are today. These rocks are primarily sandstone, grit, and shale metamorphosed into quartzite and slate by high burial pressures and temperatures. Includes the Pre-Cambrian Miette Group and Cambrian Gog Group.

3.The Middle Cambrian to Upper Jurassic (540 – 155 Ma) rocks in the Banff area are predominantly marine carbonates (limestone, dolostone) and shale and are up to 6.5 km thick. Devonian reefs and Mississippian fossiliferous limestone are the primary oil and gas reservoirs in the Canadian Rockies and the foothills.

4.A younger, upper Jurassic to Tertiary (155 – 1.9 Ma) about 5 km thick clastic wedge of terrestrial siliciclastics and coal was deposited on top of carbonate rocks. Plate tectonic compression and mountain building during the Columbian (175 – 100 Ma) and Laramide (85-45 Ma) orogenies caused uplift and erosion of older rocks in the west and redeposition of sedimentary particles in the foreland basin to the east.

The geology of the Banff area is dominated by thick, ridge-forming panels of rock that were broadly folded and progressively thrust northward over younger rocks during the Laramide Orogeny. Thrust faults trend NW to SE and in cross section they are listric and branch from a decollement above Pre-Cambrian rocks of the North American cratonic basement. The strata have been contracted to approximately 50% of their original length by "thin-skinned" tectonics. Later relaxation and extension caused the development of primarily SW dipping normal faults in the area. Younger rocks are down-dropped relative to older rocks by these normal faults. The large amount of contraction of very thick sequences of rock and the relatively minor amount of extension in the Rockies result in the high elevations. Further modification of the topography by glaciation adds to the complexity of geologic mapping in the region.

79 km; University of Calgary Field Station near Barrier Lake

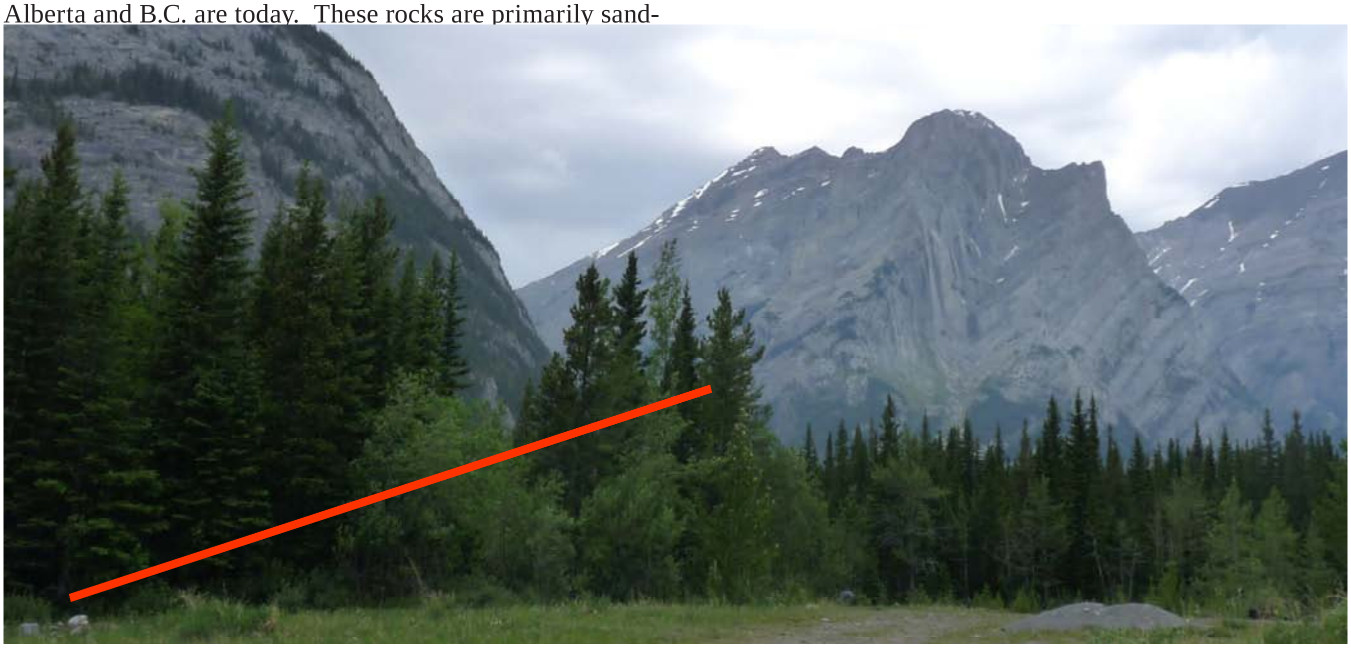


Figure 3. Mt. Kidd (red line represents the Lewis Thrust terminating into a fold pair).

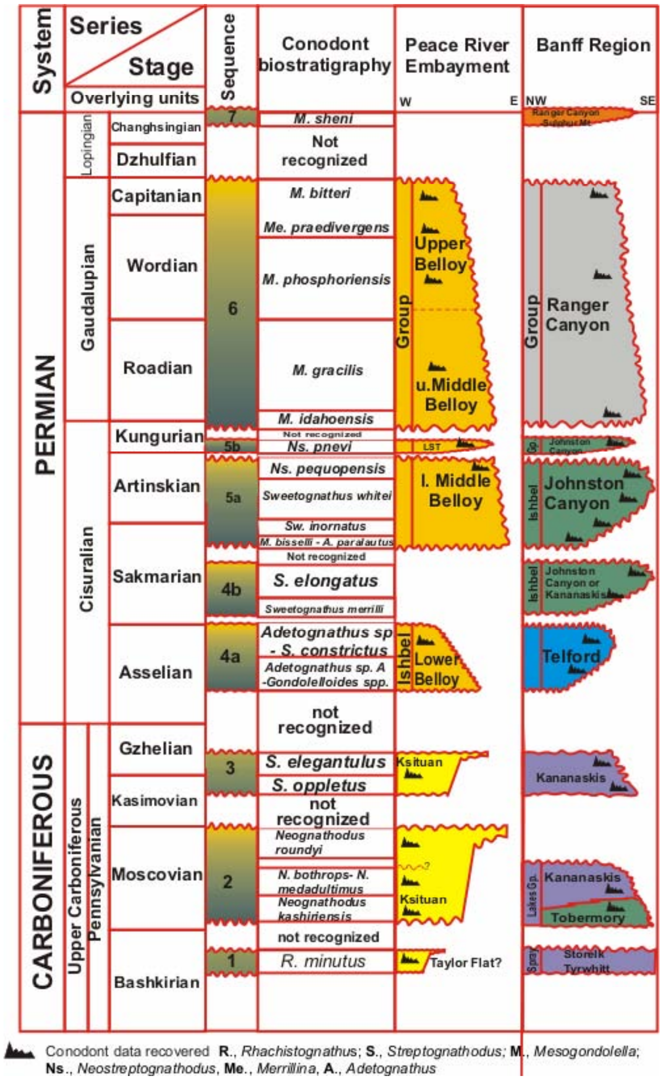


Figure 4. Pennsylvanian and Permian stratigraphy in Western Canada

90 km; Nakiska Ski Hill – site of the alpine events during the 1988 Winter Olympics hosted by Calgary.

Stop 1-1. (104 km) Mt Kidd viewpoint.

This mountain displays a fantastic anticline/syncline pair that represents the termination of the Lewis Thrust Fault (Fig. 3). The rocks exposed on this mountain include the upper Banff Formation, Rundle Group (most of the cliff forming peaks) and some Mt Head Formation at the very top. Our next two stops will include exposures within the Footwall of the Lewis Thrust.

Stop 1-2. (110 km) Fortress Roadcut Section

(50.79237 N; 115.16384 W; 1583 m)

Pennsylvanian and Permian rocks of the Tyrwhitt, Storelk, Tobermory, Kananaskis, Johnston Canyon, and Ranger Canyon formations crop out throughout the Southern Rocky Mountains (Fig. 4). These units comprise a mixed carbonate siliciclastic succession bounded and internally divided by erosional unconformities. Nearly all of these sequences correlate directly to those of the Belloy Formation in the Peace River Basin. This field trip will visit the upper four units of this succession in Kananaskis Valley where numerous, accessible outcrops are present in close proximity (Figure 1). Figure 3 depicts the ages represented by specific units from the Southern Rocky Mountains and their Belloy equivalents. In Kananaskis Valley, the Upper Tobermory, Kananaskis, Johnston Canyon, and Ranger Canyon formations contain carbonate, evaporite, and siliciclastic facies deposited in marginal and shallow marine environments. Wind and ephemeral streams in an arid climate dominated siliciclastic input into the periodically restricted basin (Fig. 5). The overall succession is thin, up to 230 m thick, and major unconformities probably represent little accommodation space on the plat-

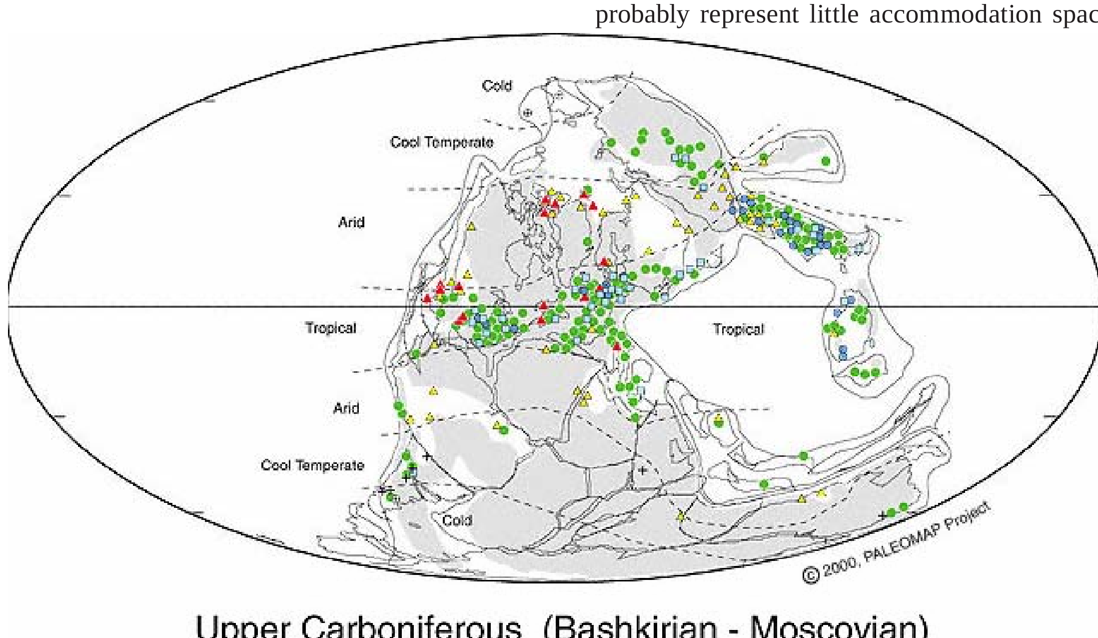


Figure 5. Pennsylvanian paleogeography from Paleomap Project website. Western Canada is in the zone marked with yellow triangles, indicating arid desert conditions.

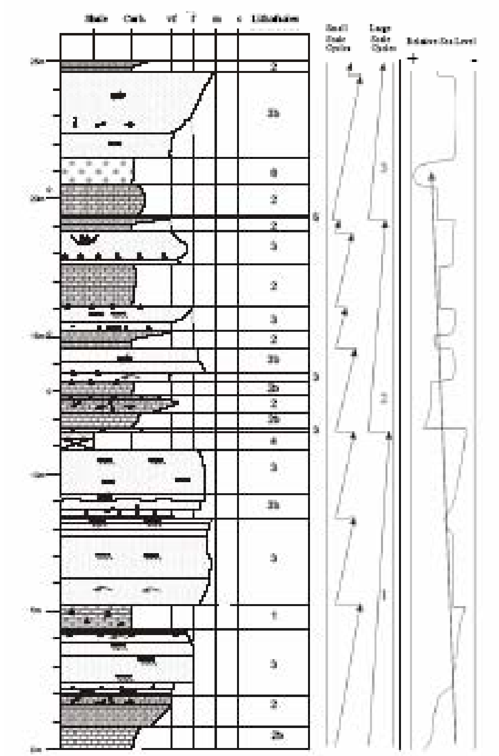


Figure 6. Fortress Ridge section with small scale cycles (3-4 m) and large scale cycles (10 m). C = conodont sample locations.

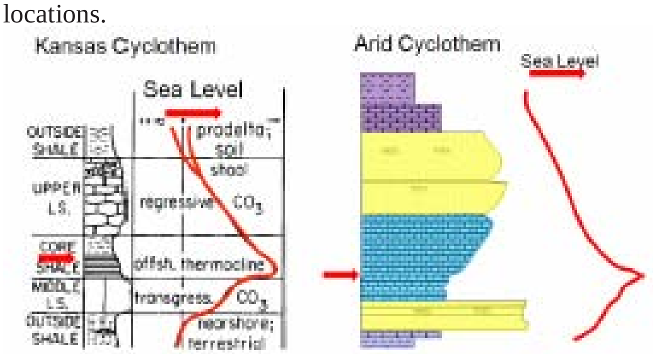
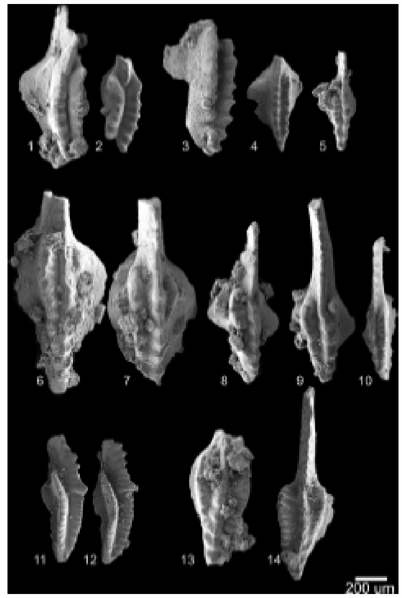


Figure 7. Arid cyclothem model.

form margin. The Johnston Canyon Formation in particular represents a starved continental shelf setting. The general environmental model presented in Figure 6 combines shallow marine systems and sabkha environments. Sabkha, lagoonal, and shoreface to offshore lithofacies are present through deposition of the Tobermory (Fig. 10), Kananaskis, and Johnston Canyon (Figs. 11, 12) formations. Arid cyclothems with a similar periodicity (roughly 100 and 400 ka) to humid cyclothems defined in the U.S. mid-continent (Ross and Ross, 1986) are present in the Tobermory and Kananaskis (Figs. 6, 7) formations. These cyclic, thin sedimentary successions are interpreted as relatively rapid fluctuations in relative sea level and are possibly correlatable with cyclothems in the United States. Figure 7 depicts these arid cyclothems and their southern counterparts; arid cyclothems are subtler than their humid equivalents. Phosphatic lithofacies formed by upwelling along the continental margin dominate the Ranger Canyon Formation where cool water also promoted siliceous



Figures 1-2: *Rhachistognathus minutus declinatus*
Sample: 1141-1
Location: 13.2 m

Figures 3-5: *Idiognathoides postsulcatus*
Sample: 1141-1 (Figure 3,4) and 1141-2 (Figure 5)
Location: 13.2 m (Figure 3,4) and 15.2 m (Figure 5).

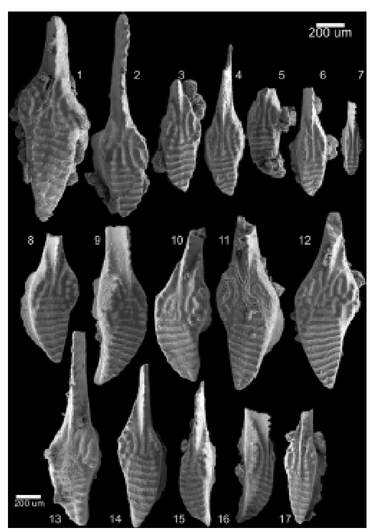
Figures 6-10: *Declinognathodus marginodosus*
Sample: 1141-2
Location: 15.2 m

Figures 11-12: *Adetognathus lautus*
Sample: 1141-2
Location 15.2 m

Figures 13-14: *Neognathodus atokaensis*
Sample: 1141-1 (Figure 14) and 1141-2 (Figure 13)
Location: 13.2 m (Figure 14) and 15.2 m (Figure 13)

200 um scale in lower right corner applies for all samples

Figure 8. From Ford, 2009.



All samples from Fortress Ridge Section

Figures 1-7: *Idiognathodus delicatus*
Sample: 1141-1
Location: 13.2 m

Figures 8-17: *Idiognathodus delicatus*
Sample: 1141-2
Location: 15.2 m

200 um scale in upper right corner applies for all figures except figure 13
200 um scale in lower left corner applies to figure 13 only

Figure 9. From Ford, 2009.

Figure 10. Major transgressive surface (red line) is probably close to the base Moscovian. Closeup to right shows transgressive lag of granules or “grit layer” (19.3 m in Fig. 7), which approximates Tobermory/Kananaskis boundary.

Figure 11.Top part of Fortress Section. Pogo stick is at contact between Kananaskis (below) and Johnston Canyon formations; the contact is the sub-Upper Sakmarian unconformity.

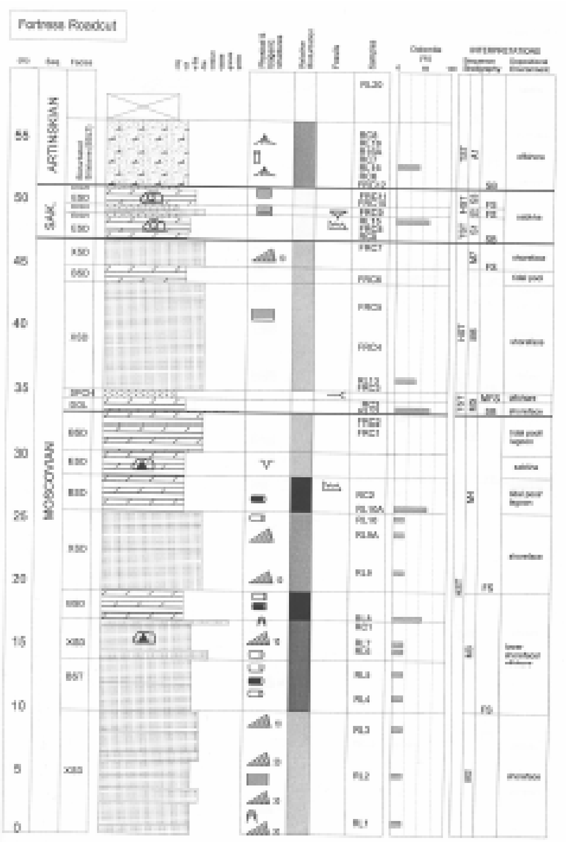


Figure 12. Fortress Roadcut Section.

biologic activity.

Biostratigraphy

Based on the fauna recovered (Figs. 8, 9) this outcrop is determined to be Lower Moscovian in age. This age is primarily based on the species *Neognathodus atokaensis*, *Declinognathodus marginodosus*, and *Idiognathoides postsulcatus*, all of which are found in the lower Moscovian of Eastern Europe. *Neognathodus atokaensis* and *Declinognathodus marginodosus* are both found in the upper Morrowan to Atokan of the USA. *Idiognathodus delicatus* is found in the uppermost Bashkirian to lower Kasimovian of Eastern Europe (Nemyrovska, 1999) and the upper Morrowan to Desmoinesian of NA. Specimens from 13.2 metres are transitional with *I. praedelicatus* suggesting that the lower part of this range is most likely. *Rhachistognathus minutus declinatus* typically is found in the Lower Bashkirian in the Donets Basin, Ukraine, but appears to extend higher in Western Canada or these specimens represent a younger homeomorph.

115 km; on the left side you will see exposures of Lower Triassic rippled shallow marine siltstone and very fine grained sandstone of the Sulphur Mountain Formation exposed near Hood Creek.

119 km; Gates to Highwood Pass; these gates and thus the road are closed from Dec 15 to June 15 each year.

Stop 1-3. (124 km) Opal Creek Section

(50.67542 N; 115.07992 W; 1838 m)

At this stop we will examine the upper Kananaskis, Johnston Canyon, Ranger Canyon, and lower Sulphur Mountain formations (Fig. 13). A 500m hike along Opal Creek is required to reach the base of the section. Here, surfaces representing the contacts between the Kananaskis and Johnston Canyon formations, and the Johnston Canyon and Ranger Canyon formations are easily visible. The Ranger Canyon – Sulphur Mountain contact is sharp. At this location, resistant chert beds of the Ranger Canyon Formation form prominent bedding plane surfaces, the top of which is juxtaposed with the recessive, silty shale beds of the lower Phroso Member of the Sulphur Mountain Formation (Figure 14). Shale of the Phroso Member constitutes a latest Permian to Early Triassic sequence, the basal transgressive beds being of latest Permian (Changhsingian) age and the base of the Griesbachian occurring 1.5m above (Figure 15). The upper sequence boundary occurs within the Vega Siltstone Member and is Dienerian in age; six parasequences have been recognized from this sequence at this locality (Figure). The contact between the Phroso and Vega members of the Sulphur Mountain Formation occurs at 38 m above the base of the Phroso. Here, brown weathering siltstone and very fine-grained sandstone overlie black silty shale; the contact is transitional. Simple horizontal burrows and rare tool marks are visible on the soles of many of the sandstone beds. Higher up, trace fossils exhibiting more complex behaviours, such as

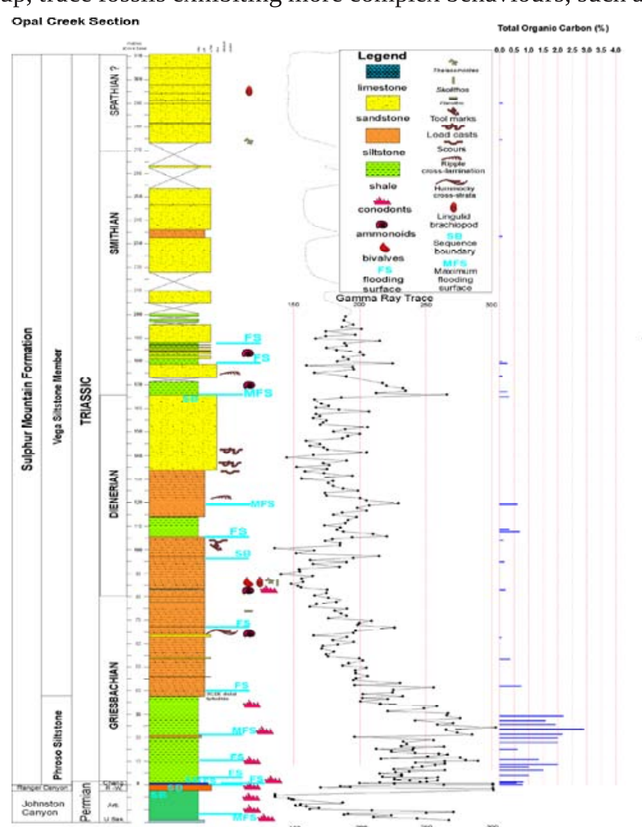


Figure 13. Opal Creek Section from Lower Permian Johnston Canyon Formation to upper Lower Triassic Sulphur Mt. Formation.

Figure 14. Base of Opal section showing contact between Middle Permian Ranger Canyon Formation and latest Permian and Lower Triassic Sulphur Mountain Fm.

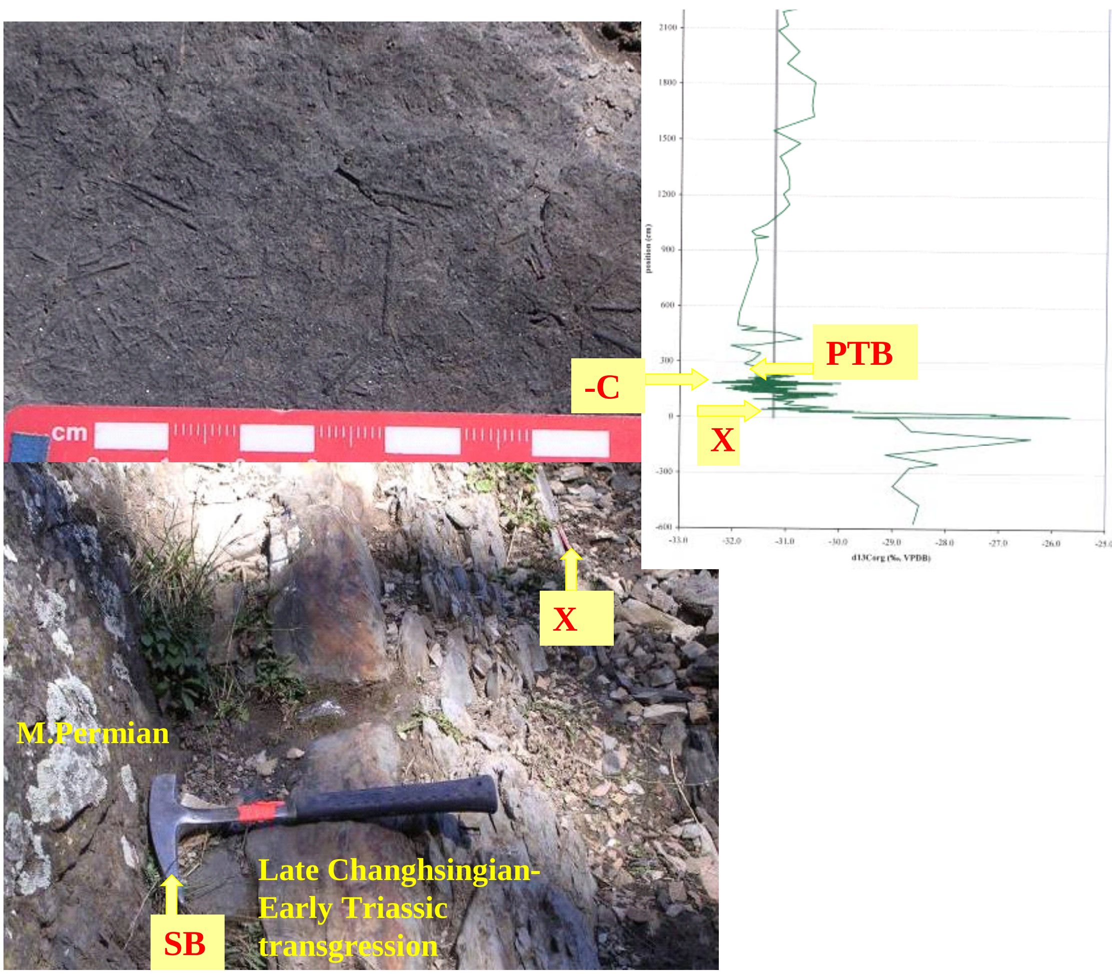


Figure 15. Details at PTB showing sequence boundary, extinction and C-isotope anomaly.

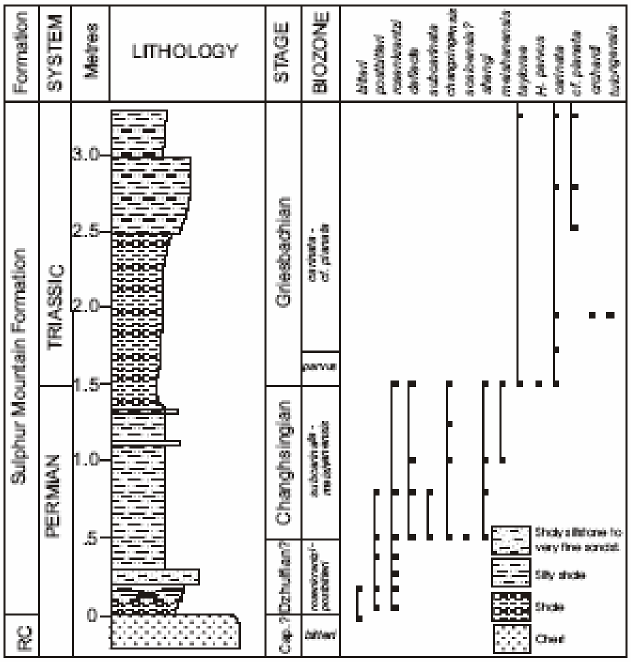


Figure 16. Biostratigraphy at the boundary (from Henderson, 1997).

Diplocraterion, Thalassinoides and *Lockiea*, become more common. Ripples, and rarely, hummocky cross-stratified beds, are present throughout the Vega Member. Loading features become more common upsection in upper Dienerian strata. The Dienerian – Smithian boundary coincides with a flooding surface (166 m, Figure 17) marking the initiation of a subsequent sequence. Above this, strata of Smithian and probable Spathian age constitute a progradational succession representing the regressive portion of this sequence. The sequence presumably ends with the Anisian transgression which coincides with the Lower – Middle Triassic boundary.

Permian – Triassic Boundary (252.2 Ma) (Figs 14-16)

The Permian – Triassic Boundary in western Canada is generally correlated in outcrop with the lithologic contact between the Upper Permian Ranger Canyon, Mowitch, or Fantasque formations and the Lower Triassic Grayling Formation or Phroso Siltstone of the Sulphur Mountain Formation. In the subsurface of the Peace River Embayment, this lithologic contact is typically between the Belloy Formation (Moscovian to Upper Permian) and the Montney Formation. The biostratigraphic boundary has recently been ratified and is designated as the first appearance of the conodont species *Hindeodus well parvus*. In outcrop of the Western Canadian Sedimentary Basin, *H. parvus* occurs 1.5

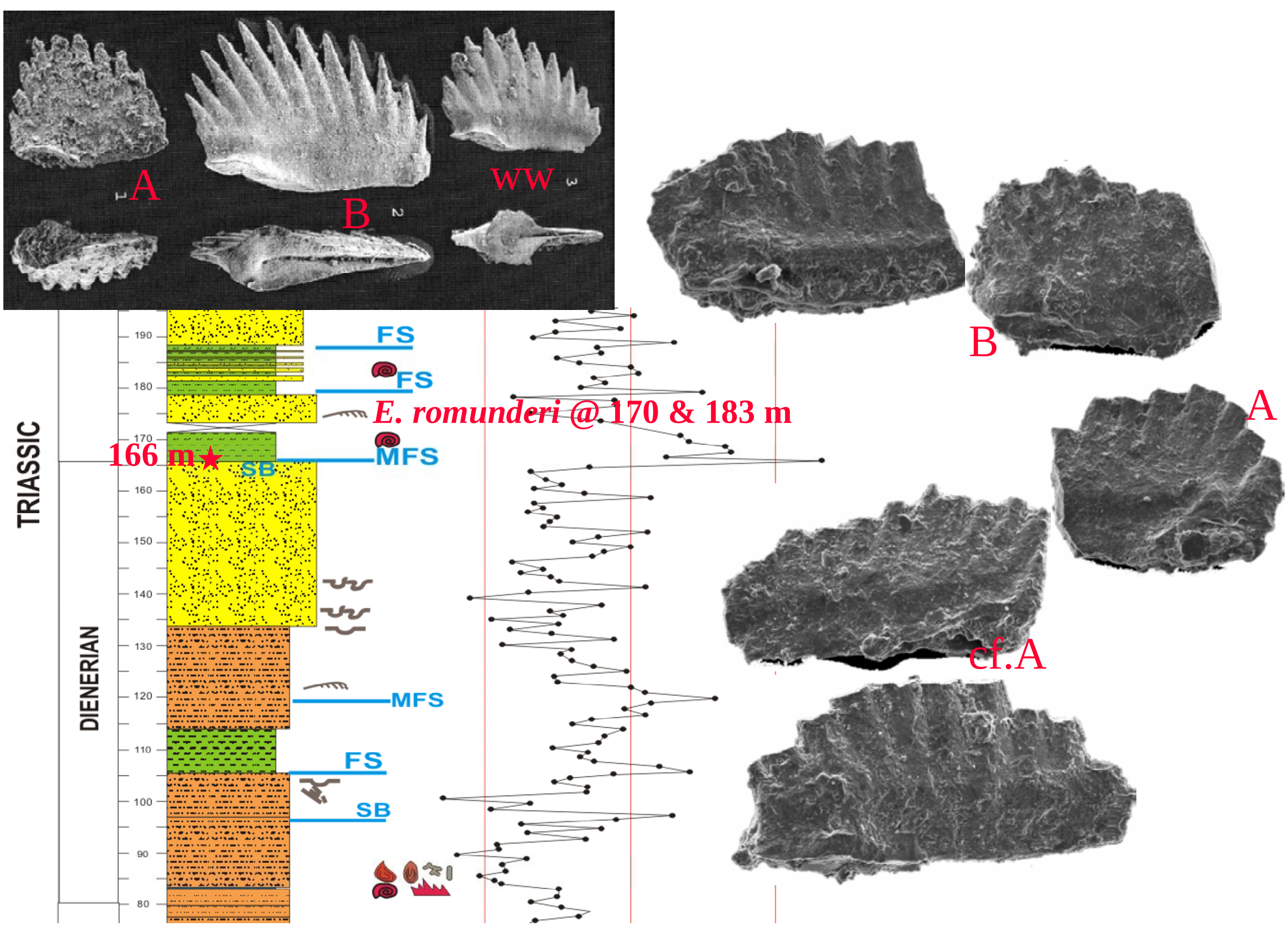


Figure 17. Base-Smithian (base-Induan) part of the section at Opal Creek.

m above the lithologic boundary and is preceded by conodonts of latest Permian age (Figure 16). This association holds true for Permian – Triassic Boundary strata in the Canadian Arctic, which implies that the biostratigraphic boundary post-dates the lithostratigraphic boundary (Henderson and Baud, 1997). Transgressive facies of the basal Montney, Grayling, or Sulphur Mountain formations comprise black to dark grey, thin-bedded shale and siltstone with rare silty limestone, dolostone and very fine-grained sandstone (Gibson and Barclay, 1989). In many areas, a transgressive, phosphatic pebble conglomerate marks the base of this succession. Fossils are rare in these strata and this lack of biota in addition to the preponderance of authigenic pyrite is suggestive of anoxic to dysoxic conditions.

Lower Triassic

Strata of the Lower Triassic differ markedly from those of the Upper Paleozoic. Siliciclastic sediments dominate most environments, likely a result of diminished biogenic carbonate and silica. Rapid climate change resulting in a shift from a cold partially glaciated conditions on the northwestern margin of Pangea to warm, arid conditions. The Phroso Member of the Sulphur Mountian Formation comprises planar laminated silty shale and rare ripple laminated siltstone; at Opal Creek it is just under 40 m thick. The distinguishing characteristic features of the Phroso Siltstone Member are: black colour, lack of any burrowing or bioturbation and the general lack of sedimentary structures other than the previously mentioned laminae. A few poorly preserved ammonite impressions have been collected at the Opal Creek locality. In contrast, the overlying Vega Siltstone Member of the Sulphur Mountain Formation includes brown weathering, occasionally burrowed, often rippled, very fine-grained sandstone and siltstone. This unit is sparsely fossiliferous, including ammonoids, bivalves, and fish remains. At the Opal Creek locality, the Vega Member encompasses Late Griesbachian to probable Spathian age. Conodont data from the Opal Creek section has aided in the identification of the Griesbachian-Dienerian and Dienerian-Smithian boundaries. Here, as elsewhere in the Western Canadian Sedimentary Basin, the Dienerian-Smithian boundary coincides with a flooding surface (Fig. 17) and the introduction of various subspecies of *Neospathodus waageni*. Interregional correlations as well as facies associations have led some workers to invoke a tectonic origin for this boundary. The depositional environment of the Opal Creek and Hood Creek sections ranges from distal offshore to lower shoreface. Tempestites are common in the lower Vega, substantiated by the preponderance of thin hummocky cross-stratified sandstone beds. Siltstone beds in the Phroso may be their distal equivalents. Higher up in the Vega member, loading and soft sediment deformation features are present, suggestive of an oversupply of sediment deposited on a somewhat steepened slope. The arid, storm dominated conditions invoked for much of the Triassic were likely established by the Griesbachian (Gibson and Barclay, 1989).

132 km; Turn onto Spray Lake Road (64 km of gravel to Canmore)

134 km; excellent view of the Opal Range on left

161 km; Buller Mountain; notice the Pine Beetle damage.

168 - 178 km; Spray Lakes and Spray Lakes Dam.

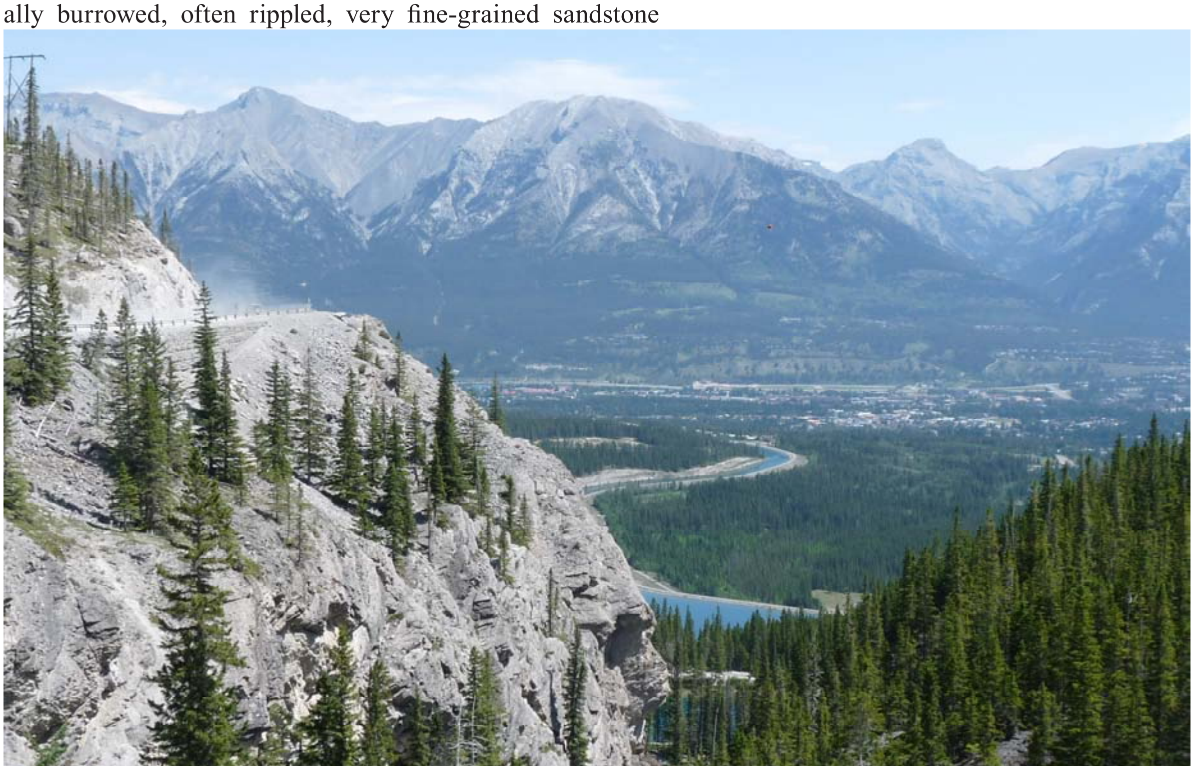


Figure 18. Photo at top of Grassi Lake trail looking north at the Canmore and the Bow Valley.

Stop 1-4. Goat Creek

Discuss Palliser, Exshaw and Banff formations overview.

Stop 1-5. Grassi Lakes

(from this point seen in Fig. 18) we will walk down through the Fairholme Group rocks (Upper Devonian stromatoporoid reef interval) to Grassi Lakes and pick up the bus again at the bottom.

The Late Devonian (Frasnian) section at Grassi Lakes, approximately 4 kilometres southwest of Canmore, Alberta, provides an excellent overview of the internal paleontologic, stratigraphic and sedimentological features of the reef complexes that were prevalent in this part of the world at this time. These strata occur on the Rundle thrust sheet above the thrust fault of the same name, along with underlying Middle Devonian and Cambrian strata and overlying other Late Devonian to Triassic strata. These rocks are thrust over Jurassic and Cretaceous rocks (Fig. 18 for day 2. See page 38).

Most of the section examined represents deposition in the interior of the Fairholme reef complex, one of the many reef complexes that grew in western Alberta and eastern British Columbia (Fig. 19) during a time of transgression in the Frasnian (Geldsetzer, 1987; Switzer *et al*., 1994; Potma *et al*., 2001). Between the reef complexes, basinal sedimentation occurred (Figs. 19 and 20). The upper part of the section represents carbonate platform strata that were deposited during both transgression and regression, with progradation of these platformal strata into the adjacent basinal areas (Figs. 19 and 20). Underlying Late Devonian strata, mostly covered at Grassi Lakes, represent diachronous deposition (Fig. 20) of carbonate platform strata on the West Alberta Arch, a paleogeographic feature that extended approximately 600 km northwestward to the Peace River region of northern Alberta (Geldsetzer and Mallamo, 1991). It is upon these carbonate platform strata that the reef complexes grew (Geldsetzer, 1987; Switzer *et al*., 1994).

On the fieldtrip, participants will be examining the Frasnian upper part of the Cairn Formation and the lower part

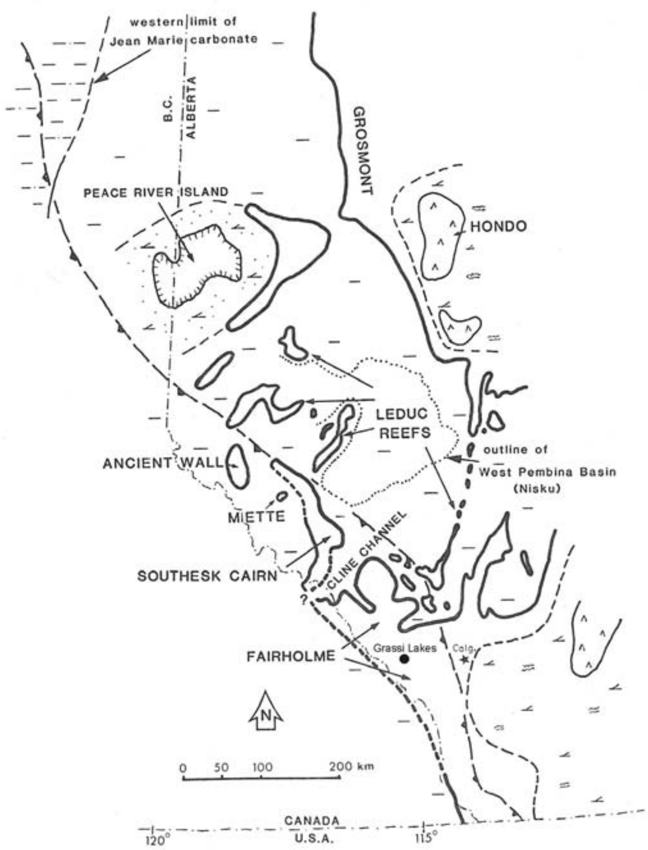


Figure 19. Map showing Late Devonian (Frasnian) reef complexes with location of Grassi Lakes section indicated (modified from Geldsetzer, 1987).

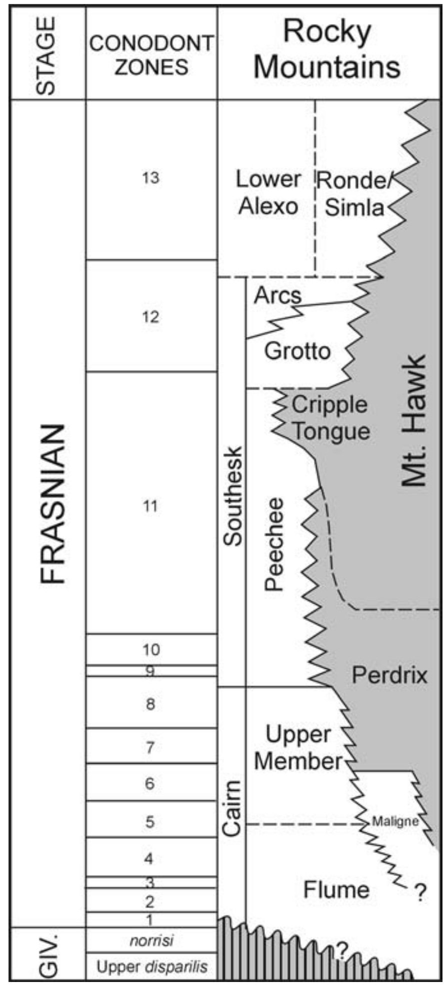


Figure 20. Correlation of Frasnian Montagne Noir conodont zones with plaformal/reefal and basinal strata in the Alberta Rocky Mountains (after McLean and Klapper, 1998). Base of zones defined on first appearances of *Polyganthus dengleri* (Upper *disparilis* Zone), *Skeletognathus norrisi* (*norrisi* Zone), *Ancyrodella rotundiloba* early form (Zone 1), *A. rotundiloba* late form (Zone 2), *A. rugosa* (Zone 3), *Palmatolepis transitans* (Zone 4), *P. punctata* (Zone 5), *Ancyrognathus primus* (Zone 6), *Ozarkodina nonaginata* (Zone 7), *Palmatolepis aff. P. proversa* (Zone 8), *P. proversa* (Zone 9), *P. domanicensis* (Zone 10), *P. jamieae* (Zone 11), *P. winchelli* (Zone 12) and *P. bogartensis* (Zone 13) (Klapper, 1997).

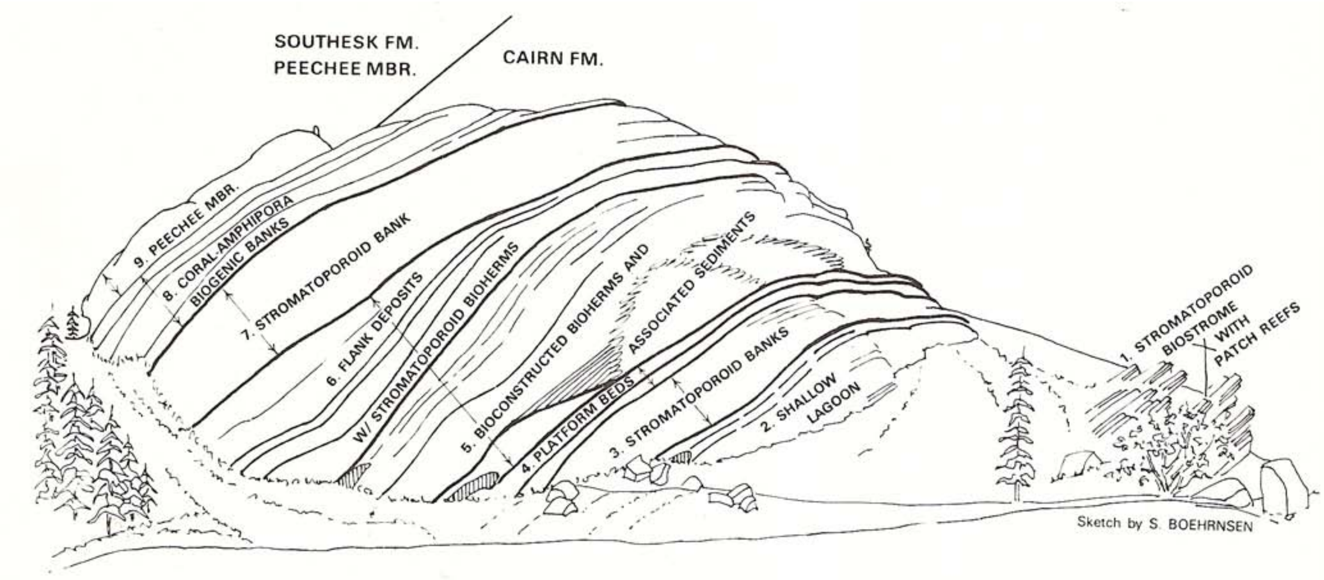


Figure 21. Line diagram of lower part of Grassi Lakes section showing major depositional units (see Fig. 23, Geldsetzer, 1987 and references therein)

of the Southesk Formation (Figs. 20-23). The entire section is dolomitized, although many primary depositional features are still visible. The Cairn Formation has been informally subdivided into a lower Flume and an upper Cairn member and the Southesk Formation is divided into three members, which are, in ascending order, the Peechee, Grotto and Arcs members (Geldsetzer, 1987; Geldsetzer and Mallamo, 1991; Figs. 20-23). Only the lower two members of the latter formation will be examined on this fieldtrip. The total thickness of exposed Cairn Formation at Grassi Lakes is about 170 m whereas the total thickness of exposed/measured Southesk Formation is about 110 m (Geldsetzer, 1987; Fig. 23).

The informal upper Cairn member of the Cairn Formation consists of alternating laminated and massive beds of dolostone (Geldsetzer, 1987). The laminated beds contain a few *Amphipora* or small stromatoporoids. The massive beds con-

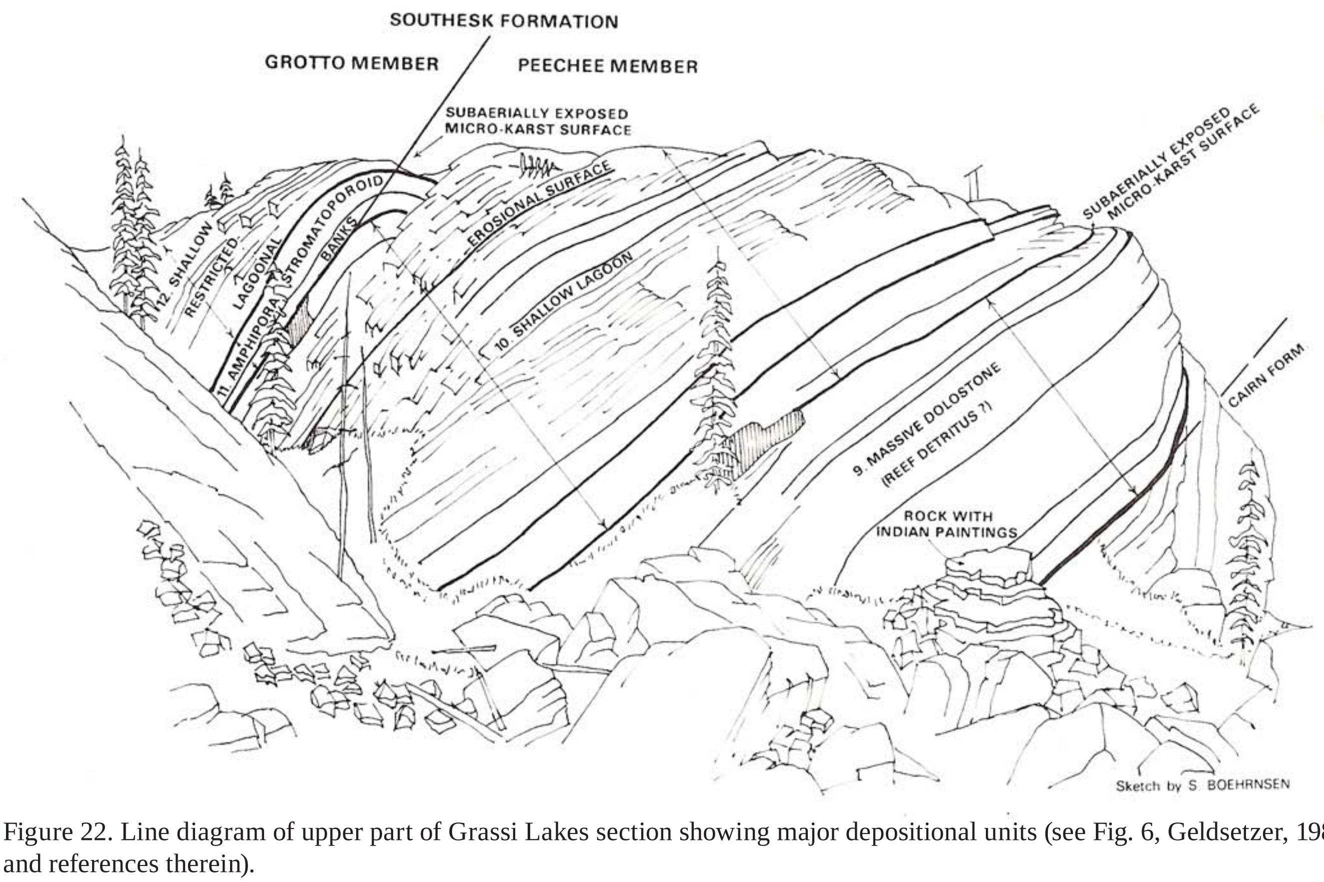


Figure 22. Line diagram of upper part of Grassi Lakes section showing major depositional units (see Fig. 6, Geldsetzer, 1987 and references therein).

sist mainly of stromatoporoids, in which many are leached in the middle. The overall depositional environment of the upper Cairn member is interpreted as restricted lagoonal grading upwards into coral-stromatoporoid bank facies (Geldsetzer, 1987; Figs. 21 and 23). The lower Flume member, which may be represented by the lowest outcrop that occurs below the covered interval (Figs. 21 and 23), consist of alternating light and dark grey weathering dolostone. This unit is more silty and argillaceous towards the base, and is occasionally laminated. Chert occurs in the upper part (Geldsetzer, 1987). The lower Flume member is interpreted as a stromatoporoid biostrome with patch reefs (Figs. 21 and 23).

The Peechee Member overlies the Cairn Formation (Figs. 20-23). The lower part of this member consists of light grey, slightly argillaceous, medium to coarsely crystalline, massive dolostone and black, slightly argillaceous, medium crystalline, dolostone with corals and gastropods (Geldsetzer, 1987; Fig. 23). The upper Peechee Member is light grey, coarsely crystalline, porous, massive dolostone. The upper contact with the overlying Grotto Member is undulatory and irregular (Geldsetzer, 1987; Fig. 23). The depositional environment of the Peechee Member represents an interval of reef detritus that is followed by shallow lagoonal conditions, within an interior reef setting (Geldsetzer, 1987; Geldsetzer and Mallamo, 1991; Figs. 22 and 23).

The overlying Grotto Member is a grey to black, medium to coarsely crystalline, medium to thick bedded, occasionally massive, commonly vuggy dolostone. There is abundant *Amphipora* and corals at both the base and top of the member. The upper contact with the overlying Arcs Member is sharp (Geldsetzer, 1987; Fig. 23). The interpreted depositional environment for the Grotto Member is an *Amphipora*-stromatoporoid bank followed by a shallow, restricted lagoon (Figs. 22 and 23). This member along with the overlying Arcs Member represent deposition of carbonate banks that prograded into adjacent shale basins (Fig. 19). The latter member, mostly covered above the section examined here, is a light grey, thick bedded to massive, dolostone with the massive beds vaguely bedded in places, with few *Amphipora* at the base. Vugs occur on weathered surfaces of the massive beds (Geldsetzer, 1987). Better exposures occur along the Spray Lakes road (Geldsetzer, 1987; Geldsetzer and Mallamo, 1991).

Several unconformities occur throughout this sequence (Figs. 22 and 23), in the form of karst surfaces, that indicate periods of subareal exposure (Geldsetzer, 1987; Geldsetzer and Mallamo, 1991).

The basinal equivalents of the plaformal/reefal Cairn and Southesk strata are the Flume, Maligne, Perdrix and Mount Hawk formations (Fig. 20), which are exposed at the edge of the Fairholme reef complex to the west and northwest of the Grassi Lakes section. These units are argillaceous, fossiliferous carbonates and shales (Geldsetzer, 1987; Geldsetzer and Mallamo, 1991; Mallamo and Geldsetzer, 1991).

The Southesk Formation is overlain by the Alexo Formation in the Banff area. The Alexo is overlain in turn by the Palliser Formation (Geldsetzer, 1987; Geldsetzer and Mallamo, 1991;

Figure 23. Stratigraphic description of Grassi Lakes section (Geldsetzer, 1987 and references therein).

Meijer Drees et al., 1993; Meijer Drees and Johnston, 1994). Briefly the Alexo Formation consists of siltstone overlain by silty dolostone and limestone interbedded with siltstone and shale, with breccia and slump structures. These lithologies are overlain by laminated dolostone (Geldsetzer, 1987; Meijer Drees *et al*., 1993). The Palliser Formation consists of a basal dolostone unit overlain by burrow-mottled dolomitic limestone throughout most the formation (Geldsetzer, 1987; Meijer Drees *et al*., 1993; Meijer Drees and Johnston, 1994). The upper part of the Palliser Formation consists of fossiliferous, occasionally nodular, limestone (Richards *et al*., 1994).

Conodont Biostratigraphy

Due to most of the Frasnian platformal/reefal strata being dolomitized, conodonts from these strata are generally rare in the fieldtrip area. However, a few were recovered from presumably upper Flume Member strata of the Grassi Lakes section (see above). The conodonts recovered were (Geldsetzer and Mallamo, 1991; Uyeno, 1991):

Icriodus expansus Branson and Mehl
Pandorinellina cf. *P. insita* Stauffer
Polygnathus cf. *P. dubius* Hinde
P. xylus xylus Stauffer

The following conodonts were recovered from the Flume Member of the Cairn Formation at the southeastern end of Mount Rundle. This section is above the Spray Lakes road, west of the Grassi Lakes section (Geldsetzer and Mallamo, 1991; Uyeno, 1991):

Icriodus subterminus Youngquist
Pandorinellina insita Stauffer
Polygnathus sp. indet.

Although the conodonts listed here are long ranging, the Flume Formation/Member is dated, utilizing data from other localities in the Rocky Mountains, as ranging from the Middle Devonian (Givetian) Upper *disparilis* to Upper Devonian Montagne Noire Zone 5 (Uyeno, 1991; McLean and Klapper, 1998; Fig. 20).

No other conodonts were recovered from the remainder of the Cairn and Southesk formations in the fieldtrip area, although they were recovered from both reef margin and basinal strata on the west side of the Fairholme reef complex (Mallamo and Geldsetzer, 1991; Uyeno, 1991; McLean and Klapper, 1998).

191 km: Parking lot for Grassi Lakes just below the Olympic Nordic Centre.

195 km; Exposure of coal and sandstone of Jurassic-Cretaceous boundary Kootenay Group as we turn toward Canmore. Mining of similar coal deposits from this area is the reason for the town of Canmore. Just before you reach Canmore, the site of the 1988 Winter Olympic Nordic events, you will see a turn-off for the Three Sisters Development. This development was delayed for years in the courts, as once again developers battled environmentalists for prime wildlife corridors. A compromise was reached which saw the developers swap land in the Wind Valley (a prime wildlife corridor due to its “montane grassland” ecosystem) for other land in the same area. Montane grassland is important for wildlife, as it provides grazing land at low elevations during the winter. This is particularly important for ungulates such as elk and deer and their predators such as wolves. Unfortunately, montane grassland is quite rare. Perhaps unfortunately, humans also seem to desire it due to its location at low elevations and access to our own transportation corridor, the highway.

As you continue down the highway near Canmore, you will see three peaks that are clustered together. Probably the most well-known peaks in the region, they are called the Three Sisters. The peaks are known locally as Faith, Hope, and Charity. As we drive past the Banff National Park gates we will enjoy the views of Cascade Mountain in front and Mount Rundle on the left of the bus. As we approach Cascade Mountain we will see an overturned succession of rocks of the Fernie and Kootenay formations (Upper Jurassic to Lower Cretaceous). These rocks represent a transition from relatively deep marine to terrestrial deposits. Coal within the Lower Cretaceous Kootenay Formation represented the initial economic fuel behind Canmore; today it is tourism. These rocks have been overturned in the footwall (below a fault) of the Rundle Thrust. The Rundle Thrust traces along the base of Cascade and Rundle Mountains. On both of these mountains a tripartite subdivision of Upper Devonian and Lower Carboniferous rocks (365 to 325 Ma) can be seen including resistant grey cliffs of the Upper Devonian Palliser Formation limestone at the bottom overlain by brown recessive rocks of the Lower Carboniferous Banff Formation (mixed siliciclastics and carbonates) and topped by the resistant cliff forming limestone of the Rundle Group.

199 km; Back onto Highway #1. Notice the Three Sisters behind and to the left – they are locally known as Faith, Hope and Charity.

205 km; Gates to Banff National Park. As we travel toward Banff you will see the prominent Cascade Mountain directly in front of us and a prominent panel of Palliser-Banff-Rundle rocks to the left, all in the hanging wall of the Rundle Thrust.

213 km; Exposures of Hoodoos on the right hand side.

216 km; Overturned exposures of the Kootenay and Fernie groups in the footwall of the Rundle Thrust.

217 km; Turn-off to Lake Minnewanka and Banff.

221 km; Banff townsite

224 km; Banff Centre (end of Day 1)

Day 2 (morning): Carboniferous sequence stratigraphy, biostratigraphy, and basin development in the vicinity of the Bow corridor, southwestern Alberta

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Introduction And Geological Setting

In southwestern Alberta parautochthonous, Famennian and Carboniferous strata are magnificently displayed in the multiple, southwest-dipping thrust sheets of the western Foothills and Front Ranges of the Rocky Mountains (Fig. 1). The Famennian strata occur in the Alexo, Palliser and lower Exshaw formations and were deposited on the western Alberta Shelf (Fig. 2). The Carboniferous succession, represented by the upper Exshaw and Banff Formation and the Rundle and Spray Lakes Groups, was deposited in eastern Prophet Trough (Fig. 3). The Famennian and Carboniferous package lies within the Western Canada Sedimentary Basin (WCSB), an immense wedge of sedimentary rocks that thickens westward from a zero edge on the Canadian Shield into the Rocky Mountain Fold and Thrust Belt of the eastern Cordillera (Porter *et al*., 1982; Ricketts, 1989).

This component of the guidebook for post-conference trip 1 is designed for the late afternoon of day 1 and most of day two and provides an overview of the Famennian to Upper Carboniferous succession along an east to west transect through the Rocky Mountain Front Ranges near the towns of Exshaw, Canmore and Banff west of Calgary. Information in the guidebook is summarized from a guidebook prepared by Richards *et al.* (2005) for the AAPG Annual Convention held in Calgary from June 19-22, 2005. In the region, a thick carbonate-dominated upper Famennian to Mississippian succession (Fig. 4) and a somewhat thinner sandstone-dominant

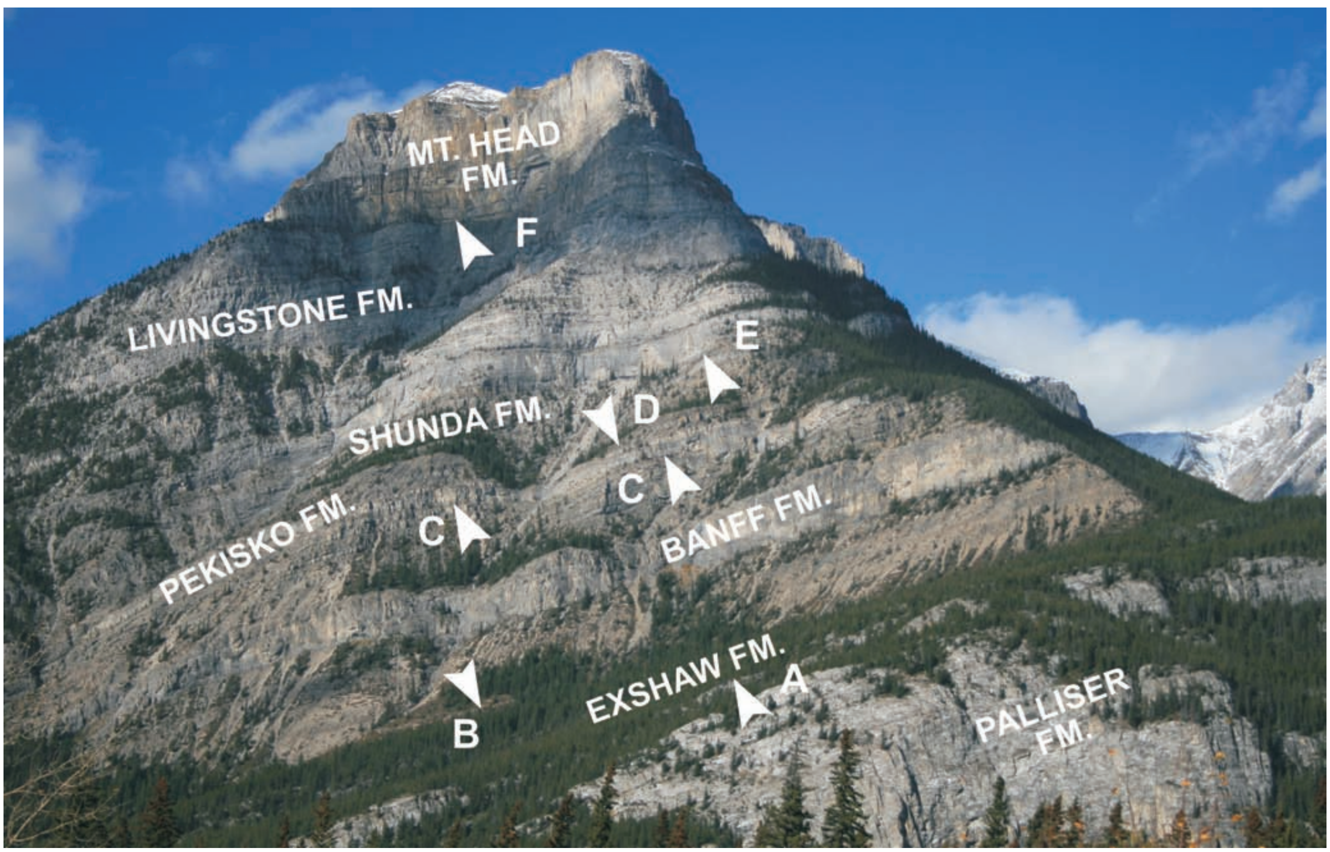

Figure 1. Upper Devonian and Lower Carboniferous succession at Grotto Mountain, Fairholme Range, eastern Rocky Mountains near town of Exshaw, Alberta. A- top of Famennian Palliser Formation and base Famennian and Tournaisian Exshaw Formation; B- top Exshaw and base of Tournaisian Banff Formation; C- approximate base of Tournaisian Pekisko Formation; D- base Tournaisian Shunda Formation; E- base of upper Tournaisian and lower Viséan Livingstone Formation; F- base of Viséan Mount Head Formation. View is toward northwest from Highway 1 (stop 2-11).

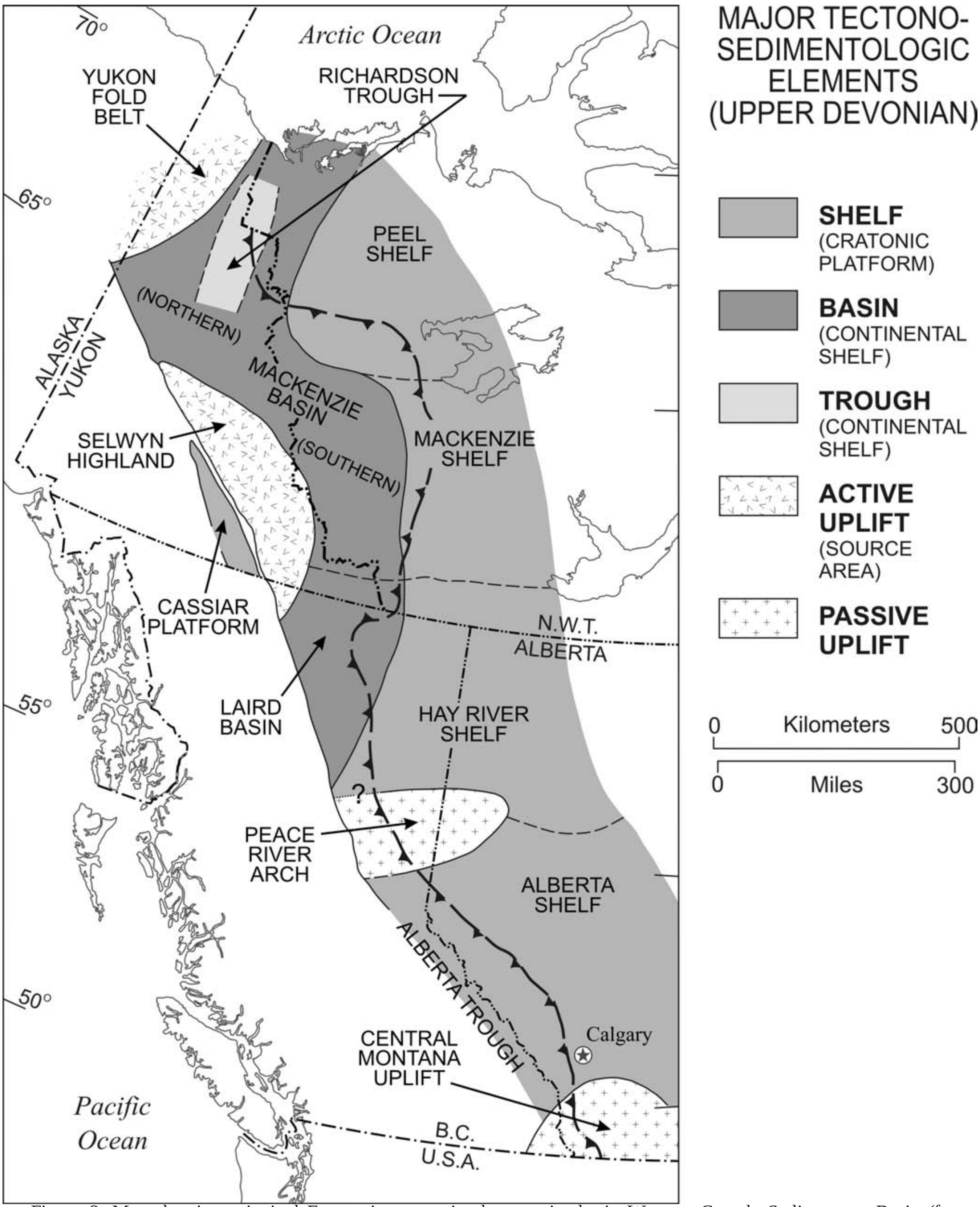

Figure 2. Map showing principal Famennian tectonic elements in the in Western Canada Sedimentary Basin (from Morrow and Geldsetzer, 1988).

Pennsylvanian package are well exposed and structurally repeated in several thrust sheets. The fieldtrip is multi-disciplinary in scope but emphasis will be on lithostratigraphic relationships, depositional origins of the diverse array of cool- to warm-water-tropical carbonate and siliciclastic lithofacies constituting the numerous transgressive/regressive

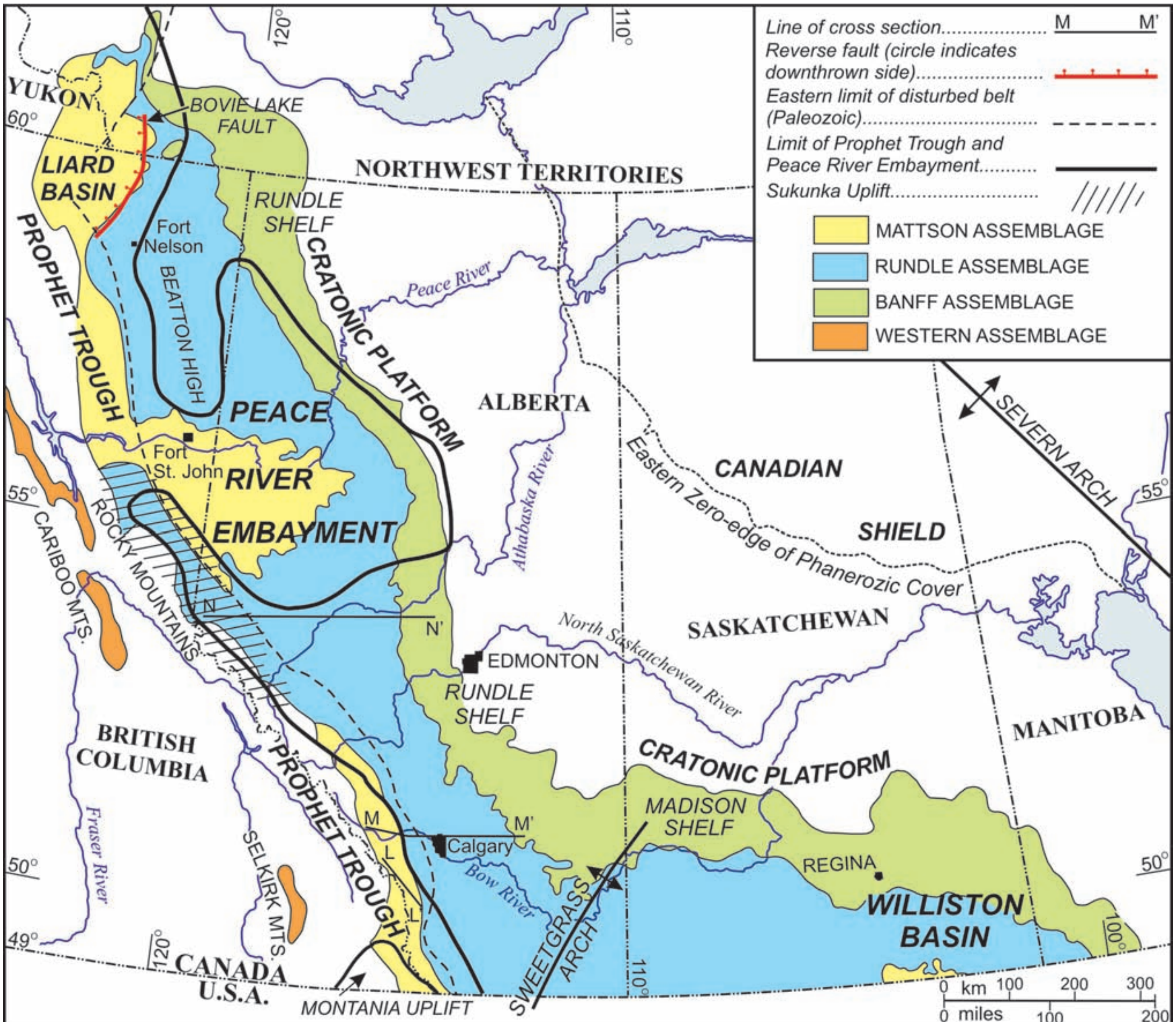

Figure 3. Map showing Carboniferous units subcropping beneath Permian and Mesozoic deposits in the Western Canada Sedimentary Basin, tectonic elements and three lines of cross-section. See Figure 12 for formational composition of Banff, Rundle and Mattson assemblages (from Richards et al., 1994a).

(T-R) sequences, and the biostratigraphy of conodonts. The focus of the late afternoon of day 1 and day 2 will be the Famennian and Mississippian (Tournaisian) carbonates and black shale along Jura Creek near the town of Exshaw and on Mount Rundle. In addition, Mississippian platform and ramp carbonates and Pennsylvanian (Bashkirian and Moscovian) sandstone and carbonate exposures will be examined briefly in the Front Ranges along Cougar Creek by Canmore.

Paleotectonic Setting

Famennian tectonic elements

During the Famennian, the principal tectonic elements in the southwestern part of the WCSB were the cratonic platform, Peace River Arch, and Alberta Trough (Fig. 2). The characteristics and Famennian tectonic histories of these elements were outlined by Douglas *et al.* (1970) and Morrow and Geldsetzer (1988). A contractional belt, episodically uplifted and intruded from the Middle Devonian into the Early Mississippian, lay along the southwestern side of the basin, which was probably in part a compressional foreland basin during the Famennian and Early Mississippian (Root, 2001; Richards, 1989; Rubin *et al*., 1990; Smith and Gehrels, 1992; Smith *et al*., 1993).

The cratonic platform was a broad, relatively stable region dominated by shallow-marine environments, but water depths generally increased southwestward, and slope environments were established along its southwestern edge. In the south, the cratonic platform has been differentiated into the Alberta and Hay River shelves, separated by the Peace River Arch (Morrow and Geldsetzer, 1988). The latter, extensively exposed during the Frasnian and early Famennian, was largely transgressed by late Famennian time. The Famennian Palliser Formation (Fig. 5) at Jura Creek and on Mount Rundle was deposited on the southwestern part of the cratonic platform.

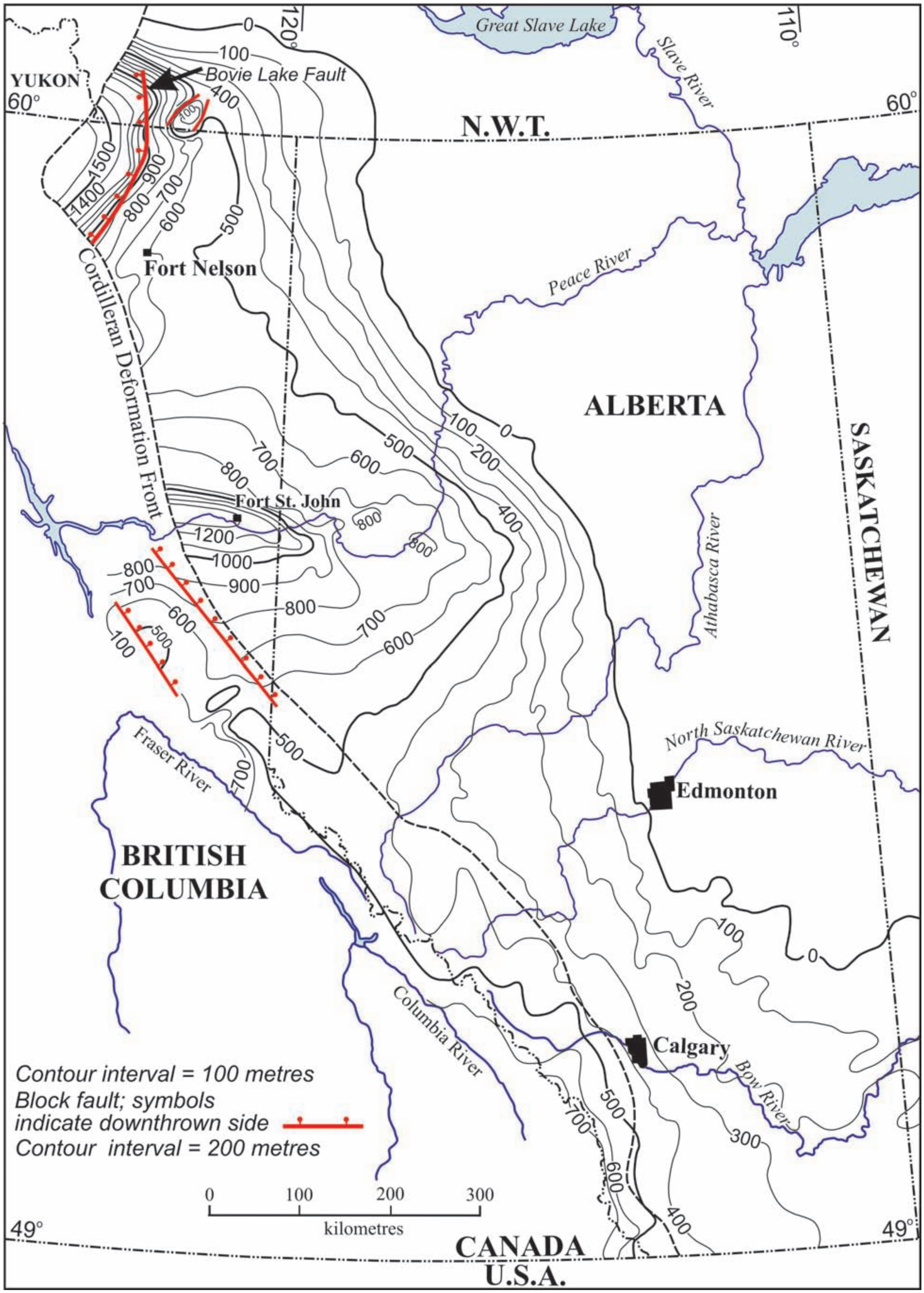

Figure 4. Isopach and distribution map for Mississippian succession, in Western Canada Sedimentary Basin (Richards et al., 1994a).

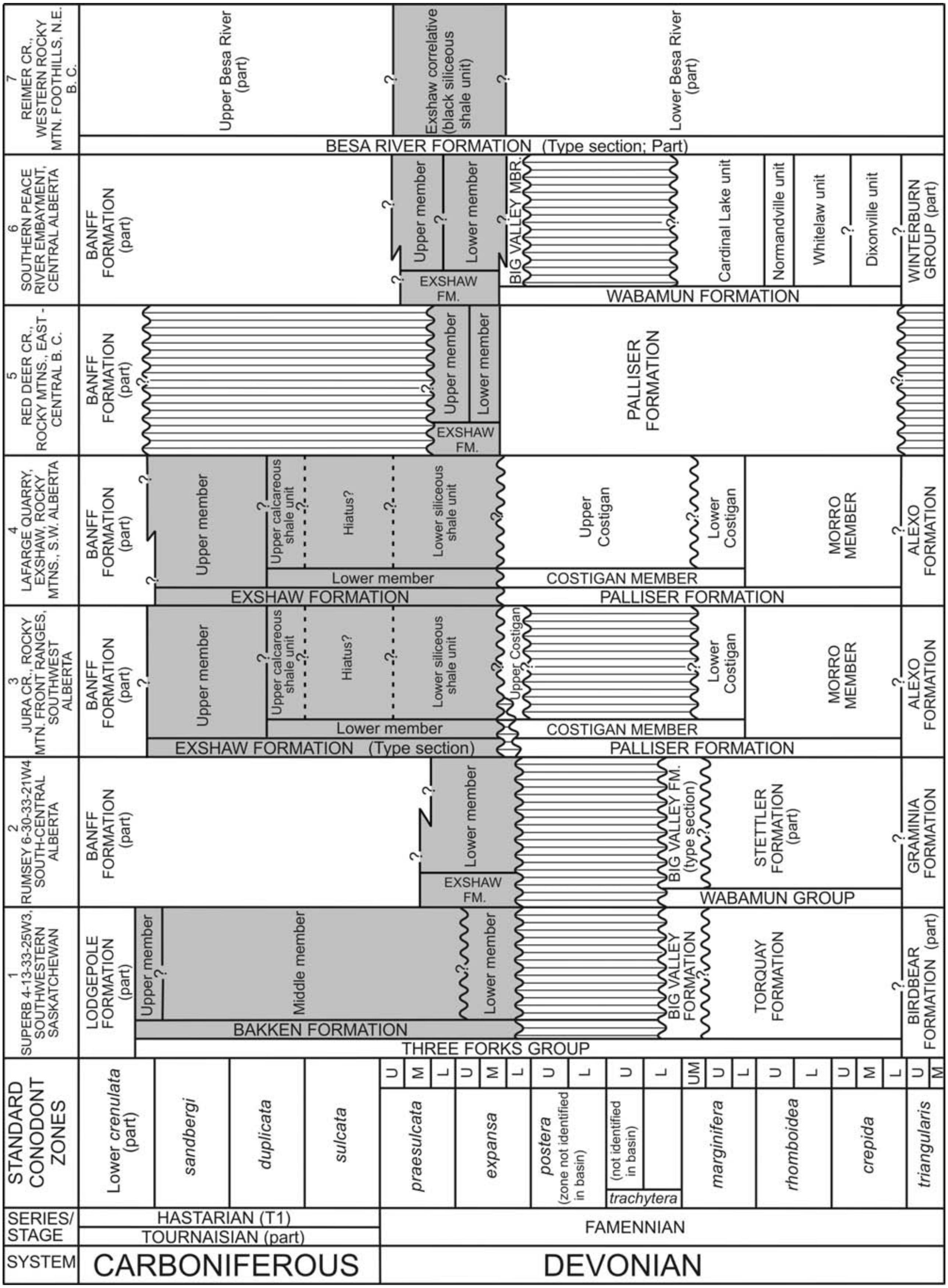

Figure 5. Correlation of Upper Devonian (Famennian) and Mississippian (Tournaisian) lithostratigraphic units in the Western Canada Sedimentary Basin with standard chronostratigraphic units and conodont zones.

The paleogeography and western extent of the cratonic platform in the southwest are not well known, but the deep Alberta Trough of Douglas *et al.* (1970) extended along part of the western cratonic platform and was connected with the early expression of the Antler Foreland Basin (Fig.6) in the western United States. The occurrence of the Alberta Trough is indicated by the presence of deep-water Famennian terrigenous clastics preserved in the lower Besa River Formation of east-central British Columbia, the Black Stuart Group of the Cariboo Mountains, and the Lussier shale (Savoy, 1992) in the western ranges of the southern Rocky Mountains.

A discontinuous, subaerially exposed positive belt resulting from an early phase of the Antler and related Cariboo orogenies (White, 1959; Douglas *et al*., 1970) was present along the western side of the Alberta Trough. To the northwest, a related contractional belt, resulting from the Ellesmerian Orogeny in northern Alaska and Yukon Territory, developed along the northwestern side of the Mackenzie Basin and its latest Devonian and Carboniferous successor - the Prophet Trough. The presence of the orogenic belts is recorded by westerly-derived Famennian conglomerate and finer grained siliciclastics in the trough successions and in the basal Famennian package deposited on the western cratonic shelf (Gordey, 1988; Gordey *et al*., 1987; Morrow and Geldsetzer, 1988; Moore, 1988). The Caribooan Orogenic Belt, a site of latest Devonian and Early Mississippian granitic plutonism and volcanism that is preserved largely in the pericratonic Kootenay Terrane (Fig. 7; Evenchick *et al*., 1984; Okulitch, 1985; Mortensen and Jilson, 1985; Mortensen *et al*., 1987; Parrish, 1992; Richards *et al*., 2002b), coincided in part with the western rim of the latest Devonian and Carboniferous Prophet Trough. The contractional belt along the western side of the trough was essentially a northern continuation of the Antler Orogenic Belt, which started to develop during the Frasnian but was not extensively subaerially exposed until the Early Mississippian (Goebel, 1991; Poole and Sandberg, 1991).

The western cratonic platform and adjacent troughs underwent episodes of moderate to pronounced subsidence. The latter, which started during the Frasnian and continued into the Mississippian, resulted at least partly from extension (Tempelman-Kluit, 1979; Struik, 1987; Gordey *et al*., 1987; Richards, 1989), but tectonic loading (Richards, 1989; Smith *et al*., 1993) and intraplate compressive stress (Bond and Kominz, 1991) may have been the major causes from the Famennian into the early Viséan.

Carboniferous tectonic elements

During the latest Devonian (late Famennian) and Carboniferous, the principal tectonic elements in the WCSB were the Prophet Trough, Peace River Embayment and cratonic platform, which included the intracratonic Williston Basin (Figs. 3, 6). The characteristics and Carboniferous tectonic histories of these elements and subordinate features within them were outlined by Richards *et al.* (1993, 1994a, 2002b). The Carboniferous in the Foothills of the Moose Mountain region west of Calgary was deposited on the eastern hinge zone of Prophet Trough, whereas that of the Front Ranges to the west was deposited within the trough. The Carboniferous of the Interior Platform was deposited on the cratonic platform and in the seaway connecting Prophet Trough and the Antler Foreland Basin to the Williston Basin.

The name Prophet Trough was introduced by Richards (1989) for the downwarped and downfaulted western margin of the North American plate of latest Devonian and Carboniferous time. Prophet Trough was continuous with Antler Foreland Basin of the western United States (Fig. 6), and extended from southeastern British Columbia to the Yukon Fold Belt. This pericratonic trough apparently had a history dominated by extension; however, it developed in the foreland of an ensialic arc or continental-margin volcanic/plutonic belt resulting from latest Devonian to earliest Carboniferous plate convergence and eastward-directed subduction. Also, growing evidence (Smith *et al*., 1993; Richards *et al*., 1993) indicates that southern Prophet Trough (south of Peace River Embayment) was a compressional foredeep from the late Famennian into the Tournaisian. Central Prophet Trough (from southern Peace River Embayment into Yukon) was also a foreland basin, but subsidence in that area and on the adjacent cratonic platform was accompanied by widespread block faulting (Barclay *et al*., 1990). The blockfaulting which took place in the latter region during the latest Devonian and early Mississippian, probably resulted at least in part from flexural deformation in a compressional setting, but back-arc extension may also have occurred. The main phase of blockfaulting in central Prophet Trough occurred from the late Viséan into the Pennsylvanian (mainly after the Antler event) and resulted from regional extension (Richards *et al*., 1993).

The western boundary of Prophet Trough was a contractional belt, extensively exposed from the Late Devonian to the early Viséan, but subsequently largely transgressed. Volcanism and plutonism took place within the trough and along its western rim, as recorded by the presence of Late Devonian and Early Mississippian plutons extending in a narrow belt (mainly in Kootenay Terrane, Fig. 7) from southeastern British Columbia into Alaska, by volcanics in northwestern Prophet Trough, and by westerly derived volcanic tuff in the lower Banff Formation at Mount Rundle and in the Exshaw Formation at Jura Creek and many other localities. Remnants of the western rim of the trough are mainly preserved in the pericratonic Kootenay Terrane (Fig. 7), but are locally preserved in the Cassiar Terrane and on the southwestern part of the ancestral North American plate.

A broad, partly fault-controlled hinge zone, marking a point at which water depths and sedimentation rates increased rapidly basinward, formed the boundary between the foreland basin (Prophet Trough) and cratonic platform to the east. From the latest Devonian into the Carboniferous, the hinge zone was positive along much of its length. Subtle secondary basins or depressions developed along the cratonward side of the hinge and had structural axes subparallel to the latter (Richards *et al*., 1994a). At the latitude of Calgary, the hinge, which apparently stepped basinward with time,

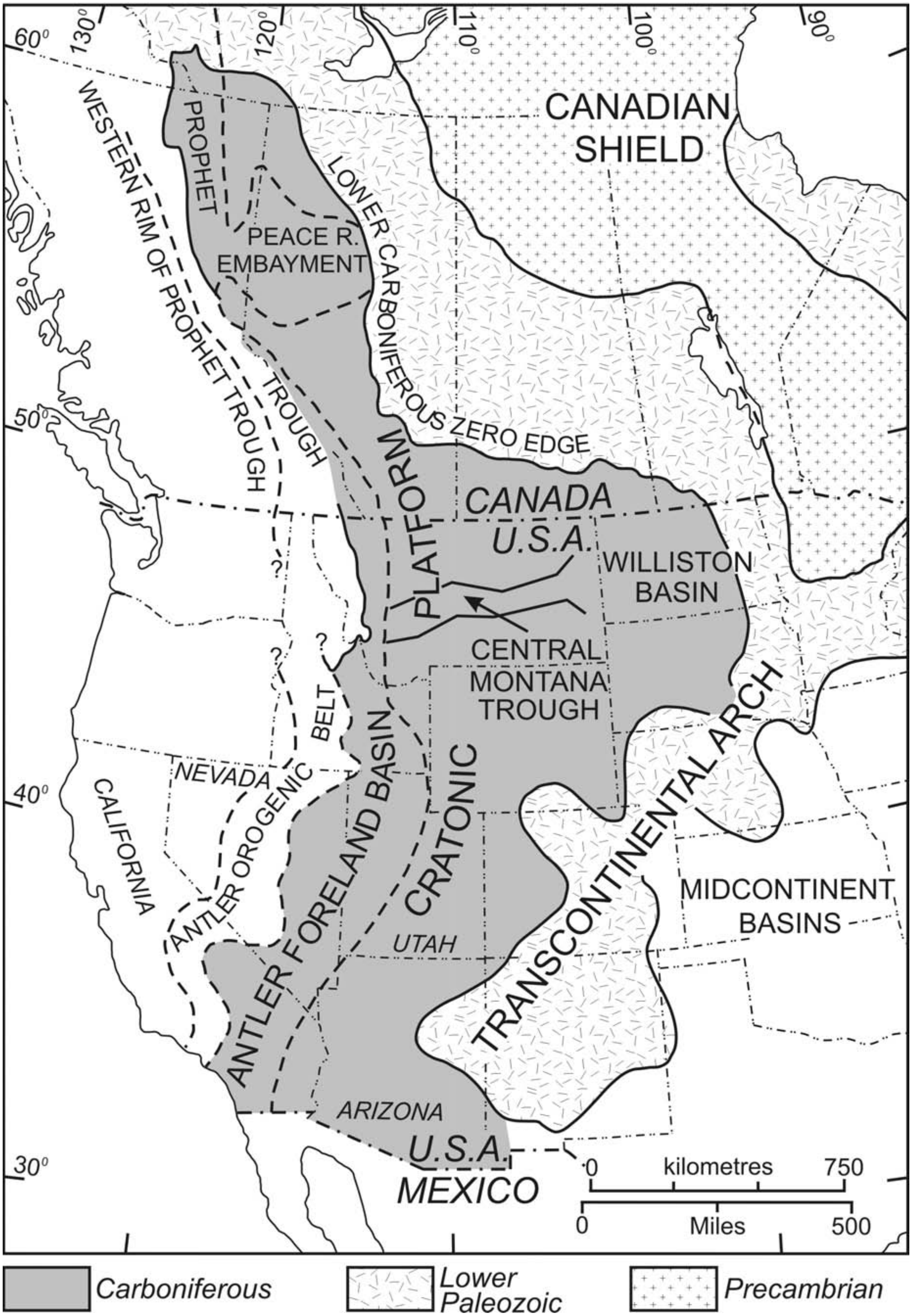

Figure 6. Map of western North America showing relation of Prophet Trough in western Canada to the Antler Foreland Basin in the western United States of America. An inner arc basin (Slide Mountain Basin) lay southwest of the western rim of Prophet Trough (modified from Richards et al., 1994a).

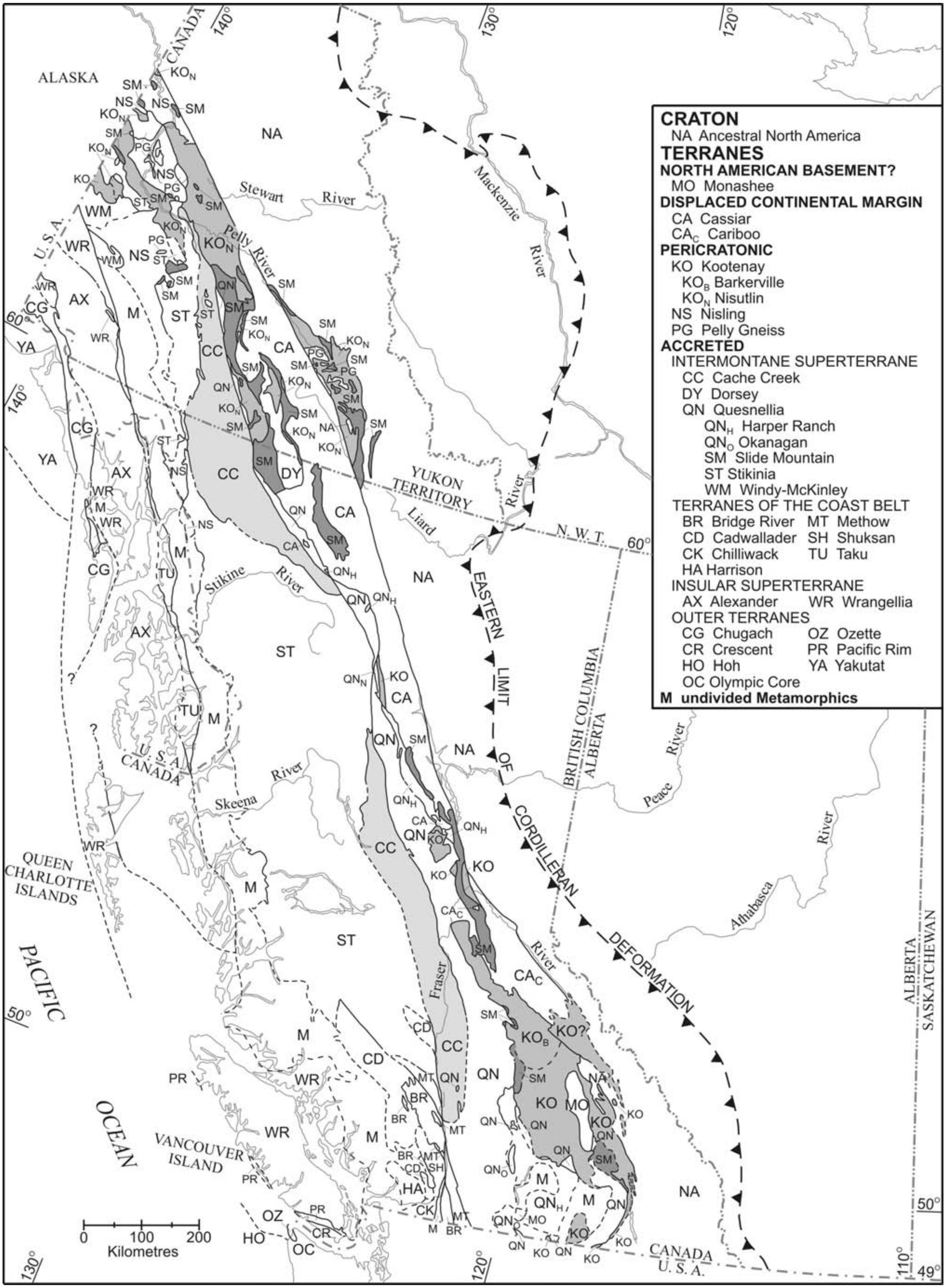

Figure 7. Simplified lithotectonic terrane map of western Canada (modified from Wheeler et al., 1988).

lay in the western Plains to eastern Foothills during the early Tournaisian as indicated by substantial westward thickening of the Exshaw and Banff formations. During the late Tournaisian and Viséan, the structural hinge probably lay near the present-day eastern limit of the southern Rocky Mountain Front Ranges. The latter position is suggested by the basinward thickening of the Shunda to Mount Head succession and its correlatives on regional cross-sections.

The eastern hinge zone of Prophet Trough and secondary basin to the east of the hinge may represent a forebulge and back-bulge basin (secondary foreland basin) produced by late Devonian to Early Carboniferous contractional events along the southwestern margin of ancestral North America. At approximately the same time, a forebulge and back-bulge basin developed along the eastern side of the Antler Foreland Basin (Goebel, 1991). A foreland basin generally comprises a foredeep and forebulge (Beaumont, 1981; Quinlan and Beaumont, 1984; Stockmal *et al*., 1986), but a low-amplitude secondary foreland basin may be developed cratonward of the forebulge (Flemings and Jordan, 1989; Jordan and Flemings, 1991).

Carbonate Depositional Models

Most of the Famennian carbonates of the WCSB were deposited on ramps (Fig. 8), whereas those of Carboniferous age were deposited on both ramps and platforms (Figs. 9, 10). The concept of a carbonate ramp used here is that of Wilson (1975), who derived his model from that of Ahr (1973). It is important to note that Ahr considered a ramp to be a 2-dimensional surface, whereas Wilson interpreted it to be a body of carbonate strata. Carbonate ramps are large buildups that prograde away from positive areas and down gentle regional slopes. Ramps lack an obvious break in slope and lithofacies on them occur as wide, irregular belts with the highest energy deposits close to the main shoreline. Both the Famennian and the Carboniferous ramp models used here are similar to the homoclinal ramp of Read (1982); however, Read considered a ramp to be a type of platform and a 2-dimensional surface.

According to Wilson (1975), carbonate platforms are large buildups that have a more or less horizontal top (shelf) and relatively abrupt shelf margins, where sediment deposited in high-energy environments occurs. On platforms, the shelf margin is separated from the main shoreline by a broad, relatively low-energy, protected-shelf environment,

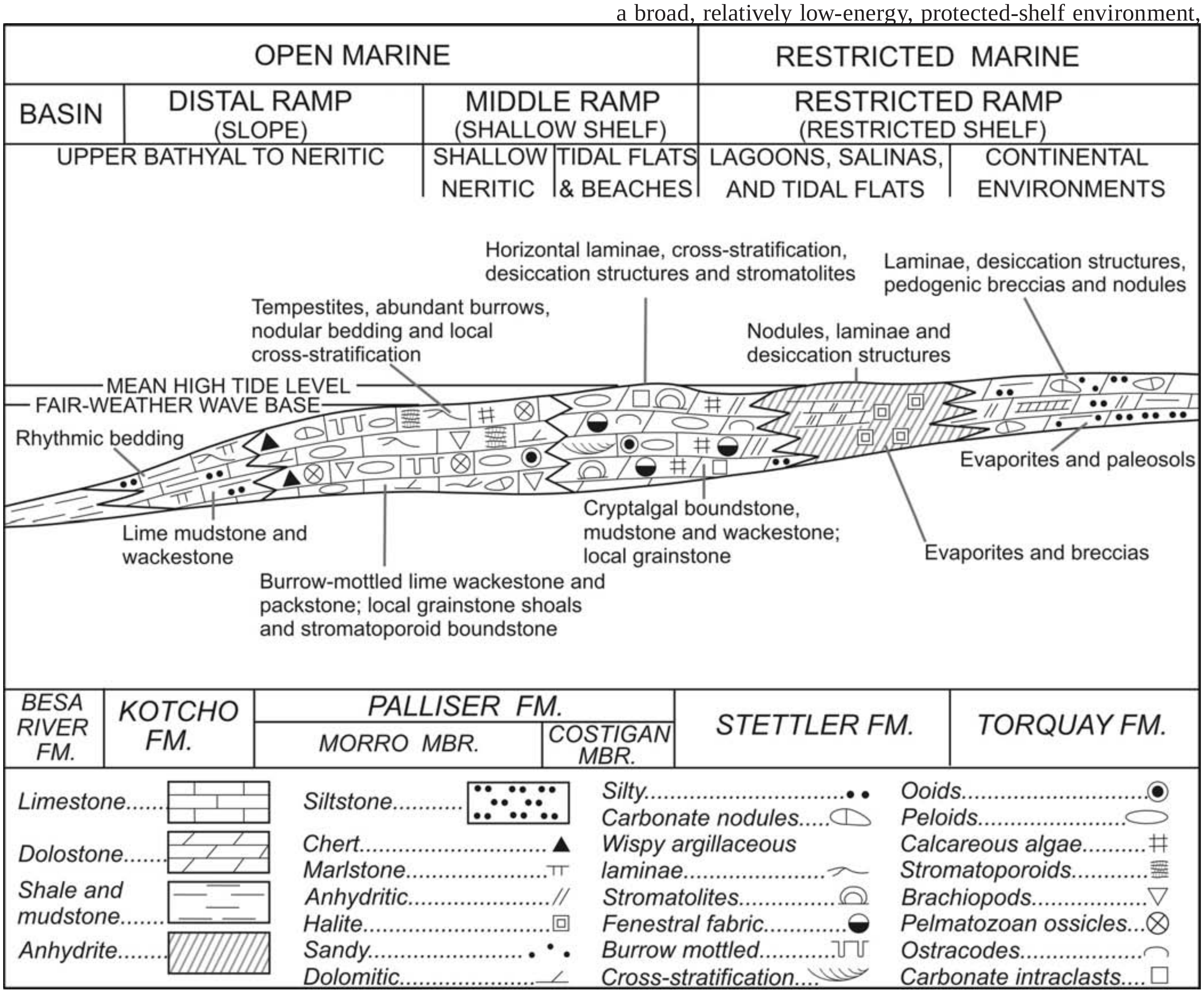

Figure 8. Generalized depositional model of a Famennian carbonate ramp (from Richards et al., 1991).

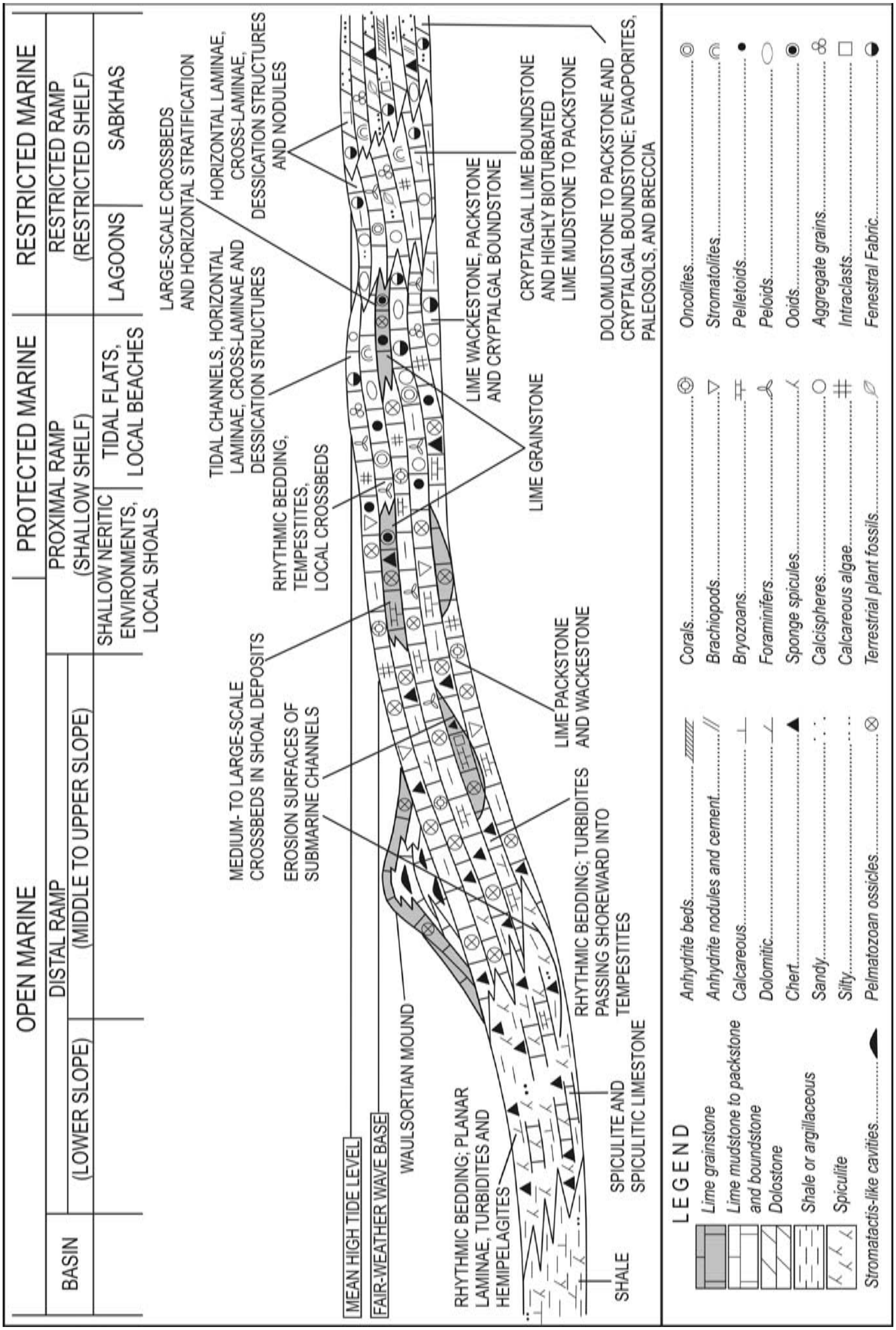

Figure 9. Generalized depositional model of a Mississippian carbonate ramp (from Richards, 1989).

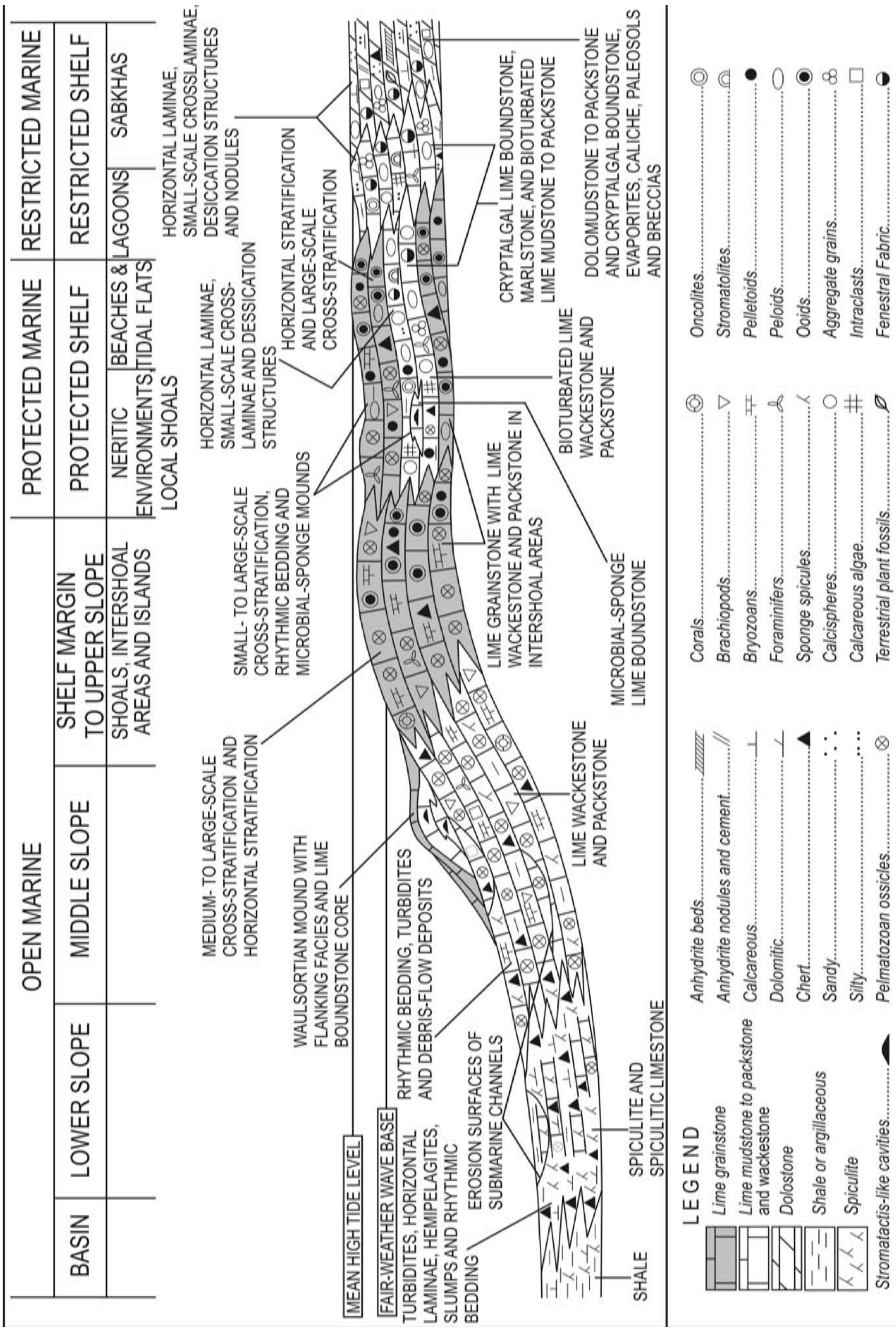

Figure 10. Generalized depositional model of a Mississippian carbonate platform (from Richards, 1989).

where carbonates are deposited in the neritic and intertidal zones. This model is similar to the rimmed carbonate shelf model of Read (1982).

On carbonate platforms, slope sedimentation is a function of the abruptness of the platform-to-basin transition and the characteristics of the shelf margin (McIlreath and James, 1978). According to McIlreath and James, the two basic types of platform-shelf margin are bypass and depositional margins. Bypass margins are at the tops of submarine escarpments where carbonate sediment is transported directly from the shelf to deep water, thereby bypassing much of the slope. In comparison, platforms that have depositional margins generally have slopes with low gradients where carbonate sediment is deposited at various water depths.

In the WCSB, the carbonate platforms of Carboniferous age had depositional shelf margins dominated by broad, shallow-water sand belts; shelf-margin reefs are lacking (Richards, 1989). The environments of highest energy generally lay on the landward part of the shelf-margin sand belt, where ooid shoals commonly developed. With some prominent exceptions, the platform lithofacies of the region lack evidence for submarine escarpments and thick, very coarse grained rudaceous deposits, which generally occur in slope deposits related to bypass margins. In contrast, the slope lithofacies form broad belts, which consist chiefly of granule- to silt-sized sediment. This indicates that the paleoslopes had relatively low gradients and were underlain by sediment wedges, which consisted mainly of lime sand and lime silt. Slope gradients were, however, sufficient to permit local slumping, deposition of some thin rudaceous deposits (< 5m thick), and the development of numerous submarine channels.

Sequence Stratigraphy

Sequence stratigraphic analysis has become increasingly popular since the development of the depositional sequence concept by Vail *et al.* (1977) and its refinement by Van Wagoner *et al.* (1988), Posamentier *et al.* (1988) and Posamentier and Vail (1988). Several types of sequence have been defined, including: tectono-stratigraphic sequences (Sloss, 1963, 1964), depositional sequences (Vail *et al*., 1977), genetic stratigraphic sequences (Galloway, 1989), and transgressive-regressive sequences (T-R sequences) which are equivalent to units commonly called T-R cycles (Johnson *et al*., 1985). Of these four types of sequence, the depositional sequence is most widely utilized, although the T-R sequence model has recently been strongly promoted (Dixon *et al*., 1992; Embry and Johannessen, 1992; Embry, 1993).

The uppermost Devonian and Carboniferous succession in southwestern Alberta is discussed herein in terms of T-R sequences because Carboniferous in the WCSB has been analyzed in terms of T-R events and sequences in several regional studies (Chatellier, 1988; Richards, 1989; Richards *et al*., 1993, 1994a). Most T-R sequences can be readily recognized in surface and subsurface Carboniferous sections using objective criteria and the correlative conformity - the transgressive surface - can be recognized in most cases. A major problem with the use of a depositional sequence for basin analysis is that the correlative conformity has little or no lithological expression and cannot be objectively located in many stratigraphic sections (Embry, 1993). The hierarchal system developed by Embry (1993) for T-R sequences is used to determine the order of magnitude of the sequences discussed.

Establishment of numerous terms accompanied development of the depositional sequence concept (Van Wagoner *et al*., 1988). The evolution of the T-R sequence model required some additional definitions, two of which require inclusion here. A maximum flooding surface (MFS) generally divides a T-R sequence into a transgressive systems tract (TST) and an overlying regressive systems tract (RST). The TST of a T-R sequence contains most of the transgressive strata and is identical to that of type-1 and type-2 depositional sequences. The RST contains the strata resulting from regression and is equivalent to the highstand systems tracts of type-1 and type-2 depositional sequence combined with either the lowstand systems tract of an overlying type-1 depositional sequence (Embry and Johannessen, 1992) or shelf-margin systems tract of an overlying type-2 depositional sequence.

Famennian Stratigraphy And Depositional Environments

Distribution and regional stratigraphy of Palliser assemblage

The Famennian of the WCSB is a thick carbonate-dominated succession widely preserved on the Interior Platform from Manitoba into southwestern District of Mackenzie and in the eastern Cordillera (Figs. 2, 5). Part of this succession will be examined on day 2 of the field trip along lower Jura Creek, where the Famennian is represented by the middle to upper Palliser Formation and lower Exshaw Formation. On the afternoon of day 1, the uppermost Palliser and lower Exshaw will also be examined briefly on the southwestern side of Mount Rundle.

Morrow and Geldsetzer (1988) included the Sassenach, Palliser and Exshaw formations in their Palliser assemblage, which is equivalent to the Palliser sequence of Moore (1988). The concept of that assemblage was expanded by Richards *et al*. (1991) to include the Alexo Formation and correlatives of the Alexo and Palliser occurring in the Wabamun and Three Forks groups of the Interior Platform (Fig. 5). The lower Exshaw, placed in the Banff assemblage by Richards (1989) and Richards *et al*. (1994a), is excluded. The Palliser assemblage generally overlies Frasnian strata and underlies the Banff assemblage (uppermost Famennian and Tournaisian) of Richards (1989). Boundaries of the Palliser assemblage are conformable in part of the Cordillera. In the Rocky Mountain Front Ranges of southern Alberta and toward the east, however, the assemblage is generally bounded by minor unconformities (Morrow and Geldsetzer, 1988; Moore, 1989).

The Palliser assemblage comprises a thick, lower T-R sequence overlain by the initial transgressive deposits of a T-R sequence that contains the Devonian/Carboniferous boundary and includes the Exshaw Formation. Deposition of the assemblage probably commenced during the time of the *Palmatolepis triangularis* conodont Zone and continued into *Palmatolepis gracilis expansa* Zone time (Morrow and Geldsetzer, 1988). Deposition started in the southwest with argillaceous carbonates, siltstone and sandstone (Sassenach and Alexo formations) and expanded eastward onto the southern Alberta Shelf (Graminia Formation). In the northwest, these initial deposits started to onlap remnants of the Peace River Arch. Continued transgression, accompanied by carbonate and evaporite deposition, formed a vast carbonate ramp that prograded westward and extended from Manitoba to District of Mackenzie (Fig. 8).

Deposition on a ramp rather than a platform is indicated by the lack of either extensive reefs or grainstone belts characteristic of the shelf margin on platforms. On the ramp, red beds with evaporites and paleosols were deposited in the east (Torquay Formation of Saskatchewan). An evaporite belt lay in southern Alberta (Stettler Formation), and a broad central belt of carbonates and subordinate evaporites extended westward to the continental shelf (Palliser, Wabamun and Stettler formations). Finally, there was a broad, ramp-like transitional belt (Kotcho and Tetcho formations of northeastern British Columbia) to the western shale basin, represented by the Besa River Formation (Moore, 1988).

In most of the WCSB, ramp development was interrupted during a middle Famennian (uppermost *Palmatolepis marginifera marginifera* conodont Zone or possibly slightly later) regional regression that was accompanied by regional subaerial erosion. The latter is indicated by the subaerial unconformity below shale and argillaceous limestone of the transgressive upper Famennian Big Valley Formation (Fig. 5; Christopher, 1961) and the upper Costigan Member of the Palliser Formation. The magnitude of the hiatus, which generally diminished basinward, was greatest in the Interior Plains, Foothills, and eastern Front Ranges of the southern Rocky Mountains. Sedimentation was apparently continuous in the western Front Ranges of Alberta, the western ranges of southeastern British Columbia, and the eastern Front Ranges of the Jasper area. Ramp development resumed during depo-

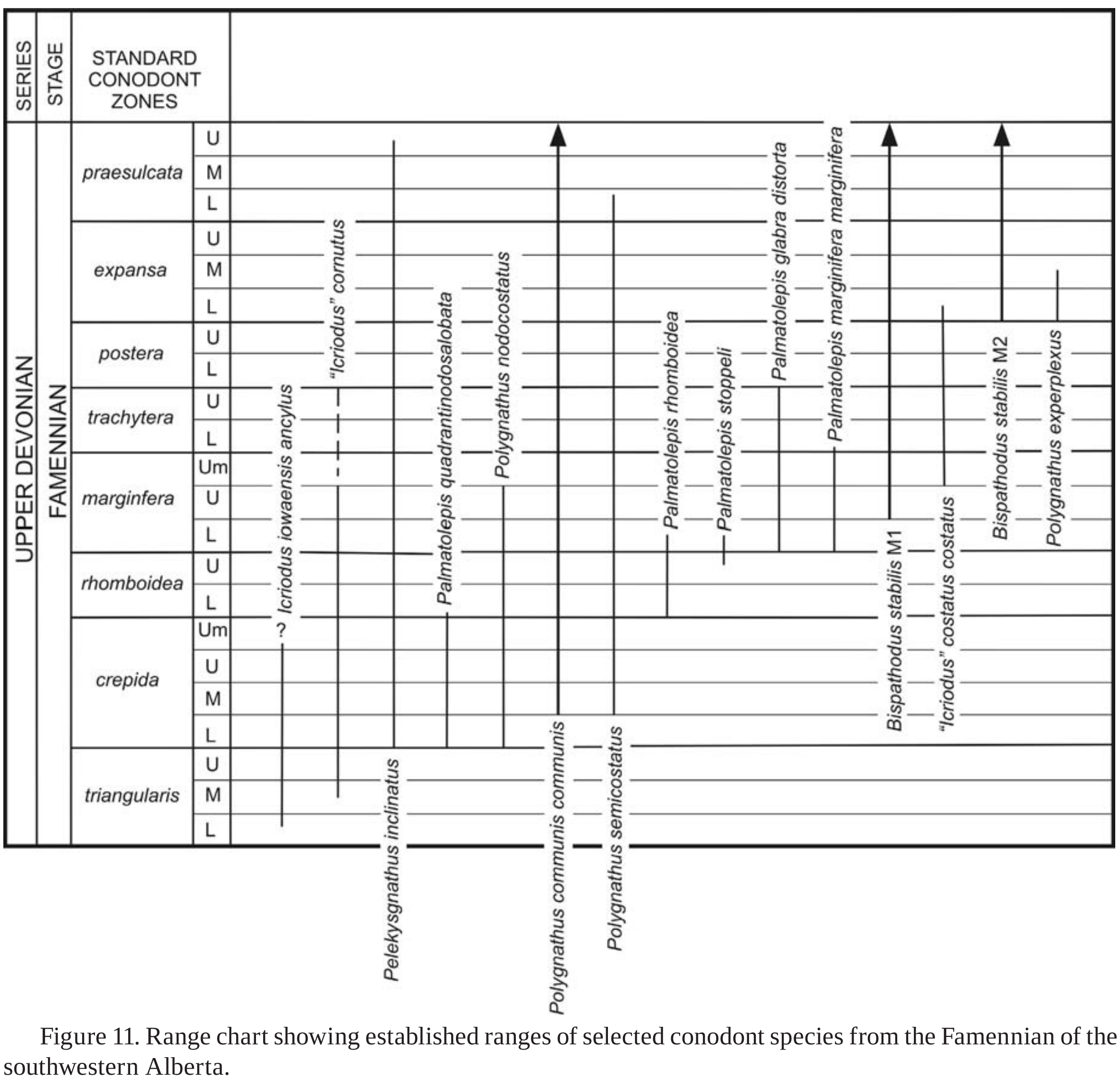

Figure 11. Range chart showing established ranges of selected conodont species from the Famennian of the Exshaw region, southwestern Alberta.

Figure 12. Correlation of Carboniferous lithostratigraphic units, southwestern Manitoba to southwestern District of vof contact uncertain; question marks indicate position of lines uncertain (from Richards et al., 1993).

Mackenzie with chronostratigraphic units and Carboniferous zonal schemes. Dashed lines indicate nature sition of the upper Famennian Big Valley Formation, but stopped prior to deposition of the Exshaw Formation.

Biostratigraphy

Conodont Biostratigraphy

The standard Upper Devonian conodont zonation used here (Fig. 11) was proposed by Ziegler (1962) and underwent major revision by Ziegler (1971) and Ziegler and Sandberg (1984). This zonation, also revised by Ziegler and Sandberg (1990), has been applied internationally. Most of the conodont biostratigraphy for the Palliser Formation was done by David Johnston. Alan Higgins, at the Geological Survey of Canada-Calgary, did most of the conodont biostratigraphy for the upper Costigan Member and overlying Exshaw Formation along Jura Creek.

Uppermost Devonian (Upper Famennian) And Carboniferous Stratigraphy And Depositional Environments

Regional Stratigraphic Framework

The uppermost Devonian and Carboniferous of the WCSB (Figs. 3, 12) is a thick succession of lithofacies deposited on the downwarped and downfaulted western margin of ancestral North America and the central to western cratonic platform. This succession, less widely preserved than the underlying Palliser assemblage, is a shallowing-upward, progradational package overall, but it records numerous transgressions and regressions. Subaerial erosion during the latest Carboniferous, Permian, and subsequent periods, removed major parts of the Carboniferous, particularly on the Interior Platform and the region west of the Rocky Mountain Front Ranges. In areas where the Carboniferous remains, it is generally unconformably overlain by either Permian or Mesozoic strata.

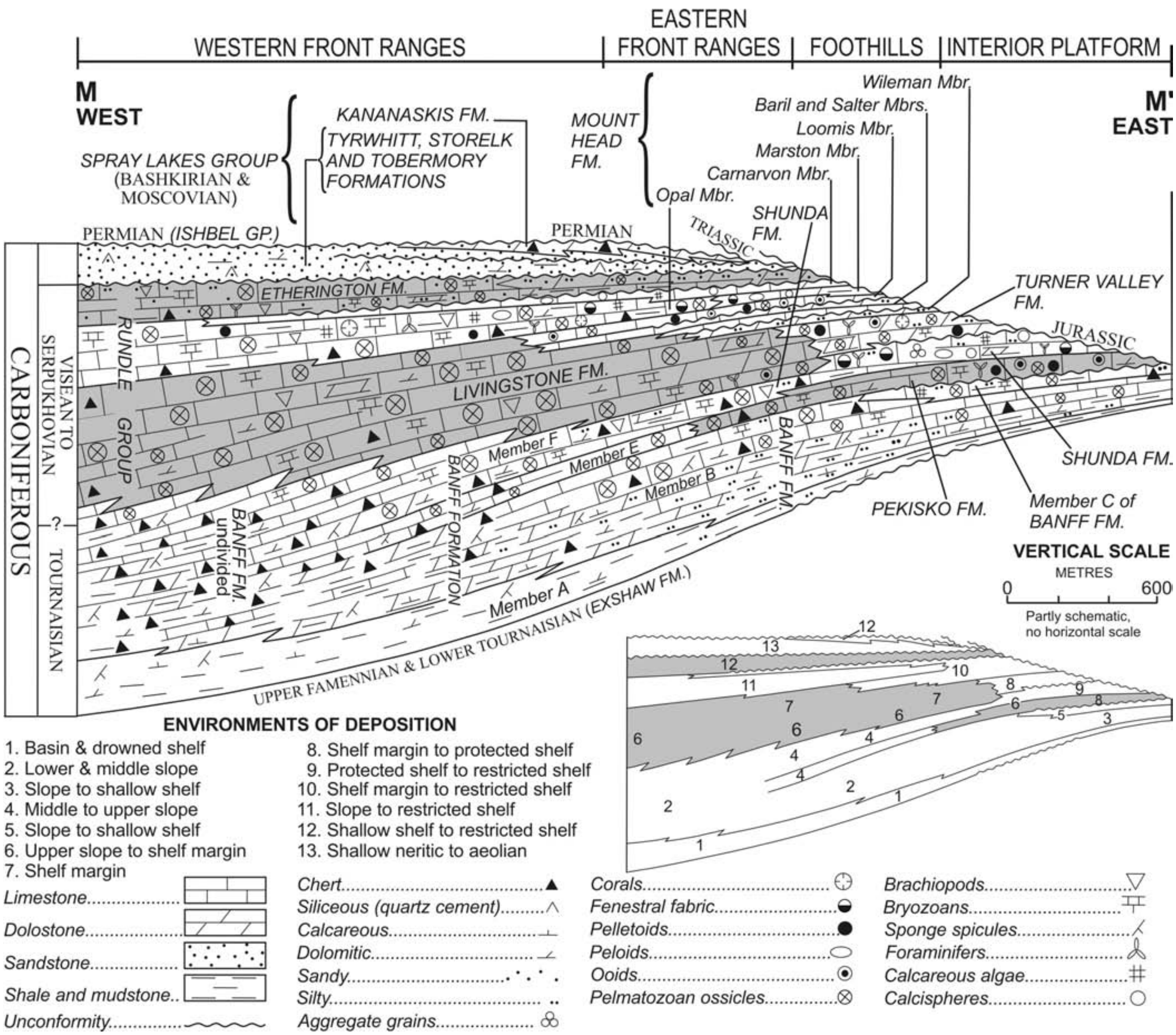

Figure 13. Partly schematic, non palinspastic cross-section showing Carboniferous of southwestern Alberta (modified from Richards, 1989). See Fig. 3 for line of section (M-M').

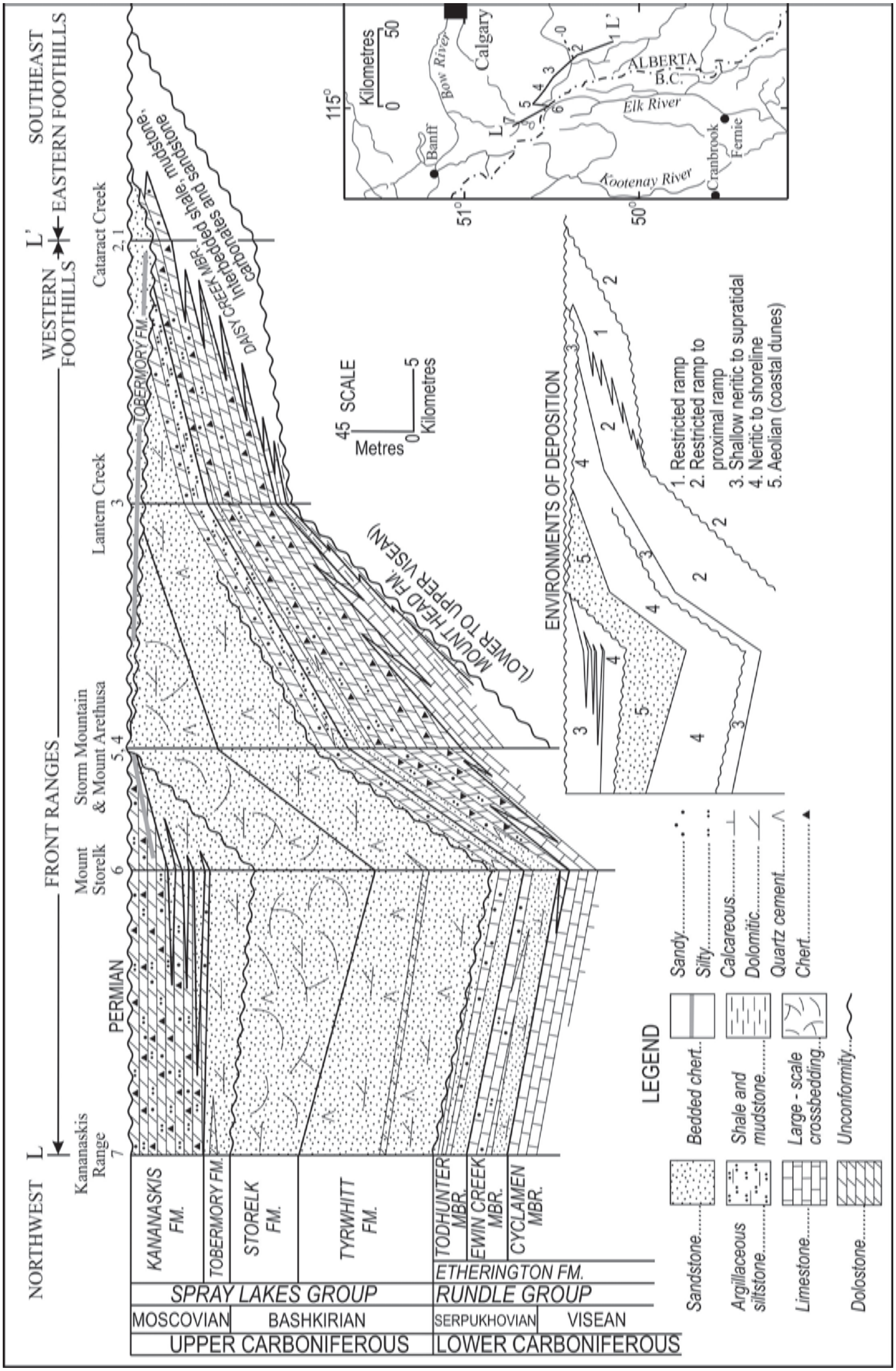

Figure 14. Partly schematic, non palinspastic cross-section L-L' showing Mattson assemblage (uppermost Rundle Group and Spray Lakes Group) of southwestern Alberta (after Scott, 1964). See Figure 3 for line of section.

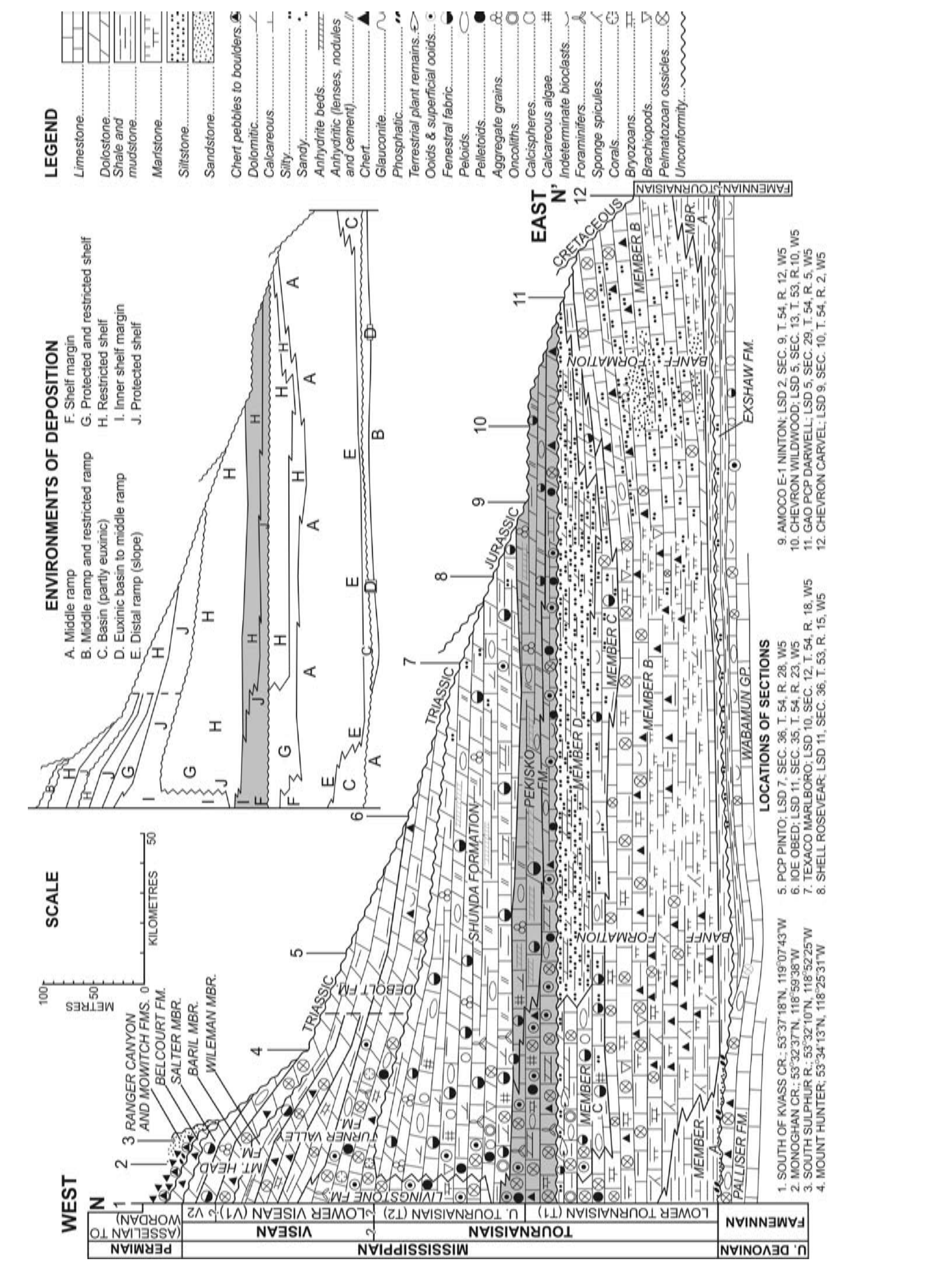

Figure 15. Partly schematic, non palinspastic cross-section N-N' showing uppermost Devonian and Lower Carboniferous of west-central Alberta. See Figure 3 for line of section. (from Richards et al., 1994a).

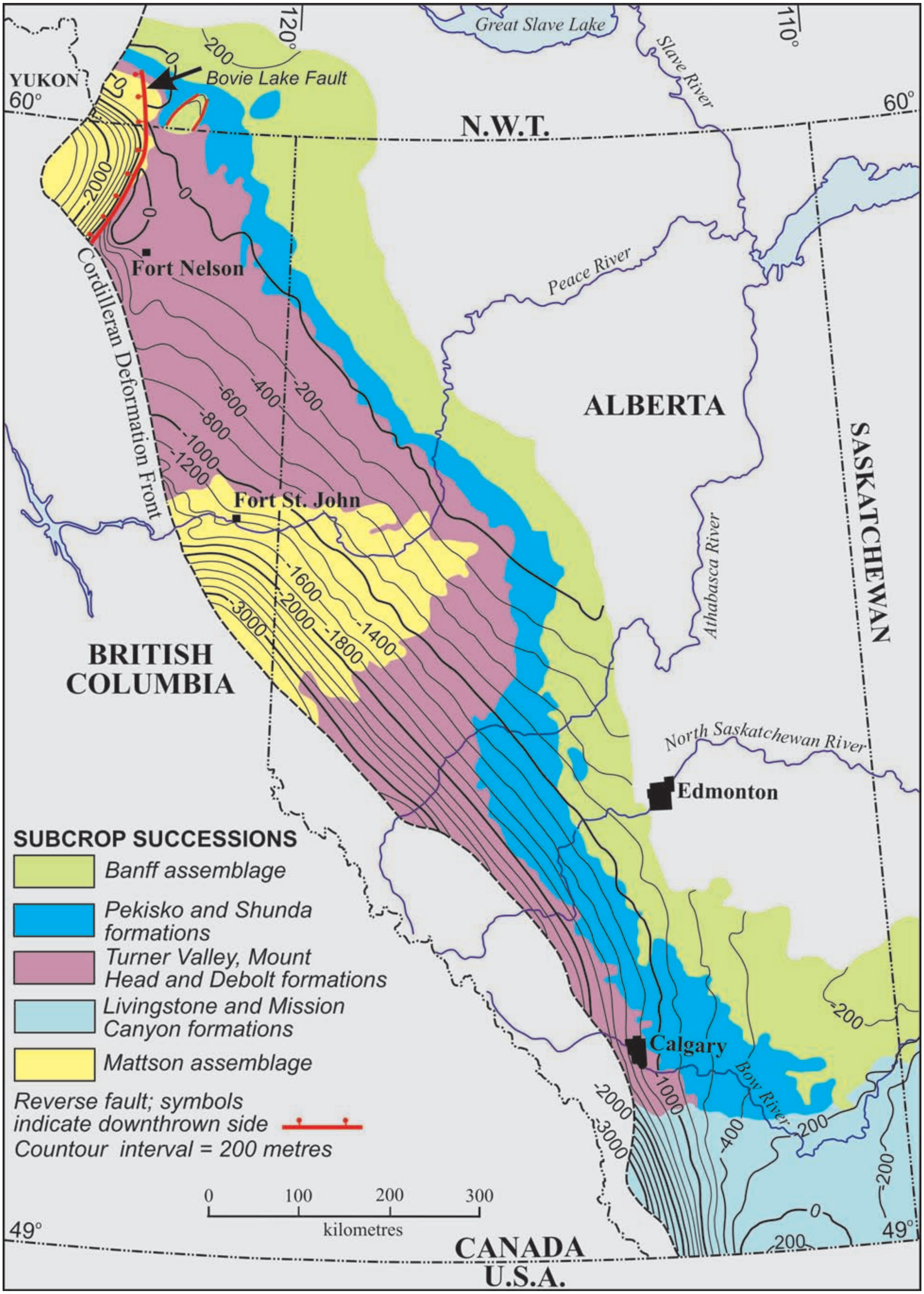

Figure 16. Structure on top of Lower Carboniferous. Map also shows subcrop distribution of Lower Carboniferous units and erosional zero edges (after Richards et al., 1994a).

The uppermost Devonian and Lower Carboniferous succession from southwestern Manitoba to southwestern District of Mackenzie was divided by Richards (1989) and Richards *et al.* (1993) into five mapable lithofacies assemblages on the basis of depositional setting, lithology and depositional history (Figs. 3, 12).

Lithofacies deposited in western Prophet Trough and on its western rim are called the western assemblage. The assemblage, largely removed by deep, post-Carboniferous erosion, includes carbonates, volcanics and remnants of an easterly thinning clastic wedge (Gordey *et al*., 1987; Richards *et al.* 1993, 2002b).

The succession to the east (Figs. 3, 12-16), which includes platform to ramp carbonates (Figs. 9, 10) and deltaic terrigenous clastics, comprises the Banff, Rundle and Mattson assemblages. Formations constituting parts of the latter three assemblages are widely exposed in the eastern Cordillera and will be examined on this field excursion. The Banff, Rundle and Mattson assemblages resemble the lower, middle, and upper depositional units, respectively, of Mcauley *et al.* (1964) and Richards *et al.* (1993, 1994a). The Mattson assemblage was expanded by Richards *et al.* (1991, 1993, 1994a) and Higgins *et al.* (1991) to include the sandstone-rich Upper Carboniferous succession (Figs. 3. 12, 14).

Fine-grained siliciclastics and cherty to argillaceous carbonates of the Banff assemblage are widely overlain by carbonates of the Rundle assemblage, which is in turn partly overlain by the sandstone-rich Mattson assemblage. From east-central British Columbia to southwestern District of Mackenzie, the Banff, Rundle and Mattson assemblages overlie and pass basinward into the Besa River Formation of the shale-dominant Besa River assemblage. In southeastern British Columbia, the Banff and Rundle assemblages pass basinward into the Lussier shale of the Besa River assemblage. The partly schematic cross-sections, Figures 13, 14 and 15 illustrate the stratigraphy of the Carboniferous of western Alberta and provide environmental interpretations.

Conodont Biostratigraphy

The conodont zonation used for the uppermost Devonian and Mississippian in the present account draws on many sources including Ziegler and Sandberg (1984), Sandberg *et al.* (1978) and Lane *et al.* (1980). A zonation of up to 18 conodont zones (Fig. 17) was outlined for the uppermost Devonian to Upper Carboniferous of the WCSB by Higgins *et al.* (1991). An earlier zonation was proposed by Baxter and von Bitter (1984). Figure 17 shows the known stratigraphic ranges of selected species characteristic of the uppermost Devonian and Mississippian of the WCSB. In general, the conodonts are rare to absent in lithofacies deposited on the restricted shelf, inner protected shelf, and inner middle ramp. They become more abundant and diversified basinward, and are most abundant, in terms of species and numbers of specimens, in the slope lithofacies. The conodont biostratigraphy for the Banff Formation and overlying Pekisko and Shunda formations at stops 8 to 10 for day 2 above the western side of the middle canyon of Jura Creek was completed by Charles Henderson at the Department of geology and Geophysics in the University of Calgary. Alan Higgins, at the Geological Survey of Canada-Calgary, did the conodont biostratigraphy for the upper Banff Formation and Rundle Group in the southwest-flowing stream along the southeastern side of Princess Margaret Mountain (GSC paleontological report 6-ACH-85).

Coral Biostratigraphy of the Banff Formation and Rundle Group

Six generic zones with 11 subzones were established by Sando and Bamber (1985) for the Lower Carboniferous coral faunas within the Western Interior Province of North America. Their zonation is applicable throughout the eastern Cordillera and Plains from northern Alaska and Yukon to Mexico. The zones and subzones are Opel zones characterized by first appearances and last occurrences. Four of the generic zones (II-V) and 8 subzones are well developed within the Banff Formation and the Rundle Group of southwestern Alberta (Fig. 12). The corals discussed in this field trip guide were identified and assigned to zones by E.W. Bamber at the Geological Survey of Canada-Calgary.

Foraminiferal Biostratigraphy

Eighteen foraminiferal zones have been recognized in the Carboniferous System of the WCSB (Fig. 12). They include zones pre-7 to 22 of Mamet and Skipp (1970), which range from the Tournaisian Stage to the Bashkirian Stage. Zones pre-7 to 18 have been widely identified in the Mississippian of the southern and central parts of the WCSB (Mamet, 1976; Bamber and Mamet, 1978; Mamet *et al*., 1986). However, zone 19 (upper Serpukhovian) and zones 20 to 22 (Bashkirian and Moscovian) are known only from the northern Yukon, where they were identified by Mamet and Ross (*in* Bamber and Waterhouse, 1971). Moscovian fusulinaceans occur in the Kananaskis Formation of the Banff region (McGugan *et al*., 1968; Ross and Bamber, 1978). Details of the foraminiferal zones and their distribution have been summarized by Bamber and Mamet (1978), Mamet and Bamber (1979), and Mamet *et al.* (1986). The foraminifers are generally common and diversified in limestone of upper-slope to restricted-shelf origin but rare to absent in deeper water deposits. The foraminiferal biostratigraphy was completed by Bernard L. Mamet at the Laboratoire de Géologié, Université de Bruxelles, Belgium.

Distribution and Regional Stratigraphy of Banff Assemblage

The Banff assemblage (Figs. 3, 12) comprises carbonates and siliciclastics preserved in several formations including the Exshaw, Bakken, Banff, and Lodgepole. Deposition of the Exshaw and overlying Banff took place in the Prophet Trough and Peace River Embayment and on the western cratonic platform. The Bakken and overlying Lodgepole were deposited mainly in the Williston Basin and on the northern Madison Shelf. In the region west of Calgary, the Banff assemblage is represented by carbonates and siliciclastics

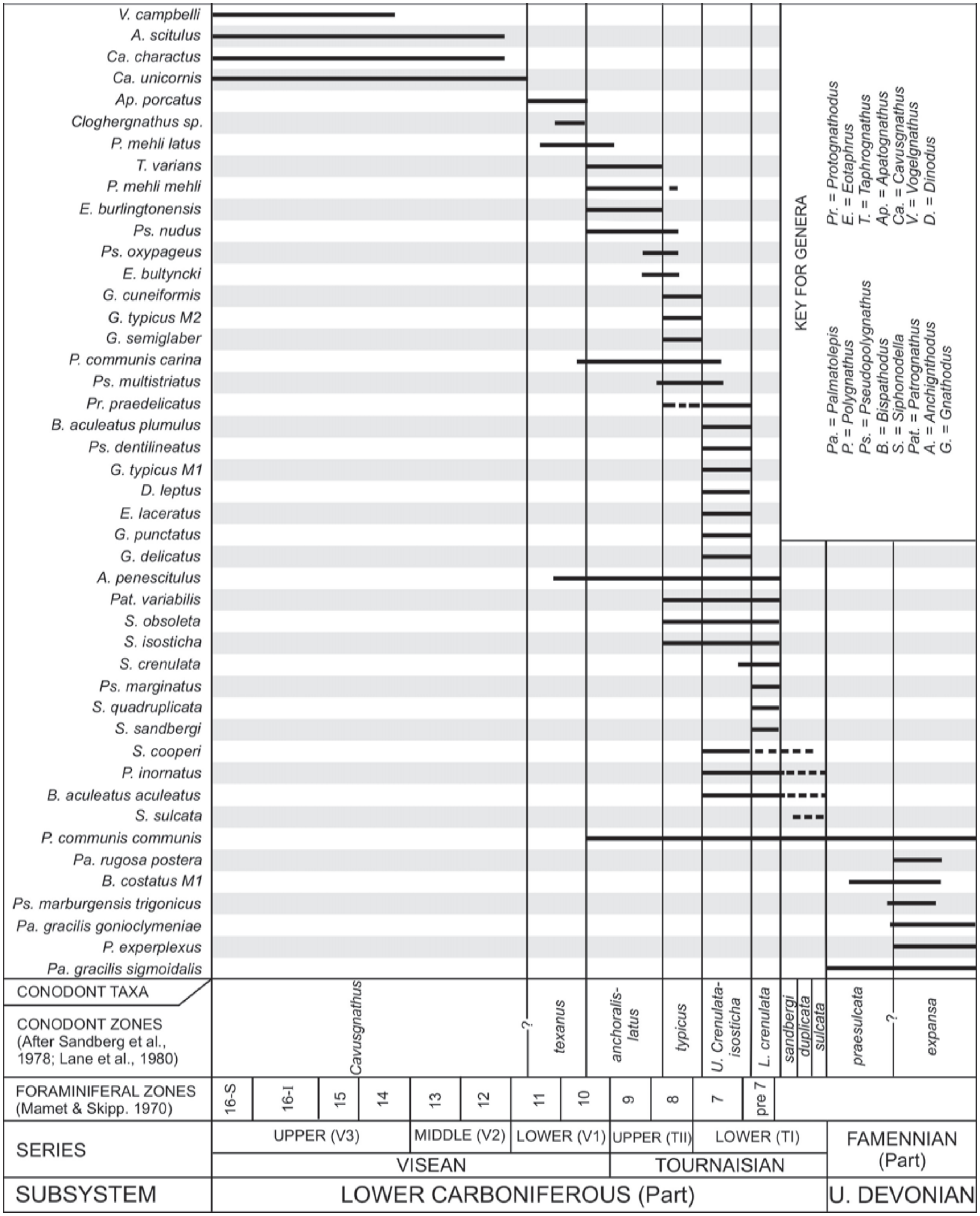

Figure 17. Known stratigraphic ranges of selected conodont species characteristic of the uppermost Devonian and Lower Carboniferous of the WCSB (from Higgins et al., 1991).

of the Exshaw and overlying Banff Formation (Figs. 12, 13, 15).

In most of the WCSB, including the region west of Calgary, the Banff assemblage disconformably overlies the Palliser assemblage. In much of the southern Cordillera, and on the Interior Platform of southernmost Alberta, the top of the Banff assemblage becomes younger southwestward (basinward) as the overlying Rundle assemblage grades into it. Elsewhere, the boundary between these two packages is generally abrupt and commonly a minor disconformity resulting from transgressive ravinement and possibly subaerial erosion as well. Deposition of the Banff assemblage began during the time of the Middle to Upper *Palmatolepis gracillis expansa* conodont zones and continued into *Gnathodus typicus* Zone time and later in the western Front Ranges.

In the Banff assemblage, the carbonate lithofacies developed on carbonate ramps and to a lesser extent on poorly differentiated carbonate platforms. Most of the shale, siltstone and sandstone were deposited in lower-slope and starved-basin to drowned-shelf settings, but shallow-neritic to supratidal siliciclastics are widespread in northern and eastern occurrences of the upper Banff and Exshaw formations and in the middle Bakken Formation. The shallow-marine shelf lithofacies generally grade southwestward into slope carbonates and siliciclastics of the assemblage. The slope lithofacies, in turn, grade basinward into shale-dominated basin deposits preserved in the lower part of the Banff assemblage and in the Besa River assemblage.

Distribution and Regional Stratigraphy of Rundle Assemblage

The carbonate-dominated Rundle assemblage (Figs. 3, 12) comprises the Mission Canyon Formation and all of the Rundle Group except the Etherington Formation (included in the Mattson assemblage). Deposition of the Rundle Group took place in the Prophet Trough, Peace River Embayment and on the western cratonic platform, whereas that of the Mission Canyon occurred in the Williston Basin and on the unstable craton (Madison Shelf) west of the Williston Basin. In the region that will be visited on the field trips, the Rundle assemblage is represented by the Pekisko, Shunda, Turner Valley, Livingstone, and Mount Head Formations (Fig. 13).

The Rundle assemblage generally overlies the Banff assemblage, but from east-central British Columbia to southwestern District of Mackenzie, western deposits of the assemblage overlie and pass basinward into the Besa River assemblage. In most areas, the Rundle assemblage is unconformably overlain by either Permian or Mesozoic strata. It is, however, overlain by the sandstone-dominated Mattson assemblage in south-central Saskatchewan, on part of the western Interior Platform and over wide areas in the eastern Rocky Mountain Fold and Thrust Belt, including the region west of Calgary (Figs. 13, 14). The contact between the Rundle and Mattson assemblages may be conformable in Saskatchewan, but it is generally disconformable from southwestern Alberta into the southwestern part of the Peace River Embayment. Farther north, the Rundle assemblage is abruptly but usually conformably, overlain by the Mattson assemblage at a contact that becomes older northwestward.

Platform and ramp carbonates dominate the Rundle assemblage, but in the northwest, the assemblage includes a great thickness of bedded chert and spiculite preserved mainly in the Prophet Formation. The shelf and shelf-margin lithofacies generally grade southwestward (basinward) into slope deposits preserved in the Prophet Formation and the upper part of the Banff Formation, but in the Interior Platform south of Calgary they grade southward into slope deposits of the Banff that were deposited in the seaway connecting the Prophet Trough and Antler Foreland Basin to the Williston Basin. The slope deposits, in turn, grade basinward into a thick succession of basin facies preserved mainly in the Besa River Formation and the lower part of the Banff assemblage.

Distribution and Regional Stratigraphy of Mattson Assemblage

The sandstone-dominated Mattson assemblage consists of the Etherington and Mattson formations, Stoddart Group, Spray Lakes Group (Tyrwhitt, Storelk, Tobermory and Kananaskis formations), and minor occurrences of the Big Snowy Group (Figs. 12, 14). In the eastern Cordillera west of Calgary, the assemblage is represented by the Etherington Formation and Spray Lakes Group. Sedimentation of the Big Snowy Group took place in Williston Basin, whereas the remainder of the assemblage was deposited in the Prophet Trough, Peace River Embayment, and locally on the western cratonic platform. In the region that will be visited on the field trip, the Mattson assemblage is represented by the Etherington Formation and Spray Lakes Group.

The Mattson assemblage, comprising sandstone with subordinate carbonates and shale, overlies the Rundle assemblage. It also overlies and passes basinward into the Besa River assemblage from east-central British Columbia into southwestern District of Mackenzie. In most areas, including most of the Rocky Mountain Front Ranges west of Calgary, the Mattson assemblage is unconformably overlain by Permian strata; but east and north of the subcrop edge of the Permian it is unconformably overlain by Triassic to Lower Cretaceous strata.

Lithofacies of the Mattson assemblage were deposited in a complex array of marine to continental environments, including carbonate ramps, deltas, aeolian coastal dunes, and siliciclastic-dominated marine shelves. Carbonate lithofacies occur in most formations in the depositional package, but predominate only in the Etherington, Taylor Flat and Kananaskis formations. Carbonates of the Etherington, Kananaskis, and Taylor Flat are probably of ramp origin, but those of the other formations do not constitute well defined carbonate buildups.

Late Afternoon Day 1 And Morning Of Day 2: Uppermost Devonian (Famennian) And Mississippian (Tournaisian) Carbonates And Black Shale On Mount Rundle And At

Exshaw, Rocky Mountain Front Ranges.

Geological setting

In the Front Ranges of the southern Rocky Mountains near the communities of Exshaw and Canmore, parautochthonous Famennian and Tournaisian strata are well displayed in the multiple southwestward-dipping thrust sheets dissected by the Bow River and its tributaries. The objective for the late afternoon of day 1 and morning of day 2 is to provide an overview of the lithostratigraphy and biostratigraphy of this succession by examining exposures on the southwestern side of Mount Rundle west of Canmore (Fig. 18) and along Jura Creek near Exshaw (Fig. 19). The deposits exposed on the southwestern side of Mount Rundle are about 20 km west of Jura Creek and about 5 km southwest of central Canmore. They are reached via the Goat Creek hiking trail, which starts at the Smith-Dorrien/Spray Trail. The localities along Jura Creek occur slightly northeast of the village of Exshaw and are accessed by a trail which starts where Highway 1A crosses the creek. In the afternoon, en route from Exshaw to Canmore, Tournaisian carbonates will be briefly examined on Highway 1A at the southeastern end of Grotto Mountain (stop 2-11, Fig. 19).

Along Jura Creek and in the adjacent Bow Valley region, the Famennian and Tournaisian are represented by a thick succession of well-exposed carbonates with subordinate black shale, siltstone and sandstone. The Famennian strata occur mainly in the Palliser Formation and overlying lower Exshaw Formation (Figs. 5, 20) and were deposited on the western Alberta Shelf. Deposition of the Tournaisian strata, preserved in the middle to upper Exshaw and overlying Banff Formation and lower Rundle Group (Figs. 12, 13), took place in eastern Prophet Trough.

The Famennian and Tournaisian deposits on the southwestern side of Mount Rundle at stops 2-1 and 2-2 (Fig. 18) are preserved in the Rundle Thrust Sheet and lie well within the Front Ranges. At this locality, the Exshaw and lower Banff formations are extensively and exceptionally well exposed. During the Laramide Orogeny, strata within the Rundle Thrust Sheet were displaced approximately 99 km northeastward relative to the autochthonous plains succession and presently lie about 16 km closer to the Jura Creek succession than during the Carboniferous. The Mount Rundle deposits are separated from those at Jura Creek by the Exshaw, Lac des Arcs, and Inglismaldie thrust sheets. The latter thrust sheet contains the succession at stop 11 on Grotto Mountain (Figs. 1, 19). The strata at Grotto Mountain and Mount Rundle were deposited well basinward of the Jura Creek succession. Therefore, many of the substantial basinward facies changes that take place within the Famennian and Tournaisian of the region become evident by examining these exposures.

The succession exposed along Jura Creek, one of the southeastward-flowing tributaries of the Bow River, is preserved in the McConnell Thrust Sheet, which constitutes the easternmost range of the Rockies at this latitude. Jura Creek has the best known readily accessible exposures of Famennian and Tournaisian strata in the Bow Valley region and is a popular destination for geological fieldtrips. However, the principal reason for selecting Jura Creek is that the black shale of the lower Exshaw Formation, which spans the Devonian/Carboniferous boundary, is exceptionally well exposed and has provided conodonts and lithostratigraphic data that suggest deposition was continuous across the systemic boundary in this area.

Jura Creek was also selected because the locality has some of the easternmost Famennian and Tournaisian exposures in the Front Ranges and can, because of recent lithostratigraphic and biostratigraphic studies, be correlated with reasonable confidence with the parautochthonous to autochthonous subsurface succession of the adjacent Rocky Mountain Foothills and Interior Plains. Some correlations between the Tournaisian units of the Rocky Mountains and those of the subsurface succession in the adjacent Foothills and Plains have been controversial. The current interpretations have emerged as a consequence of an integrated approach combining lithostratigraphy, sedimentology and biostratigraphy in the region (Richards, 1989; Johnston and Chatterton, 1991; Higgins *et al*., 1991; Savoy and Harris, 1993; Richards *et al*., 1993).

During the Mesozoic and early Tertiary Columbian and Laramide orogenies, northeastward-directed overthrusting foreshortened the western part of the Upper Devonian and Carboniferous successions, displacing western deposits to the greatest extent (Douglas *et al*., 1970; Norris, 1965). Palinspastic reconstructions (courtesy of Shell Canada Limited) indicate that the deposits at Jura Creek were displaced by approximately 83 kilometres northeastward relative to the undeformed succession on the western Interior Platform. Their displacement relative to the Famennian and Carboniferous succession penetrated in one of the nearest Foothills boreholes (10-13-26-8W5) was about 49 kilometres. Because of the substantial lateral displacement, the Mississippian succession of the McConnell Thrust Sheet differs appreciably from that of the Foothills and adjacent Plains.

Stop Descriptions Late Afternoon Day 1

Stop 2-1. Upper Palliser Formation, Exshaw Formation (20.39 m thick), and member A (14.7 m thick) of the Banff Formation in gulch on southwestern side of Mount Rundle at elevation of approximately 6800 ft (2073 m).

To get to stop 2-1, park in the parking area for the Goat Creek hiking trail, situated on the northwestern side of the Smith-Dorrien/Spray Trail (gravel road, Highway 742) .6 km west of the reservoir in the high gap (White Man Gap) above Canmore. Park in the parking lot, and hike to stop 2-12 using the Goat Creek hiking trail and stream bed below the field trip stop. Hike west about .5 to .7 km along the Goat Creek trail and then head up through the bush on the steep alluvial fan at the base of the deep gulch on the southwestern corner of Mount Rundle. The hike from the parking lot to the stop requires about three quarters of an hour.

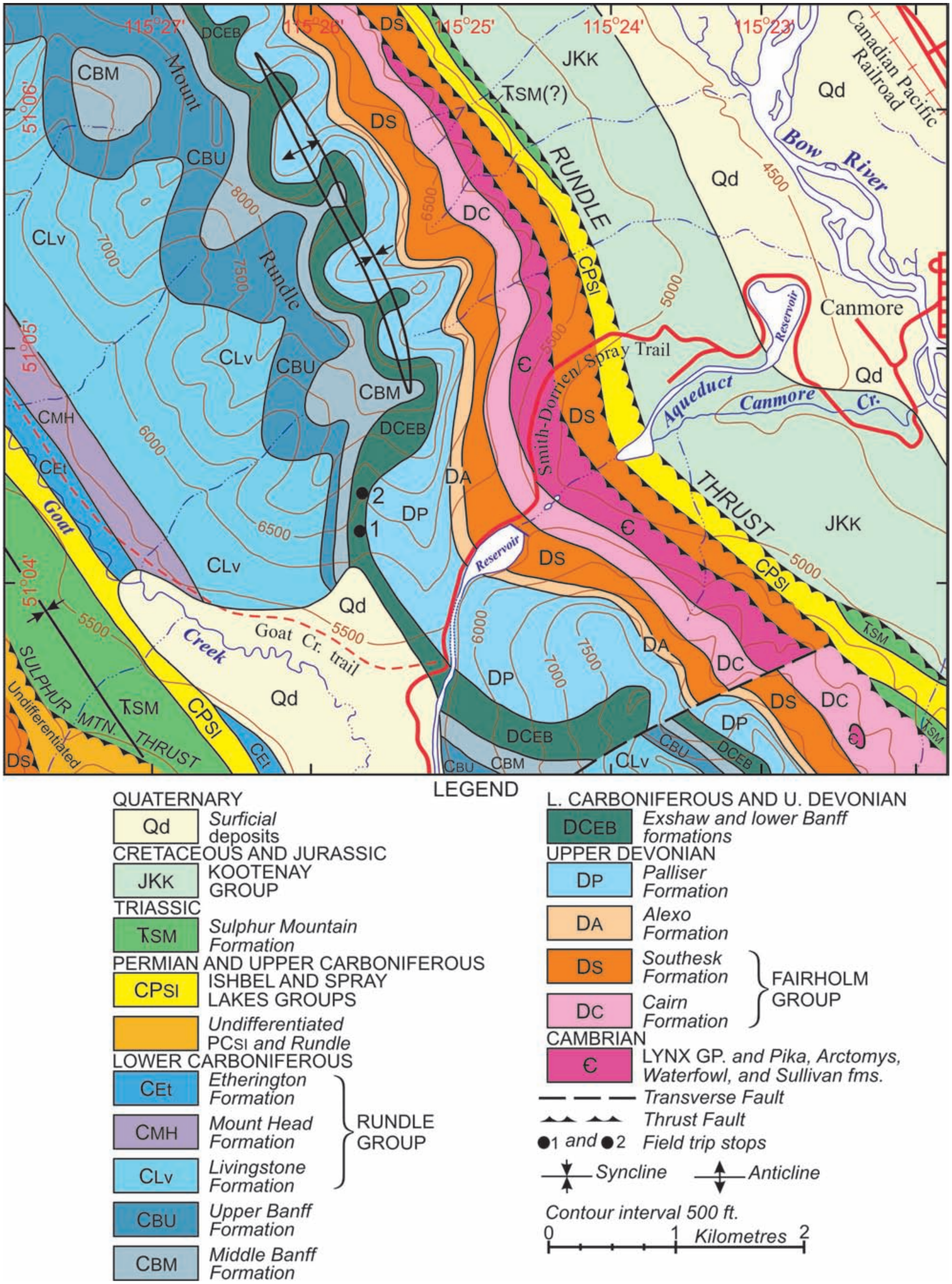

Figure 18. Simplified geological map (modified from Price, 1970) showing geology of region southwest of Canmore, south-western Alberta and location of field-trip stops 2-1 and 2-2 for the norning of day 2 on southwestern side of Mt. Rundle.

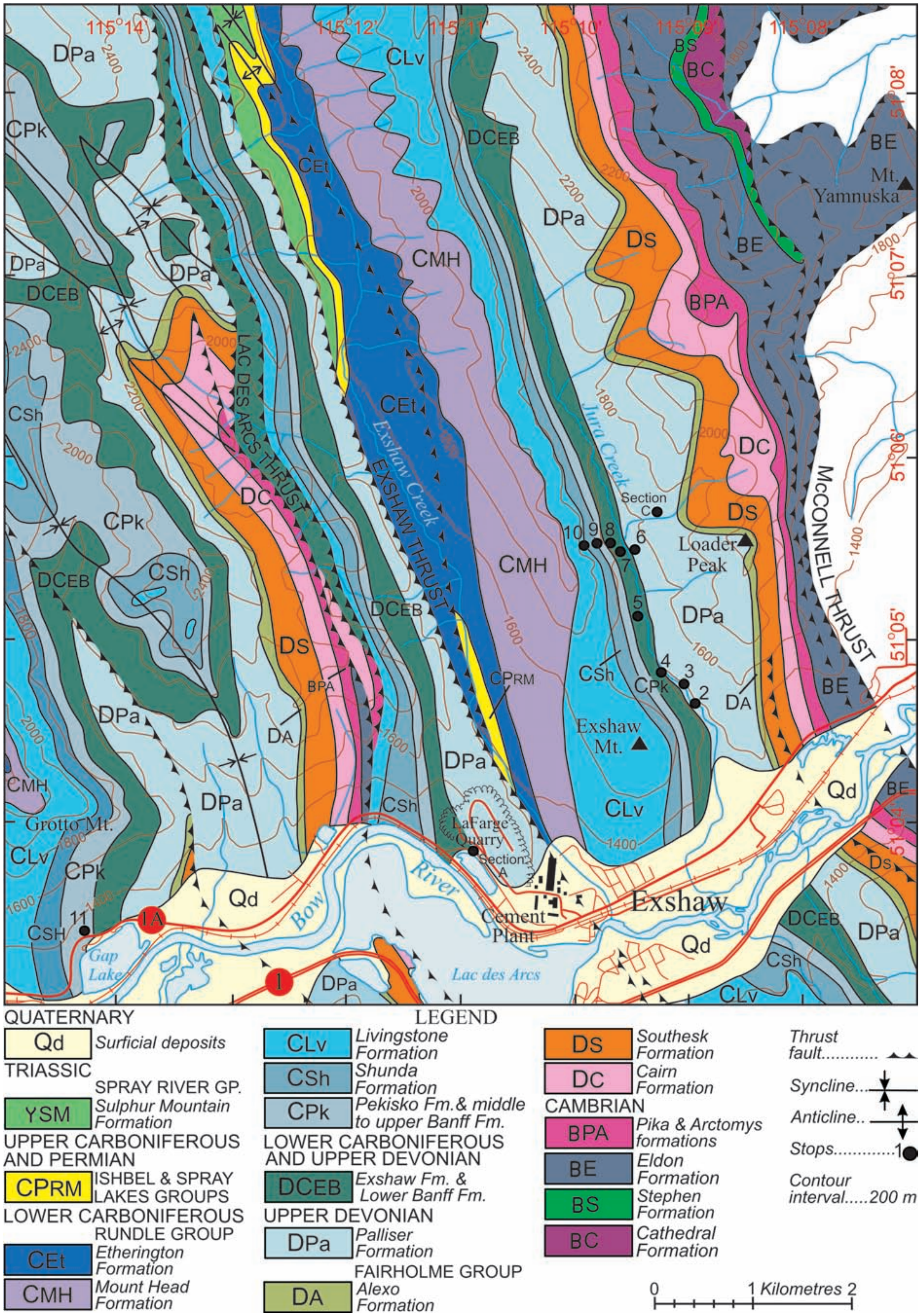

Figure 19. Geological map of the Jura Creek region, eastern Rocky Mountain Front Ranges, southwestern Alberta. Map shows section locations discussed in text and location of stops 2-2 to 2-11 for day 2. Geology modified from Price (1970).

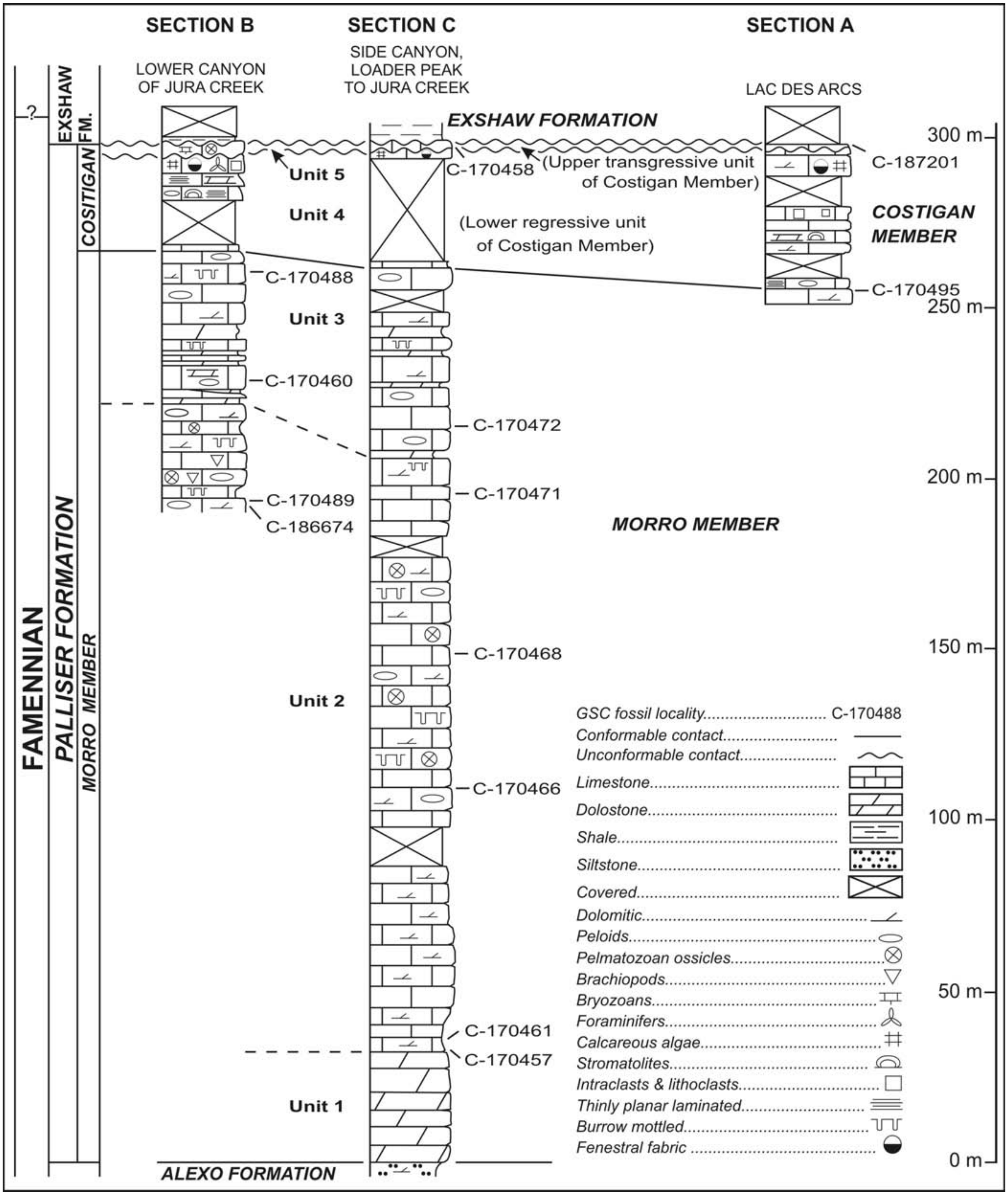

Figure 20. Generalized cross-section showing location of selected GSC fossil localities and the lithology and lithostratigraphic relationships of Famennian units in the Exshaw region, eastern Rocky Mountains, southwestern Alberta.

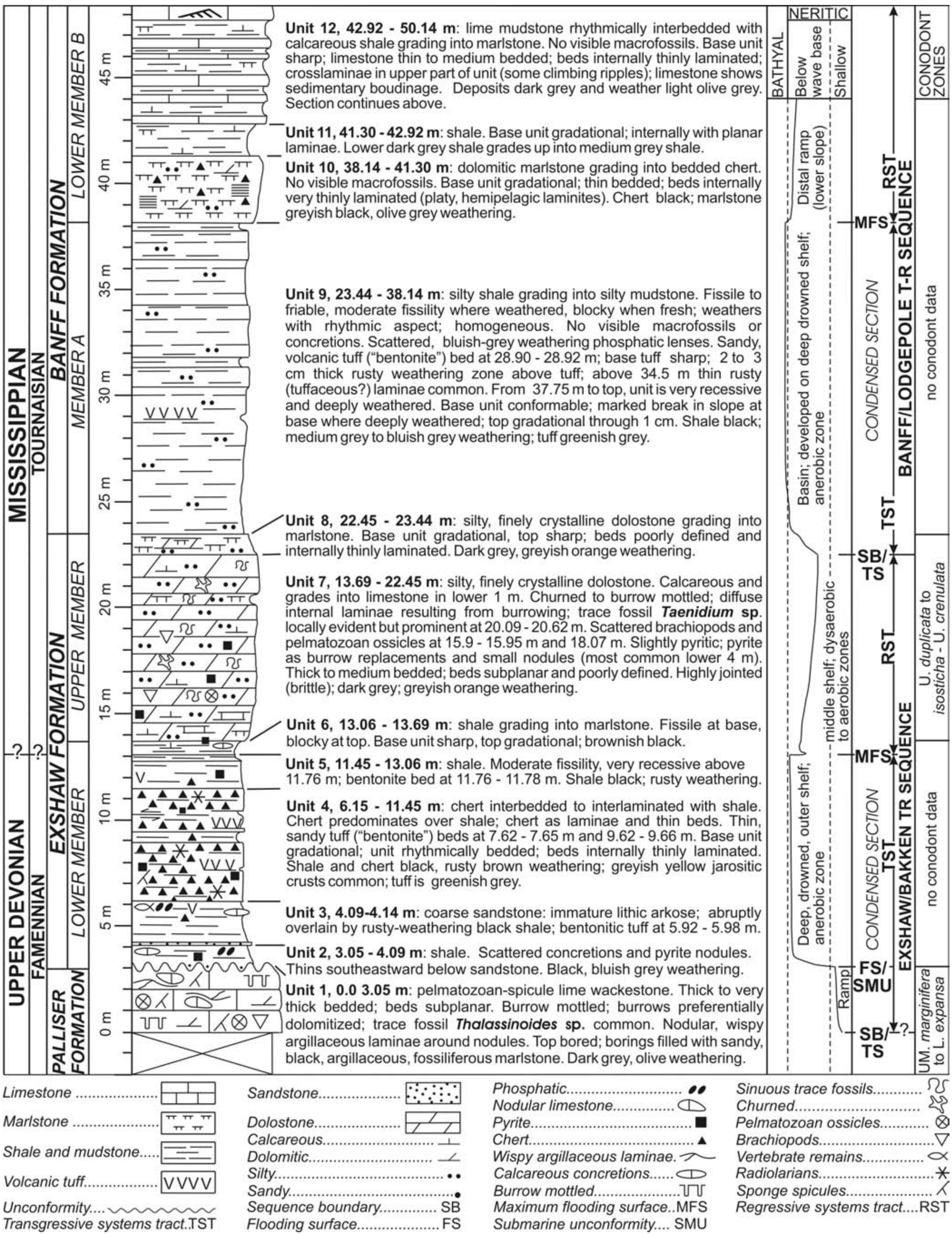

Figure 21. Columnar section showing characteristics and stratigraphic relationships of the upper Famennian to lower Tournaisian Exshaw Formation and overlying lower Banff Formation at stop 2-1 (Fig. 18), south end of Mount Rundle.

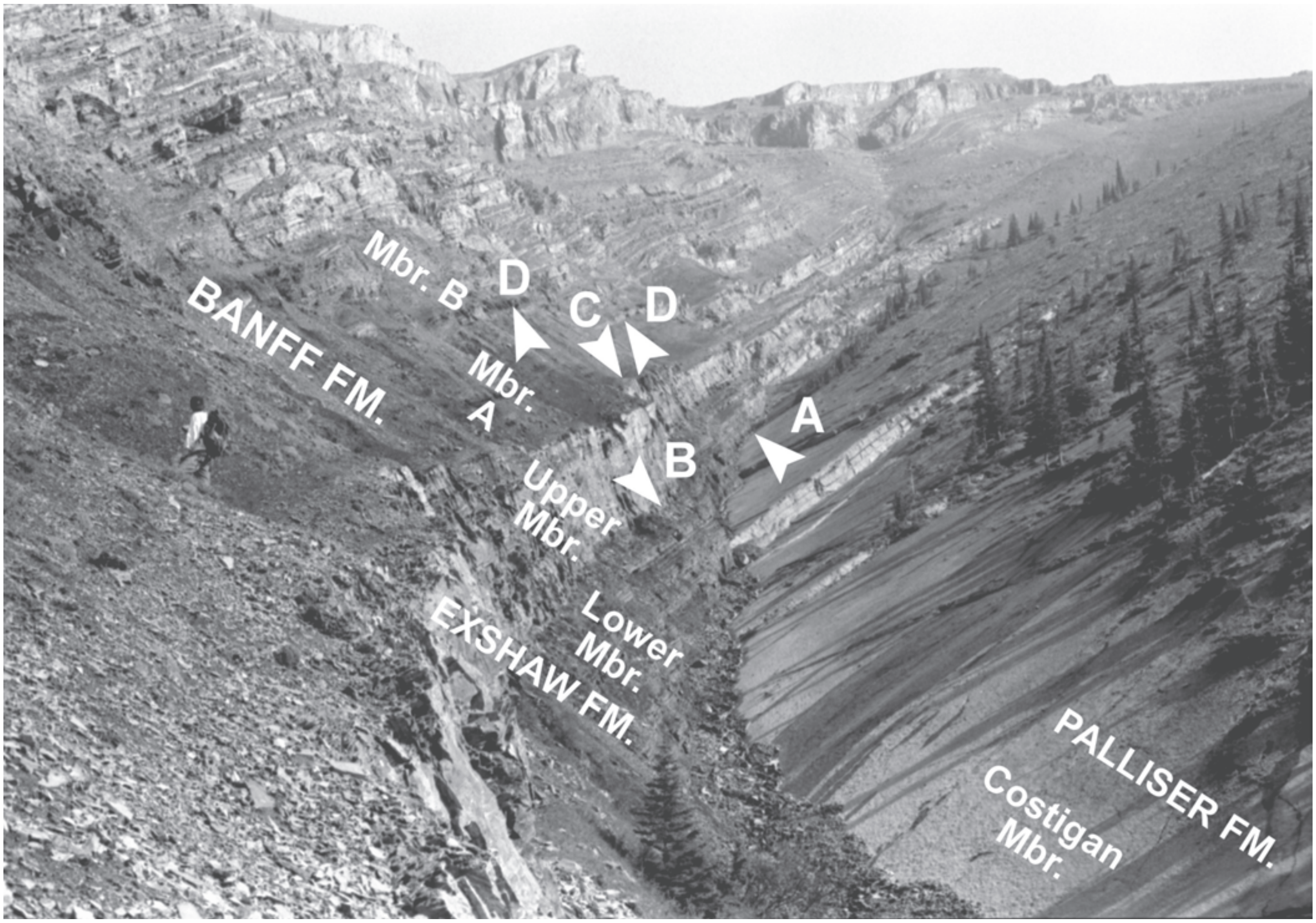

Figure 22. Famennian Palliser Formation, Famennian to lower Tournaisian Exshaw Formation (20.4 m thick), and Tournaisian Banff Formation at stops 2-1 and 2-2 on the southwestern side of Mount Rundle (Fig. 18). Stop 1 is in the foreground, whereas 2 is by the last trees in upper part of canyon. Both the lower member of the Exshaw and member A of the Banff are black shale. The view is toward the north. Arrows indicate: A- top Costigan Member of Palliser and base lower member Exshaw, B- contact between lower and upper members of Exshaw, C- contact between Exshaw and Banff , D- top lower black shale (member A) of Banff.

At the locality (Figs. 18, 21, 22), the upper Famennian to lower Tournaisian Exshaw Formation is extensively exposed. It overlies the burrow-mottled, argillaceous pelmatozoan-spicule lime wackestone of the upper Palliser Formation (only 3.05 m are exposed). The abrupt Palliser/Exshaw contact lacks evidence for subaerial exposure and erosion and is interpreted to be either a minor submarine erosion surface or a hard ground. The lower member of the Exshaw resembles that of the type section at Jura Creek by comprising a siliceous black shale unit (10.01 m thick) overlain by a slightly calcareous black shale unit (63 cm thick). The siliceous shale unit is distinguished from that of the type Exshaw by the presence of abundant, black, bedded chert. Calcareous concretions are moderately common in the siliceous shale unit.

A thin (5 to 6 cm thick) sandstone bed (arkose) is present in the black shale member 1.09 m above its base, and a thin (3 cm thick) bed of volcanic, ash-fall tuff lies 6.58 m above the base of the Exshaw.

The upper member of the Exshaw is 9.75 m thick and consists of strongly bioturbated, silty, argillaceous limestone grading upward into silty dolostone and dolomitic siltstone. Disarticulated brachiopods, concentrated into thin beds, are locally present in the upper member. Primary sedimentary structures other than planar bedding are rare, but poorly defined trace fossils resembling *Taenidium* sp. and *Helminthopsis* sp. are locally common.

The upper one metre of the upper member grades upward into the overlying black shale and mudstone of member A of the Banff Formation. Member A, 14.7 m thick, contains a thin (2 to 3 cm thick) bed of light grey volcanic tuff at 5.36 m above its base. Spiculite and carbonates of member B of the Banff conformably overlie member A.

Environmental Interpretations

The lower member of the Exshaw records deposition in basin and drowned-shelf settings. In the Mount Rundle to Jura Creek region, it was deposited in the anaerobic to dysaerobic zones and in moderately deep water (below storm wave base, but probably less than 300 m). The establishment of oxygen-deficient (anoxic) bottom conditions, recorded by high percentages of sulfides and absence of trace fossils and benthos in most of the lower Exshaw, may have resulted from high organic input. Parrish (1982) suggested that this region was one of upwelling. It would, therefore, have been an area with high organic productivity in surface layers of the ocean. The latter interpretation is supported by the high SiO_2, P_2O_5 and organic-carbon content of the lower Exshaw. The presence of these deposits above the Palliser Formation, records the culmination of a regional transgression and episode of marked water deepening (Richards *et al*., 1993, 1994a).

The upper Exshaw records shallowing, regression, and deposition in aerobic to dysaerobic environments at moderate-water depths. In the southern Rockies, including the Mount Rundle area, most of this member was probably deposited below storm wave base. Such a setting is suggested by the fine-grained, dark-coloured deposits, the presence of a trace fossil assemblage dominated by grazing traces, and the apparent absence of wave- and current-formed structures. Part of the upper member in the Foothills and region to the east was probably deposited in shallow-marine environments (above storm-wave base to shallow neritic) as it contains hummocky crossbedding, small- to medium-scale cross-stratification of wave-formed aspect and is locally overlain by ooid lime grainstone in the lower Banff Formation.

Member A of the Banff Formation was deposited in moderately deep water (well below storm-wave base). Deposition in such a setting is indicated by its lithology (condensed section dominated by black shale and mudstone), the presence of turbidites at some locations, regional facies relationships (Figs. 13, 15), and the absence of wave-formed sedimentary structures. A regional transgression and episode of marked water deepening is recorded by the presence of these deposits above the Exshaw Formation.

At stop 2-1, the uppermost Costigan Member of the Palliser and overlying Exshaw Formation were sampled for conodonts by the authors and others, but few elements have been recovered. In contrast, samples from the upper Costigan Member at stop 2-2 yielded relatively numerous elements representing several species, discussed under stop 2-2.

Stop 2-2. Upper Palliser Formation and overlying lower Exshaw Formation; upstream from stop 2-1 and on eastern side of the gulch at an elevation of approximately 7,100 ft (2,164 m). To reach this locality from stop 2-1, either hike up the extensive dip slope developed on the Palliser Formation or walk along the ledge on top of the lower Exshaw.

The upper 14.3 m of the Costigan Member are well exposed along an escarpment formed from a high-angle, northeasterly striking fault. The top of the underlying Morro Member is covered, but the contact with the overlying Exshaw is extensively exposed. Two main units constitute the Costigan at this stop. The lower unit, 12.5 m thick, becomes more resistant upward and comprises bioturbated, skeletal lime wackestone that locally contains abundant brachiopods. Many beds are argillaceous and slightly nodular. The upper 2.15 m of the member is a sharp-based unit comprising pelmatozoan-spicule lime wackestone to packstone locally containing large nautiloids. The upper 2.15 m closely resembles the upper transgressive unit of the Costigan along Jura Creek.

The restricted-ramp lithofacies that dominate the Costigan along Jura Creek are not present, and most of the member comprises open-marine facies characteristic of the middle-ramp setting of Famennian carbonate ramps (Fig. 8). Between Grotto Mountain and this locality, the restricted-marine deposits have graded basinward into open-marine facies.

Conodont Biostratigraphy

The upper Costigan Member at stop 2-2 was extensively sampled for conodonts by Richards. The results from the processing of two samples and the identification of the conodont elements within them by D.I. Johnston are presented here. A sample collected between 5 and 25 cm below the upper transgressive unit of the Costigan (2.4 - 2.2 m below base Exshaw Formation) at GSC locality C-226475 yielded *Bispathodus stabilis* (Branson and Mehl) morphotype 1 of Ziegler, Sandberg and Austin, 1974; *Branmehla* cf. *B. ampla* (Branson and Mehl); "*Icriodus*" cf. *I. raymondi* Sandberg and Ziegler; *Mehlina* cf. *M. strigosa* (Branson and Mehl); *Polygnathus communis communis* Branson and Mehl; *Polygnathus perplexus* Thomas; *Polygnathus* cf. *P. homoirregularis* Ziegler *sensu* Sandberg and Ziegler (1979) and *Polygnathus semicostatus* Branson and Mehl. This fauna is questionably assigned to the Uppermost *marginifera* to Lower *trachytera* zones. The second sample (GSC loc. C-226476), collected between 55 and 65cm above the base of the upper transgressive unit of the Costigan (1.6 to 1.5 m below base Exshaw), contains *Apatognathus*? cf. *A. varians* Branson and Mehl; *Bispathodus stabilis* (Branson and Mehl) Morphotype 1 of Ziegler, Sandberg and Austin (1974); *Bispathodus* cf. *B. stabilis* (Branson and Mehl); *Branmehla*? sp.; *Mehlina* cf. *M. strigosa* (Branson and Mehl); *Polygnathus communis communis* Branson and Mehl; *Polygnathus perplexus* Thomas; and *Polygnathus semicostatus* Branson and Mehl. The fauna from GSC loc. C-226476 is assigned to the Upper *marginifera* to Upper *expansa* zones (D.I Johnston, GSC paleontological report 02-DIJ-1995).

Return to vehicles at White Man Gap and drive northeastward to the dam at the northeast end of the reservoir. Park at the dam and hike down into the deep canyon containing Grassi Lakes and Canmore Creek to examine the Upper Devonian succession. At the end of the hike we will be picked up by the power plant.

Stop Descriptions Morning To Early Afternoon Of Day 2

Stop 2-1. Structural overview of Exshaw region from Highway 1X from entrance to large shale quarry in Upper Cretaceous Wapiabi Formation on south side of the Bow River. From this stop, the McConnell Thrust (Fig. 23, arrows A), which places Middle Cambrian carbonates of the Eldon Formation on Upper Cretaceous shale and sandstone of the Brazeau Formation, is well exposed at the base of the Eldon cliff on Mt. Yamnuska (also called Mt. John Laurie). On

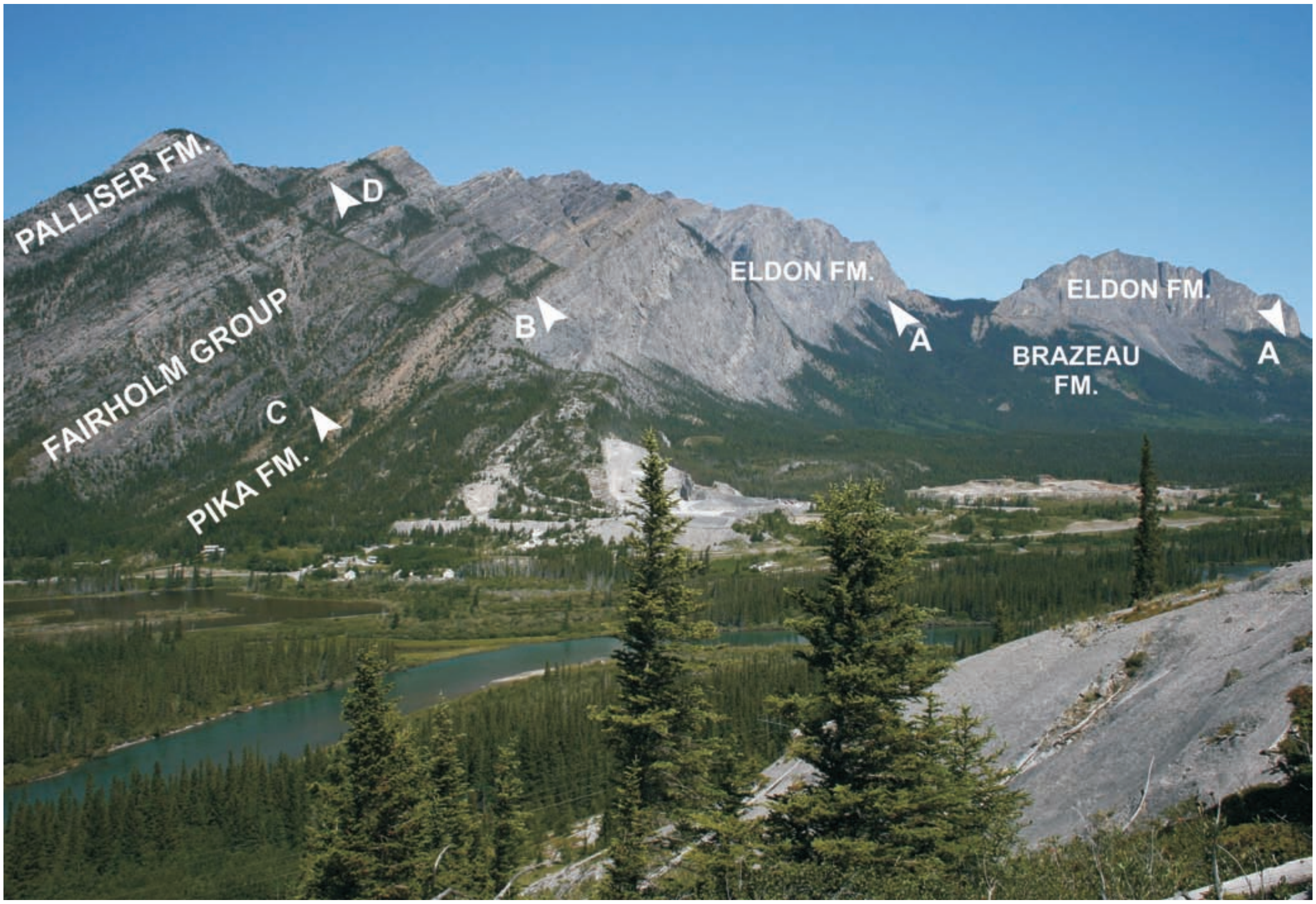

Figure 23. Looking north across Bow Valley to McConnell Thrust Sheet (arrows A indicate base) near Exshaw, Alberta. Mount Yamnuska (a klippe) lies at upper right; mountain in centre is Loader Peak. Upper Cretaceous shale and sandstone of Brazeau Formation is exposed in footwall of the McConnell Thrust Fault, and Middle Cambrian carbonates of Eldon Formation form light grey cliffs in lower hanging wall. Recessive carbonates of Middle Cambrian Pika Formation (arrow B indicates base) overlie Eldon and are unconformably overlain by Upper Devonian (Frasnian) carbonates of the Fairholme Group (arrow C indicates base); overlying Famennian Palliser Formation (arrow D indicates base) caps Loader Peak and forms prominent dipslope. Valley left (west) of Loader Peak contains Jura Creek and stops 2 -10.

Loader Peak, southwest of Mt. Yamnuska, the light grey Eldon is conformably overlain by brown-weathering carbonates of the Middle Cambrian Pika Formation, in turn unconformably overlain by medium grey dolostone of the Upper Devonian (Frasnian) Fairholme Group (arrow C indicates base). Light grey, cliff-forming carbonates of the Upper Devonian (Famennian) Palliser Formation are exposed on upper Loader Peak. Jura Creek (Fig. 19) runs along the valley developed on the southwest side of Loader Peak.

From stop 2-4 drive, via highways 1X and 1A, to Jura Creek for stops 2-2 to 2-10. Continue north on Highway 1X to the junction with Highway 1A then turn left and drive southwestward to Jura Creek, passing the lime plant of Graymont Western Canada Limited. Park on the side of Highway 1A near the location that the highway crosses Jura Creek.

The trek to the outcrops along Jura Creek starts on a broad, Quaternary alluvial fan developed at the mouth of the lower canyon of the creek. Along the western side of the fan, the lower Tournaisian Banff Formation, a coarsening- and shallowing-upward succession of distal- to middle-ramp carbonates (silty dolostone passing upward into lime wackestone, packstone and grainstone), is well exposed (Fig. 24). Overlying carbonates of the lower Rundle Group are extensively exposed on the slopes above. Continue north on the fan to the mouth of the canyon. If the creek is dry, walk upstream through the canyon to stop 2-2. Medium- to thick-bedded, fossiliferous, burrow-mottled, intraclast-peloid lime wackestone and packstone of the Famennian Morro Member of the Palliser are well exposed in the narrow canyon. If the stream is running, take the trail that starts on the west bank immediately downstream from the canyon entrance. The trail runs above the southwestern side of the canyon, entering the canyon upstream from the narrows and about .5 km downstream from stop 2-2.

Stop 2-2. Outcrop of upper part of transgressive-regressive lower and middle Famennian Morro Member of Palliser Formation (Fig. 5, 19, 25), head of lower canyon of Jura Creek, west side of creek, 1.6 km upstream from Highway 1A.

The upper part of the Morro Member comprises

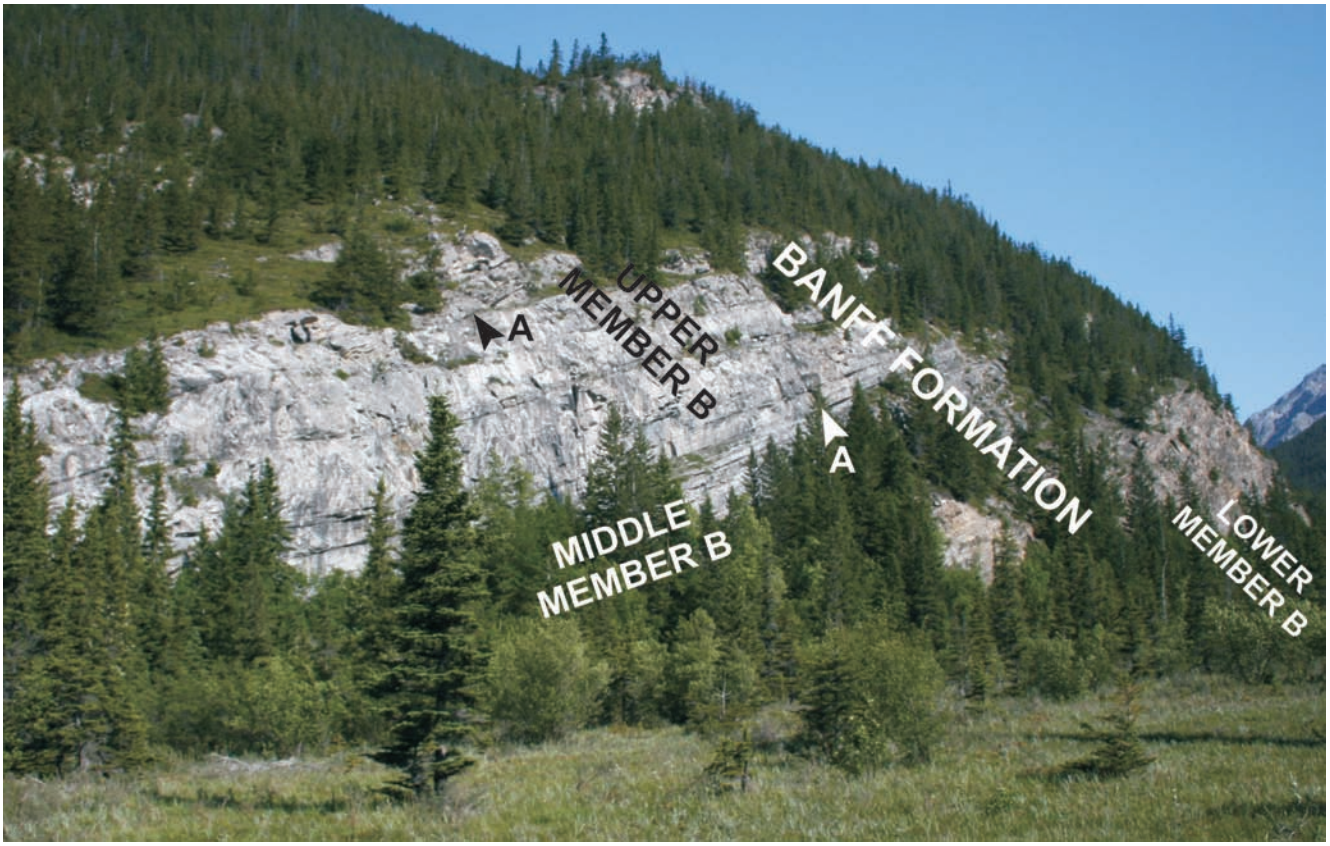

Figure 24. Lower Tournaisian Banff Formation along western side of alluvial fan developed at mouth of lower canyon of Jura Creek. The Banff comprises distal- to middle-ramp deposits (silty dolostone passing upward into lime wackestone, packstone and grainstone). Arrow A indicates contact between medium bedded skeletal lime wackestone and packstone of middle member B and the overlying thick to very thick bedded bryozoan-pelmatozoan lime grainstone of upper member B. Arrow B indicates large-scale cross-stratification developed in a submarine paleochannel fill.

Figure 25. Outcrop of middle Famennian, middle-ramp deposits of upper Morro Member of Palliser Formation at stop 2-2 (day 2) at head of lower canyon of Jura Creek, McConnell Thrust Sheet, southwestern Alberta. Recessive units are dolostone, resistant units are burrow-mottled, dolomitic lime wackestone and packstone. Man at lower left indicates scale, view is toward southwest.

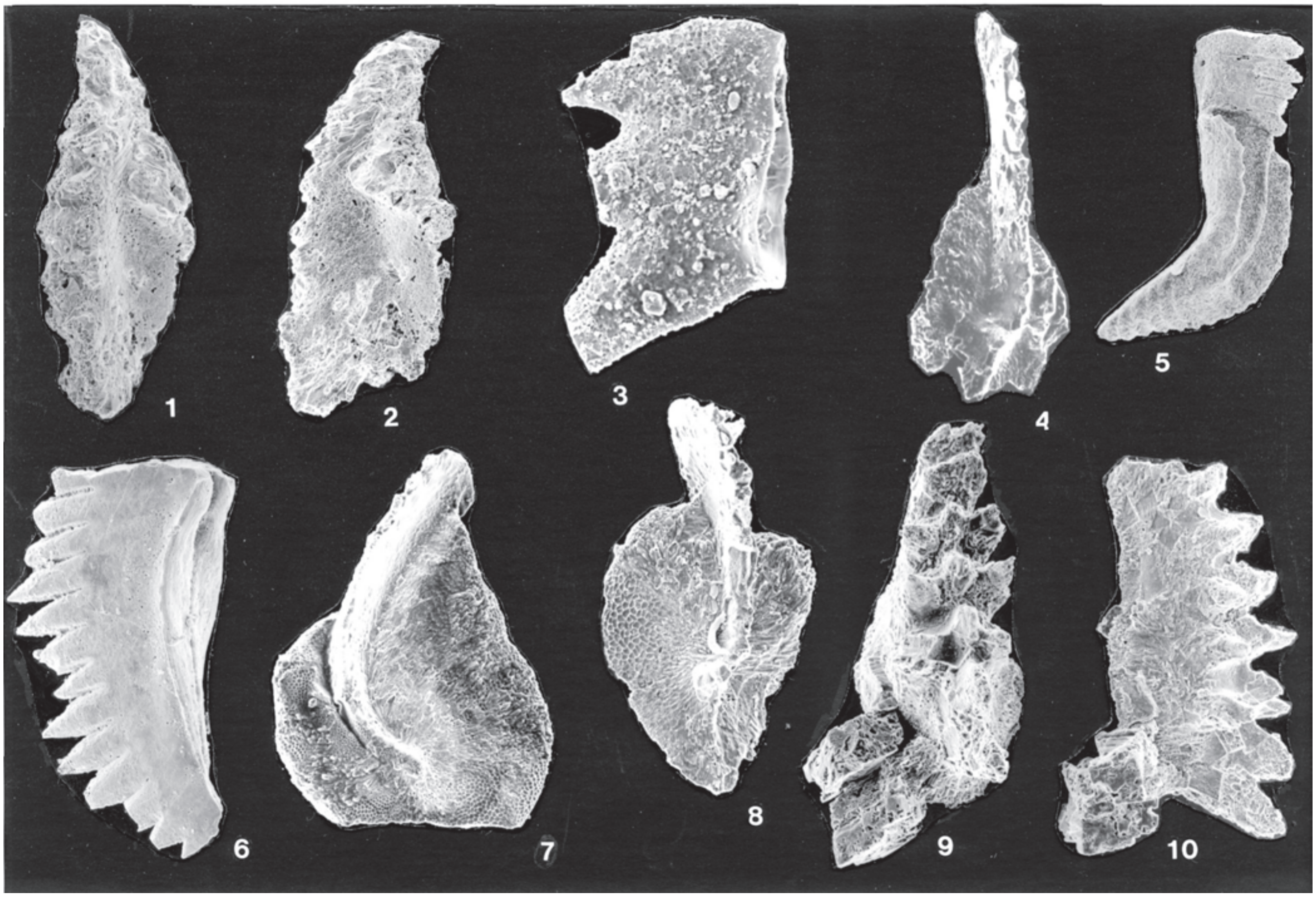

Plate 1. All figures are scanning electron micrographs of hypotypes. The specimens are from samples collected along Jura Creek and its tributaries, map area NTS 82 0/3, eastern Rocky Mountains, southwestern Alberta. All specimens are housed in the National Type Collections of Invertebrate and Plant Fossils at the Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario K1A 0E8.

Figures 1, 2. *Icriodus iowaensis ancylus* Sandberg and Dreesen, 1- oblique upper view, 2- lateral view of same specimen, GSC 100324, both X106; GSC loc. C-170468, from section C (Fig. 19) measured in side canyon entering Jura Creek from Loader Peak, Morro Member of Palliser Formation, 150 m above base of Palliser, Famennian.

Figure 3. *Pelekysgnathus inclinatus* Thomas, lateral view, GSC 100325, X150; GSC loc. C-170458, below type section of Exshaw Formation, Costigan Member of Palliser Formation, 0.5 m below top of Costigan, upper Famennian.

Figure 4. *Palmatolepis quadrantinodosalobata* Sannemann, upper surface view of fragmentary specimen, GSC 100326, X88; GSC loc. C-170457, from section C (Fig. 19) in side canyon entering Jura Creek from Loader Peak, Morro Member of Palliser Formation, 33 m above base of Palliser.

Figure 5. *Polygnathus semicostatus* Branson and Mehl, oblique upper view, GSC 100326, X55; GSC loc. C-170489, section B (Fig. 19) near head of lower canyon of Jura Creek, Morro Member of Palliser Formation, 102.6 m below top of Palliser, Famennian.

Figure 6. *Bispathodus stabilis* (Branson and Mehl) morphotype 2 Ziegler, Sandberg and Austin, lateral view, GSC 100328, X87; GSC loc. C-170458, below type section of Exshaw Formation, Costigan Member of Palliser Formation, 0.5 m below top of Costigan, upper Famennian.

Figure 7. *Palmatolepis stoppeli* Sandberg and Ziegler, upper surface view, GSC 100329, X86; GSC loc. C-170488, section B (Fig. 19) head lower canyon of Jura Creek, Morro Member of Palliser Formation, 38.2 to 38.4 m below top of Palliser, middle Famennian.

Figure 8. *Palmatolepis rhomboidea* Sannemann, upper surface view, GSC 100330, X96; GSC loc. C-170489, section B (Fig. 19) near head lower canyon of Jura Creek, Morro Member of Palliser Formation 102.6 m below top of Palliser, Famennian.

Figures 9, 10. *"Icriodus" cornutus* Sannemann, 9- upper surface view, GSC 100331, X96; 10- lateral view of same specimen, GSC 100331, X87; GSC loc. C-170466, section C (Fig. 19) in side canyon entering Jura Creek from Loader Peak, Morro Member of Palliser Formation, 109 m above base of Palliser Formation, Famennian.

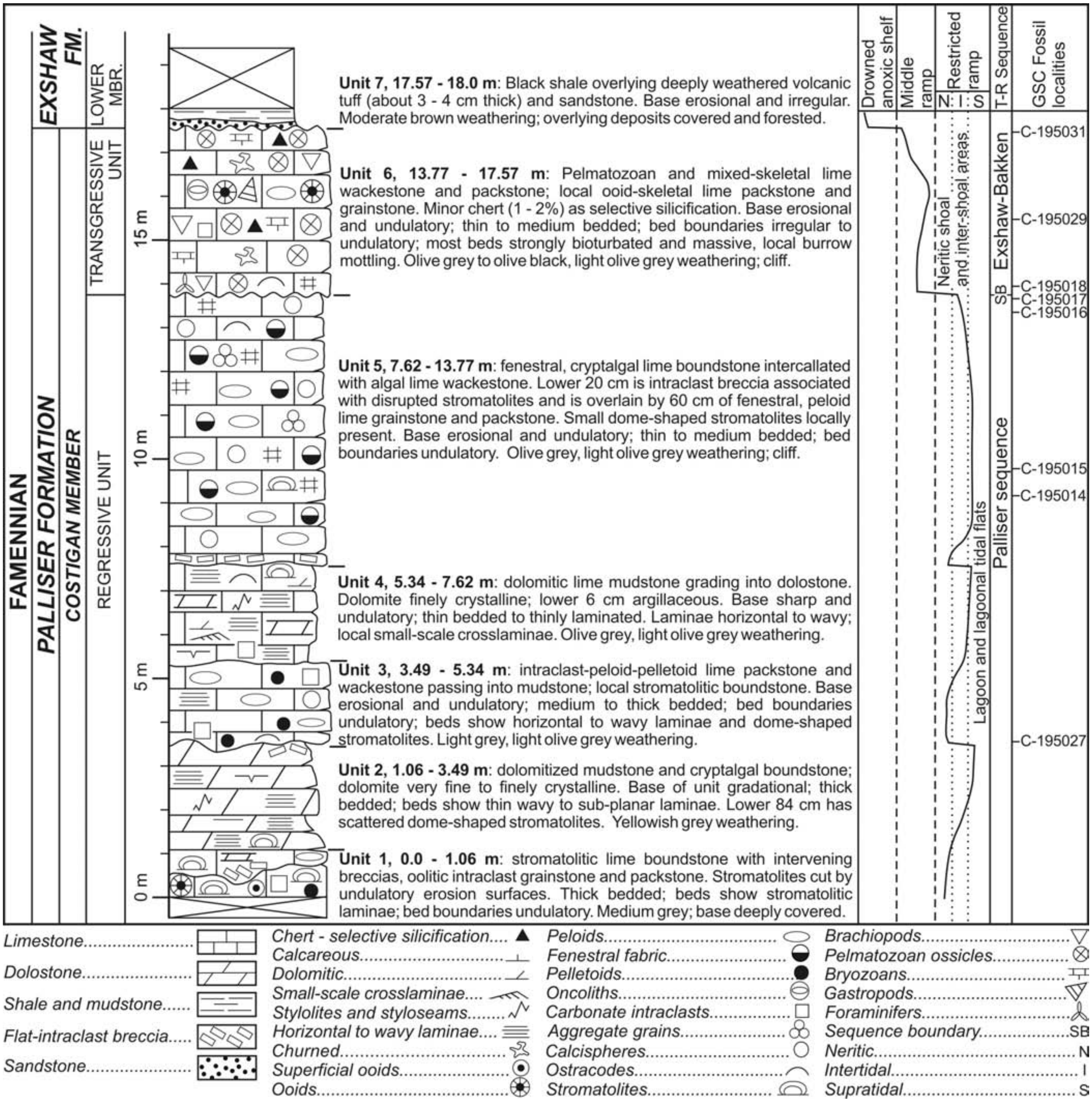

Figure 27. Stratigraphic column showing the rock types and sedimentary structures present in Costigan Member of Palliser Formation at stop 2-4 (Fig. 19), slightly upstream from lower canyon of Jura Creek.

medium- to thick-bedded, burrow-mottled, dolomitic, peloid-intraclast lime wackestone and packstone with subordinate finely crystalline, highly jointed dolostone. The lithofacies were deposited mainly in neritic, middle-ramp environments (Fig. 8); some of the dolostone units may be of intertidal to supratidal origin.

Conodont Biostratigraphy

Conodont data indicate the Morro Member is of early and middle Famennian age in the Jura Creek and Mount Rundle regions (Johnston and Chatterton, 1991; Richards *et al*., 1991; Meijer Drees and Johnston, 1994). On the whole, conodont yields from this member were low and preservation poor at Jura Creek but improved southwestward. Figure 11 illustrates the established ranges of the principal Famennian conodonts discussed in this guidebook.

Conodont data from strata in middle section B (Fig. 20; GSC locs. C-186674, C-170489, C-170460, C-170488), near the head of the lower canyon of Jura Creek, indicate the presence of strata as old as the Lower *rhomboidea* Zone to as young as the Lower *Palmatolepis marginifera margin-*

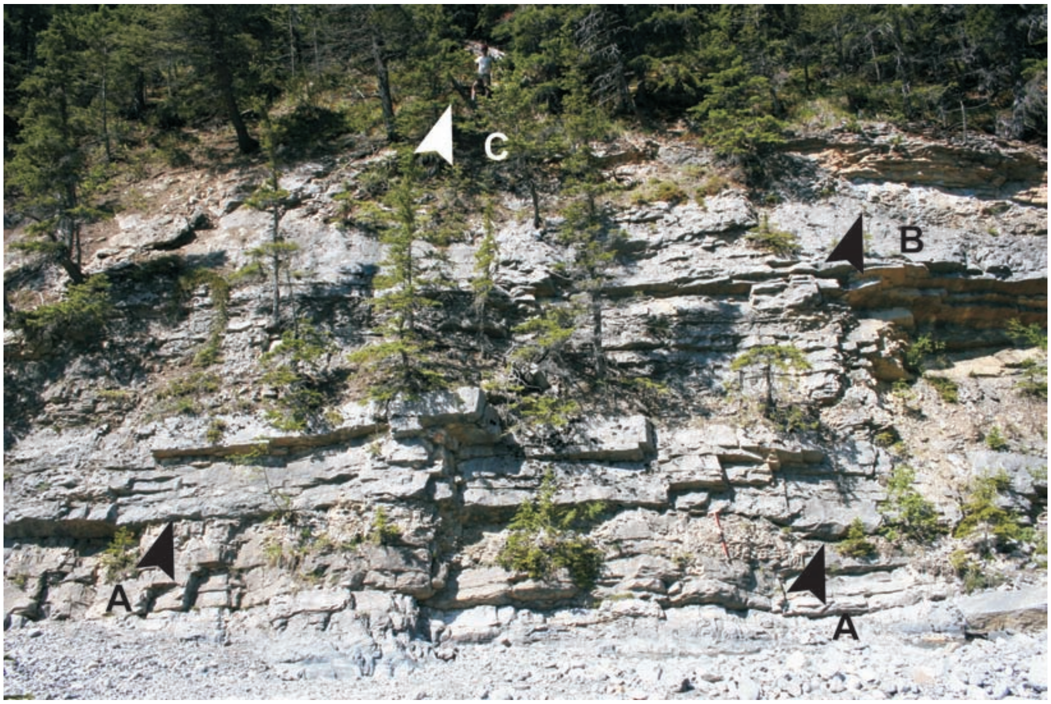

Figure 26. Outcrop of the Costigan Member of the Palliser Formation at stop 2-4 (Fig. 19) in valley slightly upstream from lower canyon of Jura Creek. Arrows indicate: A- prominent erosion surface in middle Famennian, restricted-ramp deposits of lower to middle Costigan, B- unconformity below upper Famennian, middle-ramp deposits of upper transgressive unit (3.8 m thick, Big Valley correlative) of uppermost Costigan and C- approximate base Exshaw Formation.

Figure 28. Stop 2-5 on Jura Creek; soft-sediment deformation (convoluted bedding showing isoclinal folds) in lower Banff Formation. The deposits, comprising silty dolostone grading into dolomitic siltstone and shale, resulted from slope instability during an episode of early Tournaisian subsidence in southern Prophet Trough.

Figure 29. Thin- to medium-bedded distal turbidites (CDE and DE sequences) near base of Banff Formation at stop 2-5 on Jura Creek. These early Tournaisian deposits consist of silty dolostone grading into dolomitic siltstone and shale.

Figure 30. Upper part of Costigan Member of Palliser Formation below type section of Exshaw Formation, stop 2-6 middle canyon of Jura Creek. Arrows indicate unconformity between middle Famennian restricted-shelf to proximal-ramp carbonates (algal lime wackestone, cryptalgal boundstone, stromatoporoid boundstone) and overlying upper Famennian, open-marine, skeletal lime packstone and wackestone of upper transgressive unit (2.0 m thick).

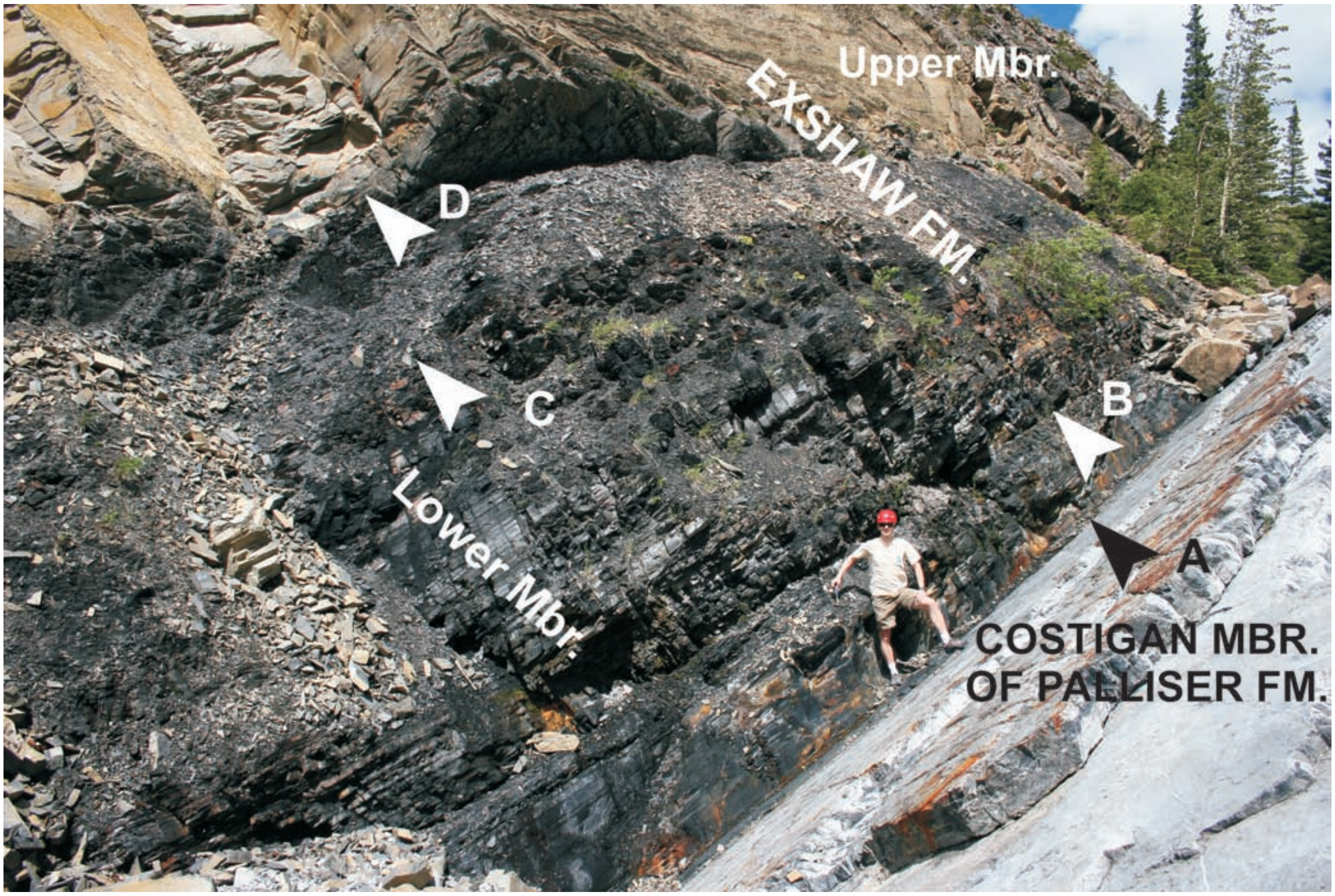

Figure 31. Upper Costigan Member of Palliser Formation and lower part of type section of Exshaw Formation at stop 2-6 in middle canyon of Jura Creek. Arrows show: A- erosional base of noncalcareous black-shale unit of lower member of Exshaw; B- thin (5.5 cm thick)volcanic tuff bed in lower member of Exshaw; C- abrupt base of the calcareous black-shale unit of lower member; and D- gradational basal contact of the upper member (silty limestone and siltstone) of Exshaw. View is toward northwest.

ifera Zone (Richards *et al*., 1994b). Faunas from the section included *Palmatolepis stoppeli* Sandberg and Ziegler, collected 38.2 to 38.4 m below the top of the Palliser Formation (GSC loc. C-170488). A sample from 102.6 m below the top of the Palliser at this section (GSC loc. C-170489) yielded *Palmatolepis rhomboidea* and *Polygnathus semicostatus. P. rhomboidea* first appears at the base of the *rhomboidea* Zone and ranges upward into the Lower *marginifera* Zone (Austin *et al*., 1985). *P. semicostatus* was also collected 71.2 m below the top of the Palliser. The presence of *P. stoppeli*, first appearing in the Upper *rhomboidea* Zone and ranging upward into the Lower *marginifera* Zone (Ziegler and Sandberg, 1984), indicates the top of the Morro Member would be no younger than the lower part of the latter zone (see Plate 1).

The overlying Costigan Member is of middle and late Famennian age in the Exshaw/Jura Creek region (Richards *et al*., 1994b). Basal beds of the Costigan probably lie within the Upper *rhomboidea* Zone as indicated by faunas from the upper Morro Member at section B (stop 2-2, Fig. 20). Along Jura Creek, strata between the Morro Member and upper transgressive unit of the Costigan yielded only long ranging taxa: *Polygnathus nodocostatus* Branson and Mehl, *P. semicostatus*, and *Apatognathus* spp. (GSC locs. C-165140, C-165144, C-136779, and C-195027).

Stop 2-3. Boundary between Famennian Morro and Costigan members of Palliser Formation, 1.7 km upstream from Highway 1A, about .1 km upstream from stop 2-2, east side of Jura Creek at head of lower canyon.

The middle Famennian uppermost Morro Member consists of dolomitic, bioturbated lime wackestone and packstone locally showing thin laminae and the trace fossil *Chondrites* sp. These deposits record the early phase of a regression that culminated with deposition of the restricted-ramp lithofacies of the overlying lower Costigan Member. In the Jura Creek region, the Morro Member and Costigan Member below the *Palmatolepis gracilis expansa* conodont Zone constitute a third-order T-R sequence. The lower sequence boundary is at the base of the Morro Member and the upper sequence boundary is in the upper part of the Costigan Member. In a comprehensive region study, Peterhänsl and Pratt (2008) divided this sequence into three T-R subsequences, which are widely developed but can not be not readily identified along Jura Creek. A maximum flooding surface is not clearly devel-

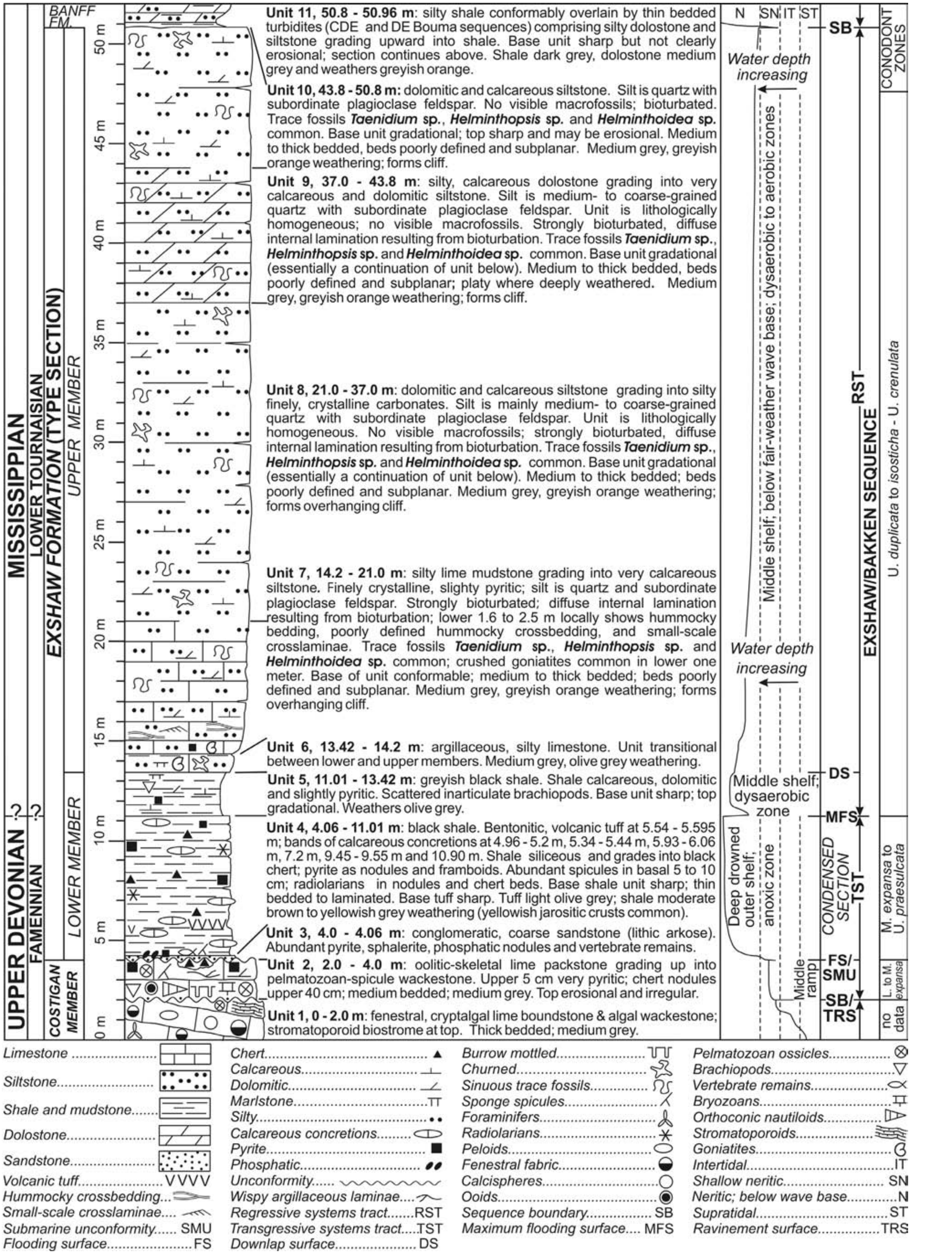

Figure 32. Columnar section of uppermost Palliser Formation and type section of the Exshaw Formation at stop 2-6 in middle canyon of Jura Creek.

Figure 33. Siliceous black shale in lower member of Exshaw Formation at stop 2-6 on Jura Creek. Exposure shows planar-laminated nature of the shale, a calcareous concretion and a thin (2.0 to 5.5 cm thick) recessive bed of bentonitic volcanic tuff (arrow) comprising potassium feldspar, quartz and mixed-layer clays.

oped and the transition between the TST and RST probably lies within the middle part of the Morro Member.

Dolomitic limestone of the lower Costigan Member shows thin sub-planar laminae, small-scale crosslaminae, and limestone intraclasts. The deposits at this stop were deposited in the shallow-neritic to intertidal environments on a middle-ramp setting.

Stop 2-4. Middle and upper Famennian upper Costigan Member of the Palliser Formation and uppermost Famennian to lower Tournaisian deposits of the basal Exshaw Formation (Figs. 19, 26, 27). The stop, 1.9 km upstream from Highway 1A, is the low cliff on the southwestern side of the valley immediately upstream from the head of the lower canyon of Jura Creek.

The lower 13.8 m of the Costigan Member at this outcrop is dominated by fenestral cryptalgal lime boundstone, algal lime wackestone, and intraclast-peloid lime wackestone to packstone. Also present are finely crystalline dolostone, peloid lime mudstone, and ooid-peloid lime grainstone. This lower interval has prominent erosion surfaces, stromatolites, breccias resulting from penecontemporaneous erosion, breccias caused by dissolution of evaporites, desiccation structures, and thin transgressive-regressive sequences. These strata, deposited mainly in middle- to restricted-ramp environments, record the culmination of the regional middle Famennian regression that commenced during deposition of the upper Morro Member.

The upper 3.8 m of the Costigan Member at this stop unconformably overlie the lower interval and are mainly bryozoan-pelmatozoan lime wackestone and packstone. This upper unit, unconformably overlain by poorly exposed black shale and deeply weathered volcanic tuff of the basal Exshaw Formation, records a late Famennian regional transgression. The latter is also recorded by the correlative upper Big Valley Formation to the east. The upper Costigan Member, together with the siliceous black shale and chert unit of the overlying Exshaw Formation, constitute the transgressive systems tract of the Exshaw/Bakken T-R sequence. The base of the latter sequence, lying at the base of the upper Costigan is interpreted to be a ravinement unconformity and a second-order sequence boundary.

Conodont biostratigraphy

Long-ranging conodonts dominated by *Apatognathus* sp. were collected from the lower 13.8 m of the Costigan. The most productive sample was collected from GSC locality C-195027 (3.5 to 3.6 m above base of outcrop). Conodont data from the Costigan at section A (Figs. 19, 20) and from the upper Morro Member along Jura Creek indicate the member below its upper transgressive unit is within the *marginifera* and *trachytera* zones in the Exshaw area.

The upper transgressive unit of the Costigan at this stop lies within the *expansa* conodont Zone, as indicated by conodont assemblages from this unit at stop 2-6. Only long-ranging conodonts were collected at stop 2-4.

Biostratigraphy of Foraminifers and Calcareous Algae

Abundant calcareous algae and scattered foraminifers are present in the Costigan Member at stop 2-4 (Richards *et al*., 1991, 1994b). The principal algae and foraminifers recognized in samples (GSC locs. C-195014 to C-195017) collected from the lagoonal and tidal-flat deposits of the lower Costigan (Fig. 27) include: "*Archaesphaera*" sp., *Brunsiina* sp., *Calcisphaera* sp., *Eotournayella* sp., *Glomospiranella* sp., *Issinella* sp., *Kamaena* sp., *Palaeoberesella* sp., *Parathurammina* sp., *Proninella* sp., *Protoumbella* sp., *Tournayella* sp. and "*Vicinesphaera*" sp. These assemblages, provisionally assigned to zone 2 of Mamet (1967), indicate a middle Famennian or slightly younger age. A sample (GSC loc. C-195018, 3.67 m below top of Costigan) collected from the upper transgressive unit of the Costigan at stop 2-4 contains an assemblage that is also provisionally assigned to zone 2 and contains: *Brunsiina* sp., *Calcisphaera* sp., *Eotournayella* sp., *Girvinella* sp., *Glomospiranella* sp., *Issinella* sp., *Kamaena* sp., *Palaeoberesella* sp. and *Tournayella* sp.

Stop 2-5. Transgressive, lower Tournaisian deposits of lowermost Banff Formation, west bank of Jura Creek, in valley 2.25 km upstream from Highway 1A.

Convoluted bedding resulting from penecontemporaneous soft-sediment deformation is common at the southern end of the outcrop (Fig. 28). Sparsely fossiliferous, silty dolostone grading into dolomitic siltstone constitute the convoluted beds, which are overlain by turbidites grading upward into thinly planar-laminated, hemipelagic, silty dolostone. Slightly down section, thin-bedded, distal turbidites (CDE and DE sequences) are well exposed (Fig. 29). The latter, lying immediately above the Exshaw Formation, comprise silty dolostone and dolomitic siltstone grading upward into shale. Siltstone of the upper member of the Exshaw Formation is exposed in the creek bed immediately below the turbidites, but the contact between the Exshaw and Banff is generally covered by stream gravel.

The Banff constitutes a second-order T-R sequence (Banff\Lodgepole sequence). The lower sequence boundary is the major flooding surface at the base of the Banff Formation. In the Jura Creek area, the lower sequence boundary is sharp but further west it is gradational. At stop 2-5, the TST of the Banff/Lodgepole sequence is poorly developed and appears to be represented by a thin, lower, dark grey shale unit overlain by a unit comprising siltstone turbidites and convoluted beds.

Stop 2-6. Middle canyon of Jura Creek, 3.1 km upstream from Highway 1A (Fig. 19). The lower regressive unit and overlying upper transgressive unit of the Costigan Member of the Famennian Palliser Formation (Figs. 30, 31) are exposed on the east side of Jura Creek. The type section of the uppermost Famennian to lower Tournaisian Exshaw Formation, 46.8 m thick, is exposed on the west side (Fig. 32).

Only the upper beds of the lower regressive unit of the Costigan, deposited in middle- and restricted-ramp settings, are exposed. They are dominated by algal lime wackestone to packstone and fenestral, cryptalgal lime boundstone yielding calcareous algae and foraminifers assignable to zone 2 of Mamet (1967) and long-ranging conodonts. At the northwestern end of the exposure, the tabular stromatoporoid, *Labechia palliseri* Stern, is preserved at the top of the unit and forms a small biostrome.

The lower regressive unit is unconformably overlain by upper Famennian deposits of the uppermost Costigan (2.0 m thick). At the northwestern end of the exposure, the stromatoporoids in the upper part of the lower Costigan are truncated at the contact and an angular relationship is evident. The upper two metres of the Costigan records a late Famennian regional transgression and comprises bryozoan-pelmatozoan lime packstone to wackestone with subordinate lime grainstone.

The Exshaw, which abruptly overlies the Costigan Member, comprises a lower shale-dominated member (9.42 m thick) gradationally overlain by an upper member (37.5 m thick) consisting of dolomitic siltstone and silty limestone (Figs. 31, 32). The abrupt Palliser/Exshaw contact is erosional, showing minor irregular relief below a thin sandstone and conglomerate bed; but the surface lacks evidence for subaerial exposure and erosion.

The lower member, containing the Devonian/Carboniferous boundary, consists of a thin, (2 to 6 cm thick) basal phosphatic sandstone and conglomerate bed, a middle unit of noncalcareous black shale and chert (6.95 m thick), and an upper unit of calcareous shale (2.41 m thick). The middle unit is mainly planar-laminated, pyritic, sparsely fossiliferous, shale. It also contains calcareous concretions and a thin tuff bed (5.5 cm thick, Fig. 33) consisting mainly of mixed-layer clays, potassium feldspar, and quartz. Sandstone of the basal Exshaw at this locality has a clast composition resembling that of the tuff bed and is probably reworked tuff. Beds of volcanic tuffs are relatively common at the base of the Exshaw at other localities in the eastern Rockies and grade into sandstone. Geochemical analyses indicate that the concentrations of nickel, zinc, and molybdenum are highest in the basal sandstone bed and decrease upward within the black shale unit. X-ray diffraction analyses (Richards *et al*., 2002b) indicate the basal sandstone contains up to 8% sphalerite (ZnS) and 2% vaesite (NiS_2).

Conodont assemblages, assigned to the Middle *expansa* to Upper *praesulcata* zones, have been extracted from the concretions in the lower member but have low species diversity and contain few specimens (Richards and Higgins, 1988; Richards *et al*., 1994b). The calcareous upper shale unit contains pyrite, inarticulate brachiopods, and rare Mississippian (Tournaisian) conodonts. Most of the lower member was deposited below storm wave base in the anaerobic and dysaerobic zones (Richards *et al*., 2002b).

The trace fossils *Taenidium* sp. and *Helminthopsis* sp. are abundant and conspicuous in the upper member, deposited in outer-neritic to upper-bathyal environments. Primary sedimentary structures other than subplanar bedding are not evident in most of the slightly pyritic, medium- to thick-bedded member. In the lower 1.6 to 2.5 metres of this unit, however, some smooth faces resulting from the spalling of large blocks display low-amplitude hummocky bedding, poorly defined hummocky crossbedding, and small-scale crosslaminae. Carboniferous conodonts occur in the lower limestone of this member but are rare (Macqueen and Sandberg, 1970).

The Exshaw Formation and underlying upper transgressive unit of the Costigan Member jointly constitute a second-order T-R sequence in which the upper Costigan and lower siliceous black shale unit constitute the transgressive systems tract. The maximum flooding surface of the sequence lies at the top of the siliceous black shale unit (a condensed section) of the lower member. Regional deepening, transgression, and establishment of anoxic bottom conditions are recorded by the lower black-shale unit. The upper part of the shale member records the onset of dysaerobic conditions and shallowing, which culminated with deposition of the upper member (Richards and Higgins, 1988). The RST of the sequence comprises the upper calcareous shale unit and the overlying upper member.

Pyroclastics and radiometric dating of the Exshaw

Two main categories of volcaniclastics occur in the Exshaw Formation of the Western Canada Sedimentary Basin: ash-fall crystal tuff and relatively clean arkosic sandstone to conglomerate. These two groups of volcaniclastics, also preserved in the overlying Banff Formation, grade into tuffaceous shale and carbonates. Most occurrences of the crystal tuff have been extensively altered to sandy clay (“bentonite”).Within the Exshaw Formation, all known occurrences of the crystal tuff are preserved in the lower member. Beds and laminae of yellowish-grey ash-fall tuff, up to 1.5 m thick, occur in the member at many localities from southwestern Alberta into east-central British Columbia (Macdonald, 1987; Richards *et al*. 2002b). They lie mainly in the lower siliceous shale and chert unit but are present locally in the upper calcareous shale unit. Macdonald (1987) recognized two main tuff horizons in the eastern Cordillera - one immediately above the basal sandstone of the lower member and the other in the upper part of the lower member. The study of Richards *et al*. (2002b) suggests that the thickest and most widely distributed tuff deposits occur at or near the base and top of the lower siliceous shale and chert unit.

Richards *et al*. (2002b) extracted zircons and monazite crystals from the ash-fall tuff beds in the Exshaw Formation at several locations in the WCSB for U-Pb dating. The tuff and related clays were selected for the analyses as they show less evidence for marine reworking and potential contamination by detrital grains than the arkosic sandstone to conglomerate. The monazite analyses from the Nordegg tuff, which we will see on day 4 of the field trip, gave the best age constraints with an excellent $^{207}Pb/^{235}U$ age of 363.34 ± 0.39 Ma. This result is in close agreement with the zircon data from the same tuff which give a $^{206}Pb/^{207}Pb$ age of 363.4 ± 3.1 Ma and illustrates the contrast in the error and precision of monazite versus zircon analyses. The analysis of monazites from a tuff bed at Red Deer Creek in east-central British Columbia resulted in $^{207}Pb/^{235}U$ ages of 361.1±1.0 Ma but there is scatter of uncertain origin in the data, therefore, it was not possible to assign crystallization ages with the same confidence as the Nordegg tuff.

The pyroclastics in the lower member of the Exshaw Formation and the lower shale unit (member A) of the overlying Banff Formation resulted from latest Devonian to Tournaisian volcanism and plutonism in western Prophet Trough and along a volcanic/plutonic belt to the west.

Using the Re-Os isotope system, Selby and Creaser (2005) obtained an age of 361.3 ± 2.4 Ma for the upper part of the siliceous black shale unit in the type section of the Exshaw. That age compares favourably to the one (360.7 ± 0.7 Ma) obtained by Trapp *et al*. (2004) through numerical interpolation of U-Pb zircon dates for the Devonian-Mississippian boundary in the Hasselbachtal section, an auxiliary stratotype section for the Devonian-Carboniferous boundary in Germany.

Conodont Biostratigraphy

Conodonts assigned to the Lower to Middle *expansa* zones were collected from the upper transgressive unit of the Costigan by Richards and Higgins (1988). The richest and most diverse assemblage was collected from GSC locality C-136780 (1.9 m below top of Costigan): *Polygnathus semicostatus* Branson and Mehl, *Polygnathus experplexus* Sandberg and Ziegler, *Polygnathus communis communis* Branson and Mehl and *Apatognathus* sp.

The Carboniferous/Devonian boundary, coinciding with the base of the *Siphonodella sulcata* conodont Zone (Paproth and Streel, 1984; Flajs and Feist, 1988; Paproth, *et al*., 1991), probably occurs in the Exshaw Formation at its type section and at many other localities in the southern Rockies (Macqueen and Sandberg, 1970; Richards and Higgins, 1988; Savoy and Harris, 1993).

The basal sandstone and conglomerate bed of the Exshaw Formation at its type section yielded a specimen of *Palmatolepis* referable to either *P. perlobata* Ulrich and Bassler or *P. rugosa* Branson and Mehl (Macqueen and Sandberg, 1970) and assignable to the *expansa* Zone. A calcareous concretion collected from the black shale member 90 cm above the base of the type Exshaw (GSC loc. C-136786) yielded *Bispathodus costatus* E. R. Branson morphotype 1 of Ziegler, and *Apatognathus* sp. This fauna belongs to the Middle *expansa* to Middle *Siphonodella praesulcata* zones of latest Devonian age. Concretions collected from the black shale at 3.1 and 5.6 m above the base of the type section (GSC locs. C-136787 and C-136788, respectively)

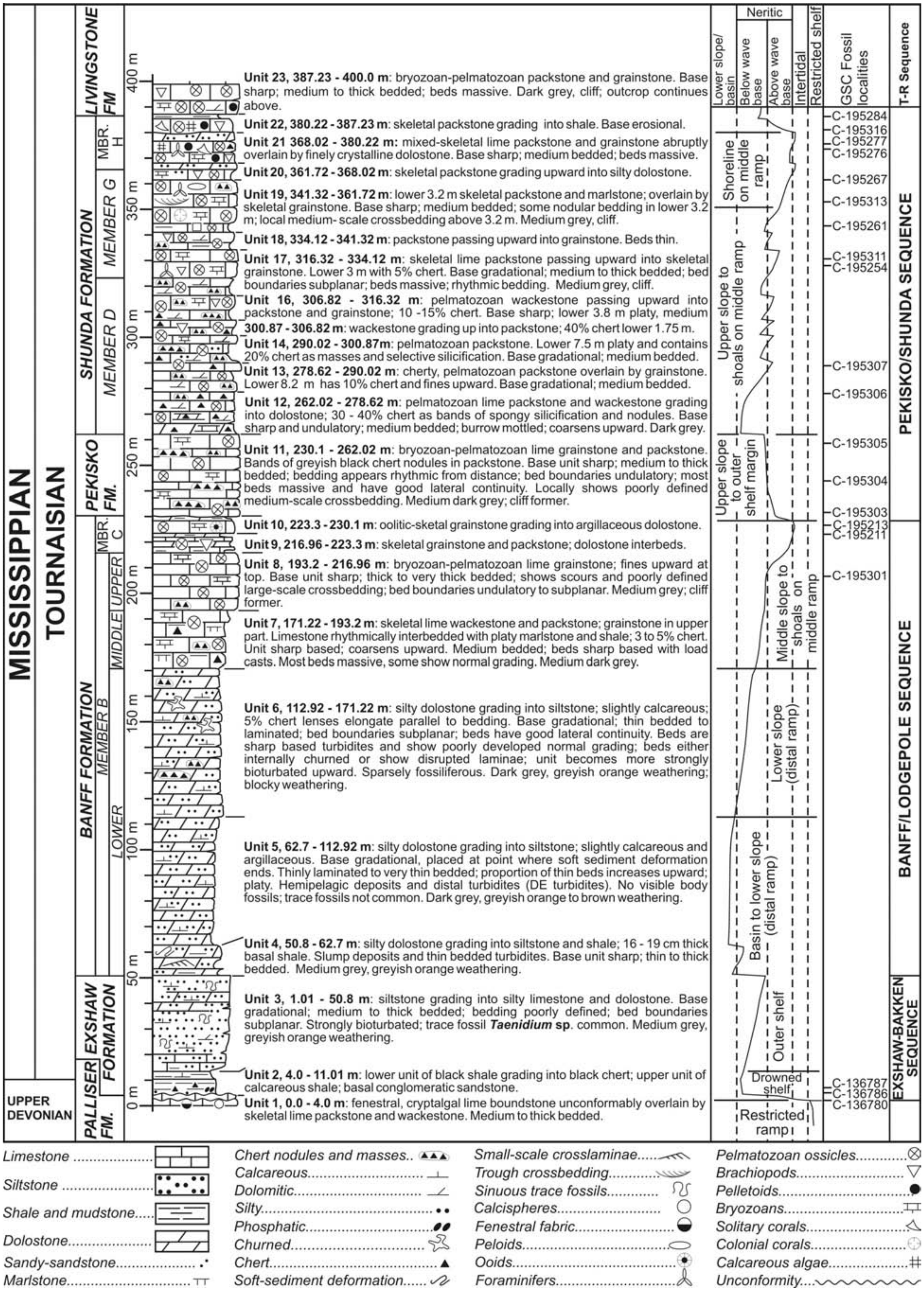

Figure 35. Columnar section showing uppermost Palliser Formation, Exshaw, Formation, Banff Formation and lower Rundle Group (Pekisko, Shunda, and Livingstone formations) at stops 2-6 to 2-10 (Fig. 19), middle canyon of Jura Creek.

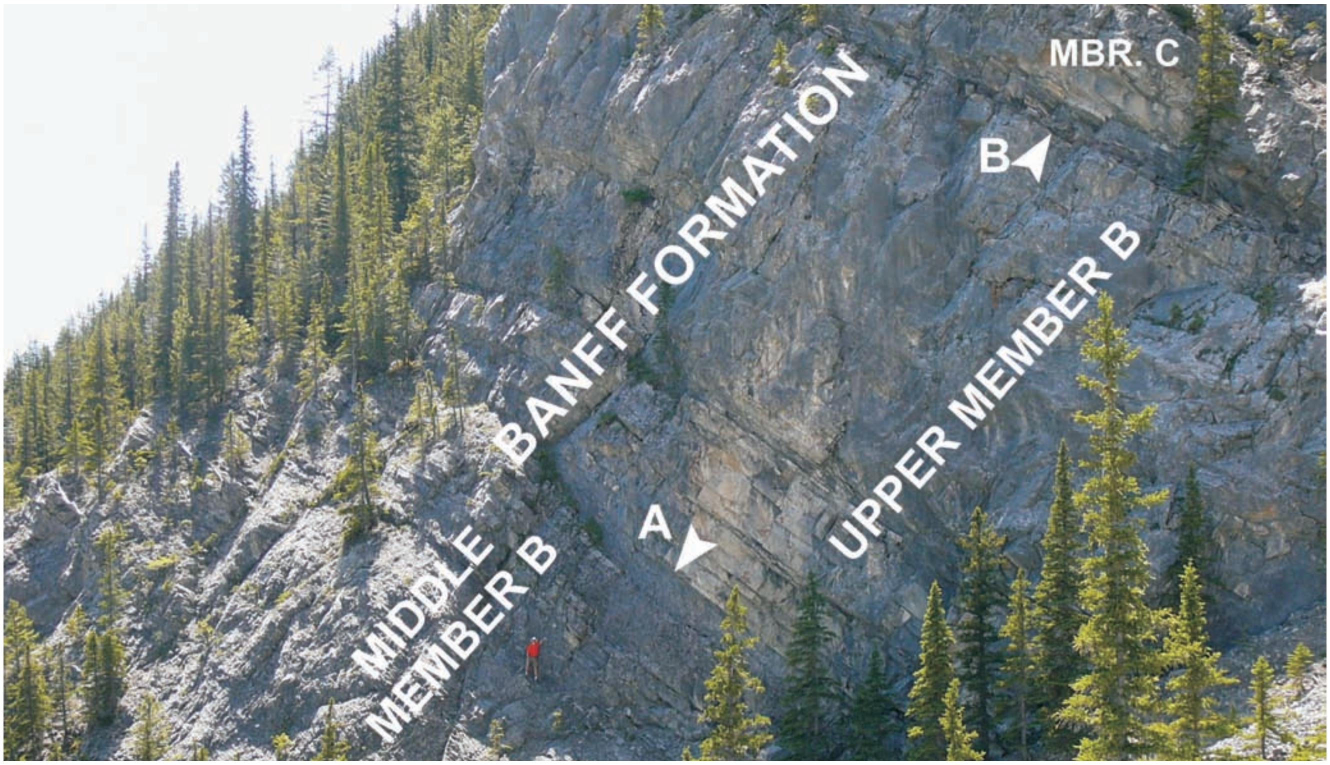

Figure 36. Sharp contact (arrow A) between middle member B and upper member B of the lower Tournaisian Banff Formation at stop 2-8 above type section of the Exshaw Formation on Jura Creek. Middle member B comprises sharp-based beds of bryozoan-pelmatozoan lime wackestone, packstone and grainstone that grade upward into marlstone and were deposited in middle-slope (distal-ramp) environments. Upper member B comprises bryozoan-pelmatozoan lime grainstone deposited in upper-slope environments and on shoals developed in middle-ramp settings. Arrow B indicates the top of member B and the top of member C.

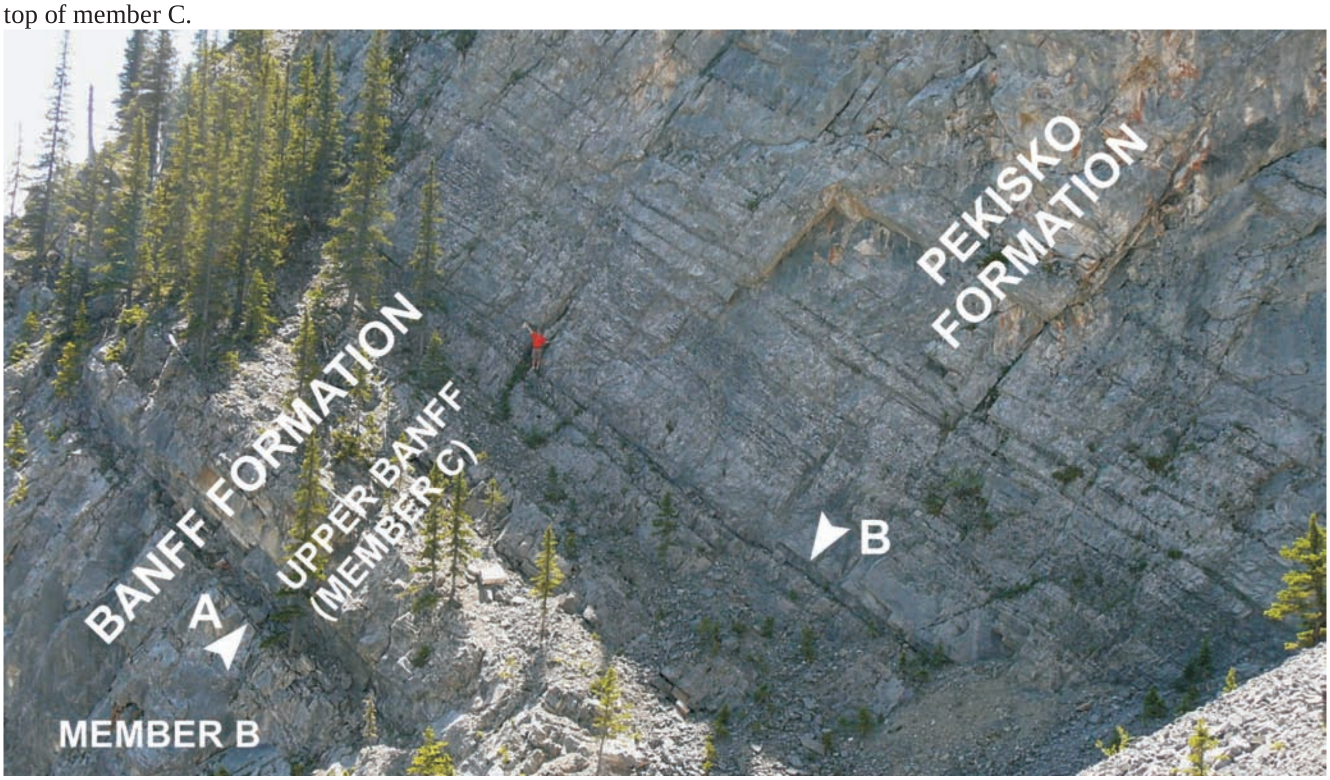

Figure 37. Looking southward to member C of the Banff Formation (arrows A and B mark base and top, respectively) and overlying Tournaisian Pekisko Formation at stops 2-8 and 2-9 in side canyon above Jura Creek. Member C comprises recessive units of dolostone overlain by resistant units of ooid-skeletal and bryozoan-pelmatozoan lime grainstone of middle-ramp origin.

Figure 38. Sharp contact (white arrow) between shelf-margin to upper-slope deposits (bryozoan-pelmatozoan lime grainstone) of Pekisko Formation and overlying drowned-shelf deposits (chert-rich, dolomitic lime wackestone) of member D of the Shunda Formation. At stop 2-9, in gully above type section of Exshaw Formation on western side of Jura Creek; men (on talus) indicate scale.

yielded *Palmatolepis gracilis sigmoidalis* Ziegler. In view of the conodonts collected from underlying strata, the last two faunas can be no older than the Middle *expansa* Zone and no younger than the Upper *praesulcata* Zone (Richards and Higgins, 1988). The faunas are, therefore, of latest Devonian age. Savoy and Harris (1993) also recovered faunas representing the Middle *expansa* to *praesulcata* zones from the lower part of the black shale member, and reported *Bispathodus stabilis* and *Polygnathus communis* in addition to the taxa listed above.

Carboniferous conodonts are not common in the Exshaw Formation, but their distribution indicates that the Devonian/Carboniferous boundary is within the black shale member of the Exshaw at some localities in southwestern Alberta (Higgins *et al.* 1991). At the type Exshaw, siphonodellids including *Siphonodella cooperi* Hass, were reported by Macqueen and Sandberg (1970) from the upper 76 cm of the black shale member. *S. cooperi* first appears in the Upper *Siphonodella duplicata* Zone and continues upward into the Upper *Siphonodella crenulata*-*Siphonodella isosticha* Zone (Sandberg *et al*., 1978), thereby indicating an Early Mississippian (early Tournaisian) age. *S. cooperi* has also been reported from the siltstone member of the Exshaw at stop 2-1 on Mount Rundle (Macqueen and Sandberg, 1970). Several specimens of *Siphonodella duplicata* (Branson and Mehl) were recovered from a bed in the upper Exshaw at Arête Mountain that yielded Lower Carboniferous goniatites identified by Pamenter (1956) and Schindewolf (1959) (Macqueen and Sandberg, 1970). *S. duplicata* makes its first appearance at the base of the *duplicata* Zone and ranges upward into the Lower *Siphonodella crenulata* Zone (Sandberg *et al*., 1978).

Conodont data indicate that the contact between Upper Devonian and Lower Carboniferous strata at the type Exshaw lies in a 2.94 m thick interval that has not been precisely dated by fossils. The interval extends from 1.3 m below the top of the middle, noncalcareous shale unit to 1.64 m above the base of the upper calcareous shale unit. The Carboniferous-Devonian boundary is provisionally placed at the sharp contact between the two shale units, near the middle of the 2.95 m thick interval. Strata of earliest Carboniferous age (within the *sulcata* and *duplicata* zones) have not been positively identified and are either absent or in a highly condensed sequence.

The age of the upper member of the Exshaw at its type section and other Bow Valley localities has not been precisely established. It is, however, probably within the *duplicata* to Lower *crenulata* zones of early Tournaisian age (Richards and Higgins, 1988; Higgins *et al*., 1991).

Stop 2-7. Abrupt contact between the Exshaw and Banff formations (Figs. 32, 34) on west side of middle canyon of Jura Creek, about 3.1 km upstream from Highway 1A. To reach this outcrop from stop 2-6, walk upstream to the head of the middle canyon of Jura Creek, then scramble southwestward and upslope over the partly covered and deeply weathered upper Exshaw to the first prominent break in slope above stop 2-6.

The basal Banff Formation, of early Tournaisian age, comprises dark-grey shale overlain by sparsely fossiliferous, silty dolostone to silty limestone turbidites and deposits showing soft-sediment deformation (convoluted bedding). These strata, which represent the TST of the Banff\Lodgepole sequence at this locality, were deposited in basin and slope environments. The sharp lower sequence boundary is a major flooding surface. Strata in the lowermost Banff record a major regional transgression and episode of marked deepening that culminated with deposition of the thick overlying unit of hemipelagic, which consists of thinly planar-laminated silty dolostone. Subsidence, recorded by the deepening, resulted from the Antler Orogeny and related Cariboo event along the western margin of ancestral North America.

Stop 2-8. Member B and overlying member C of the Tournaisian Banff Formation (Figs. 35, 36) about 150 m west of Jura Creek in steep side canyon, 3.3 km northwest of Highway 1 A. To reach this stop from stop 2-7, return to the head of the middle canyon on Jura Creek. From the canyon proceed upstream (about 100 to 125 m) to the first alluvial fan on the west side of the valley; scramble up the fan to stop 2-8.

At stops 2-7 to 2-8, the Banff Formation (179.3 m thick) comprises four main units (Fig. 35): 1) lower member B (50.8 - 171.22 m), 2) middle member B (171.22 - 193.2 m), 3) upper member B (193.2 - 216.96 m) and 4) member C (216.96 - 230.1 m). Lower member B includes a thin (16 to 19 cm thick), dark grey shale bed that abruptly overlies the Exshaw Formation and may represent member A, a black-shale unit, of the lowermost Banff.

Silty dolostone grading into siltstone constitute most of lower member B. The lower 11.9 m (unit 4) of lower member B show convoluted beds and thin bedded turbidites. Overlying unit 5 (50.2 m thick) is a recessive succession of planar-laminated, silty dolostone of hemipelagic to distal-turbidity-current origin. The planar-laminated facies is, in turn, gradationally overlain by a moderately resistant succession of thin-bedded, silty dolostone turbidites (unit 6, 58.3 m thick) that records the onset of shallowing and progradation in the member.

Rhythmically bedded, moderately recessive middle member B (unit 7, 22 m thick) consists of sharp-based limestone beds (tempestites or turbidites of wackestone to bryozoan-pelmatozoan lime grainstone) grading upward into marlstone. The upper contact of the unit is sharp and broadly undulatory.

Overlying upper member B (23.76 m thick) comprises a cliff-forming succession of medium- to very thick bedded bryozoan-pelmatozoan lime grainstone. Medium- to large-scale crossbedding and large scours (submarine channel fills) are locally evident in this unit along the valley of Jura Creek.

The moderately recessive upper Banff (member C) is mainly oolitic, skeletal lime grainstone (Figs. 35, 37). Two main intervals of finely crystalline, argillaceous dolostone overlain by lime wackestone and grainstone are also present. The lower and middle components of member B were deposited in distal-ramp (lower to middle slope) settings. Upper member B and overlying member C record shallowing-upward in upper-slope to high-energy, shallow-neritic environments on a carbonate ramp.

At this locality, the maximum flooding surface of the Banff/Lodgepole sequence is tentatively placed at the top of unit 4 (Fig. 35). The upper sequence boundary of the Banff/Lodgepole sequence is an undulatory transgressive surface at the base of the overlying Pekisko Formation.

Conodont biostratigraphy

From 136 m above the base of the Banff in strata assigned herein to middle member B (unit 7), Savoy and Harris (1993) recovered a conodont fauna assignable to either the highest Lower *crenulata* Zone or lower part of the Upper *crenulata-isosticha* Zone. In this section (Fig. 35), deposits in the lower Pekisko Formation lie within the Upper *crenulata-isosticha* Zone.

Biostratigraphy of Foraminifers and Calcareous Algae

Foraminifers and calcareous algae are moderately common in two samples collected from the upper Banff (member C) at stop 2-8 but were not observed lower in the formation. A sample collected at 4.56 m above the base of member C (221.52 m above base section; GSC loc. C-195211, Fig. 35) contains *Asphaltinella* sp., *Columbiapora johnsoni* Mamet, *Pekiskopora*? sp. and *Tuberendothyra tuberculata* (Chernysheva). The second sample (GSC loc. C-195213; 224.72 m above base section), collected 7.76 m above the base of member C, contains *Asphaltinella* sp. (very abundant), *Columbiapora johnsoni* Mamet, and *Tuberendothyra* sp. These two samples contain a microflora that has been called the *Asphaltinella* and *Columbiapora* microfacies (Mamet, 1984), and is widely developed in the Madison Group of Wyoming and Montana and in the Pekisko Formation of west-central Alberta. Where the *Asphaltinella* and *Columbiapora* microfacies have been precisely dated in western North America, they always occur in the lower part of Zone 8 of Mamet and Skipp (1970). In member C, the presence of *T. tuberculata* suggests that at least part of the member is correlative with the Pekisko Formation to the northwest.

Stop 2-9. Pekisko Formation and lower to upper parts of the overlying Shunda Formation, in the side canyon above stop 2-8 and the Banff Formation (Figs. 37, 38).

The moderately recessive upper Banff Formation (member C) is abruptly overlain by the cliff-forming Pekisko Formation (unit 11, Fig. 35), of early late Tournaisian age. Medium- to thick-bedded, bryozoan-pelmatozoan grainstone and packstone constitutes most of the Pekisko, which is 31.9 m thick at stop 2-9. Prominent bands of black chert nodules are conspicuous in the lime packstone. Most of the beds have good lateral continuity and the unit looks rhythmically bedded from a distance. Overall, the Pekisko fines upward and records deposition in outer-shelf-margin to upper-slope environments during a major regional transgression.

At stop 2-9, the Pekisko Formation is abruptly overlain by upper Tournaisian carbonates of the Shunda Formation (125.2 m thick), which comprises parts of two main T-R subsequences within the third-order Pekisko/Shunda sequence (Fig. 35). The lower subsequence, which includes the Pekisko and members D, G, and lower H of the Shunda, extends to the top of a sandy dolostone bed (upper unit 21, Fig. 35) 7.0 m below the overlying Livingstone Formation. The transgressive surface of the lower subsequence, coinciding with the sequence boundary for the Banff/Lodgepole and Pekisko/Shunda sequences, lies at the base of the Pekisko. The Pekisko represents the TST of the subsequence, and the maximum flooding surface lies at the Pekisko-Shunda contact. Members D, G and lower member H of the overlying Shunda represent the RST of the subsequence. In the Shunda, the deposits of this lower sequence include cherty, bryozoan-pelmatozoan lime wackestone and packstone grading upward into sandy dolostone, lime grainstone, and packstone deposited in slope to middle-ramp settings. The silty to sandy dolostone to dolomitic siltstone of lower member H records the culmination of a regional regression.

Conodont biostratigraphy

Along Jura Creek, most of Pekisko Formation is in the Upper *crenulata-isosticha* Zone and only the upper 4.3 m of the Pekisko above the Exshaw stratotype (stop 2-9) can be unequivocally assigned to the *Gnathodus typicus* Zone (Richards *et al*., 1991, 1994b). In the section, the boundary between these two zones lies between 12.92 and 27.62 m above the base of the Pekisko.

Conodont faunas from the Upper *crenulata-isosticha* Zone within the Pekisko Formation at stop 2-9 above the type Exshaw (GSC locs. C-195303, C-195304) and at Princess Margaret Mountain by Canmore (GSC locs. C-136427, C-136430) contain *Anchignathodus penescitulus* (Rexroad and Collinson), *Gnathodus delicatus* Branson and Mehl, *G. typicus* Cooper morphotype 1 of Lane, Sandberg and Ziegler, *Polygnathus communis carina*, *P. communis communis*, *P. inornatus*, *Protognathodus praedelicatus* Lane, Sandberg and Ziegler, *Pseudopolygnathus dentilineatus* E. R. Branson, *Siphonodella crenulata*, *S. isosticha*, and *S. obsoleta* Hass (see Plate 2; Richards *et al*., 1991).

Samples from the Upper *crenulata-isosticha* Zone at stops 2-8 and 2-9 above Jura Creek yielded 0 to 25 elements per kilogram. The best production was 100 elements from a four-kilogram sample collected from locality C-195304, between 12.92 and 13.22 m above the base of the Pekisko.

At stop 2-9, the only conodont assemblage from the Pekisko Formation that was assigned to the *typicus* Zone was collected at GSC locality C-195305, between 27.62 and 27.92 m above the base of the Pekisko (Fig. 35). The fauna, derived from a 4.09 kg sample, comprised 190 elements (46 elements per kilogram) and included *Bispathodus aculeatus aculeatus*, *Bispathodus* sp. *B. spinulicostatus* (E. R. Branson), *Gnathodus cuneiformis* Mehl and Thomas, *G. typicus* morphotype 2, *Hindeodus*? sp. and *Polygnathus communis carina* Hass. The latter is the most abundant species.

Biostratigraphy of Foraminifers and Calcareous Algae

The lime packstone and grainstone in the upper part of the lower sequence locally contain abundant calcareous algae and foraminifers assigned to zone 8 of Mamet and Skipp (1970). Samples from GSC localities C-195254 and C-195261, which were collected at 64.8 and 80.6 m above the Shunda's base, respectively, contain *Asphaltinella* sp., *Earlandia* sp., *Kamaena* sp., *Latiendothyra* sp., *Palaeoberesella* sp., *Septaglomospiranella* sp., Salebridae, *Septatournayella* sp., and *Tuberendothyra tuberculata* (Chernysheva). In addition to the taxa listed above, samples (GSC locs. C-195267, C-195276, C-195277, C-195282, C-195284) collected in upper member G and member H (from 25.86 to 0.76 m below top) include *Calcisphaera* sp., *Earlandia clavatula* (Howchin), *Protoumbella* sp., and *Spinoendothyra* sp. Assemblages that resemble those from the upper Shunda at Jura Creek have been widely recognized in the lower Shunda Formation of western Alberta and east-central British Columbia (Mamet, 1976; Mamet *et al*., 1986).

Coral biostratigraphy

At Jura Creek, solitary and colonial rugose corals are moderately common in the upper Shunda Formation, but are rare in the lower and middle parts of the formation. Two small collections of rugose corals were collected from the upper Shunda (member H) at stops 2-9 to 2-10. From GSC locality C-195318, 13.06 to 13.86 m below the base of the Livingstone Formation, three colonies of *Stelechophyllum circinatus* (Easton and Gutschick) were collected along with several specimens of the solitary rugosans *Vesiculophyllum* sp. and *Sychnoelasma* sp. *S. circinatus* also occurs in correlative strata in east-central British Columbia and Arizona.

Stop 2-10. Uppermost Shunda Formation (upper 7.2 m) and basal beds of the overlying Livingstone Formation (Figs. 35, 39) 350 to 400 m west of Jura Creek at the head of a side canyon, 3.3 km northwest of Highway 1A. To reach this stop, proceed westward and upward from stop 2-9 to the light-grey cliffs of the basal Livingstone.

Lithofacies of the uppermost Shunda Formation (unit 22 in upper member H) overlie a minor erosion surface resulting from transgressive ravinement and comprise mixed-skeletal lime packstone and subordinate grainstone grading upward into lime wackestone and shale. Deposition took place on the drowned shelf of a ramp during an important regional transgression. The ravinement surface at the base of unit 22 appears to correlate with the ravinement unconformity at the base of the upper T-R subsequence of the Shunda Formation at Moose Mountain in the western foothills.

Figure 34. Sharp contact between the upper member of the Exshaw Formation and basinal dark grey shale (member A) of the Tournaisian Banff Formation at stop 7 above type section of the Exshaw Formation on Jura Creek. Overlying deposits in lower Exshaw are thin-bedded turbidites consisting of silty dolostone and siltstone grading upward into shale

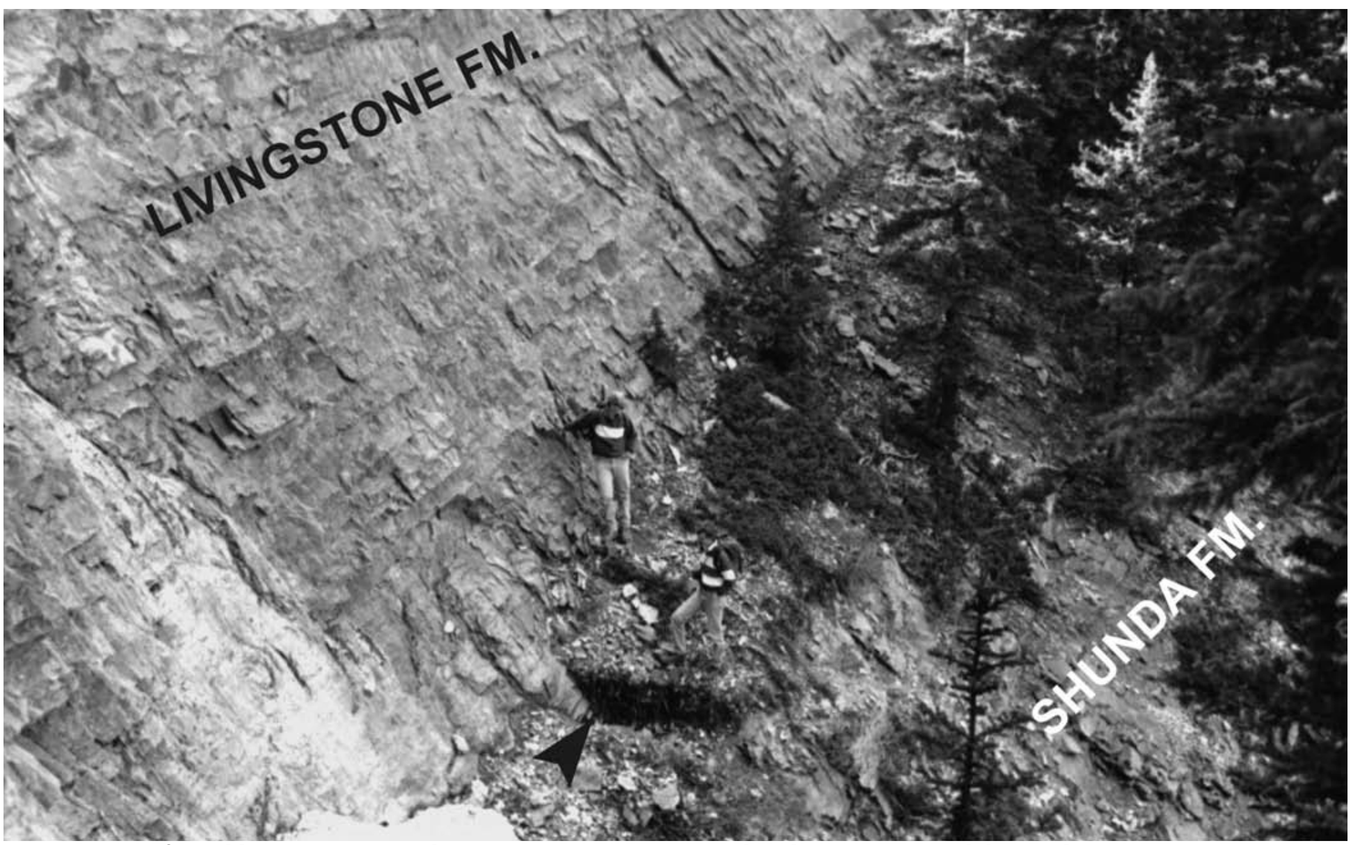

Figure 39. Conformable contact (arrow) between upper Tournaisian Shunda Formation and the overlying upper Tournaisian to lower Viséan Livingstone Formation at stop 2-10 (Fig 19), above type section of Exshaw Formation on Jura Creek. Uppermost part of Shunda (exposed in trench) comprises shale grading upward into dolomitic lime wackestone; lowermost Livingstone Formation comprises dolomitic lime packstone grading upward into bryozoan-pelmatozoan lime grainstone.

Calcareous algae and foraminifers assigned to zone 8 of Mamet and Skipp (1970) are locally common in the limestone near the base of unit 22. At GSC locality C-195319, 6.96 to 6.46 m below the base of the Livingstone, several specimens of the solitary rugose coral *Vesiculophyllum* sp. were collected. Colonies of the tabulate coral *Syringopora* sp. are also moderately common.

Cliff-forming carbonates of the Livingstone Formation gradationally overlie the Shunda Formation. The medium- to thick-bedded basal Livingstone comprises dolomitic, bryozoan-pelmatozoan lime packstone grading upward into lime grainstone. Overlying deposits of the formation (300 to 320 m thick in this area) are mainly skeletal lime grainstone and dolomitized, skeletal grainstone deposited in upper-slope and shelf-margin environments.

Upper member H constitutes the TST of a high-order T-R subsequence within the Pekisko/Shunda sequence. The shale bed of the member contains the maximum flooding surface of the subsequence. The subsequent regression is recorded by uppermost Tournaisian deposits of the lower Livingstone Formation, which constitutes the regressive systems tract of the subsequence. By using lithological criteria alone, the top of the third-order Pekisko/Shunda sequence can not be readily located in the grainstone-dominated Livingstone.

Conodont biostratigraphy

Deposits in the lower subsequence of the Shunda Formation at stops 2-9 to 2-10 are within the *typicus* conodont Zone. Most of the faunas collected are dominated by long-ranging species. The richest sample collected (GSC loc. C-195307, 25.5 to 25.8 m above the Pekisko) contained 92 elements per kilogram, but was dominated by *Polygnathus communis carina*. A more diverse assemblage, but containing only 6 elements per kilogram, was collected at GSC locality C-195313 (between 89.8 and 90.1 m above the Shunda's base). Assemblages (GSC locs. C-195306, C-195307, C-195311) from the lower and middle Shunda at stops 2-9 and 2-10 contain only long ranging taxa: ?*Hindeodus* sp., *Polygnathus communis carina*, and *P. communis communis*. Richer, more diverse assemblages were collected from the upper Shunda between stops 2-9 to 2-10. A sample from GSC locality C-195313, between 89.8 and 90.1 m above the base of the Shunda (35.56 to 35.26 m below top) between stops 2-9 and 2-10, yielded *Eotaphrus* sp. cf. *E. bultyncki* (Grossens), *Hindeodus* sp. and *Polygnathus communis communis* (see Plate 2; Richards *et al*., 1991, 1994b).

A sample from GSC locality C-195316, between 119.0 to 119.2 m above the base of the Shunda (6.36 to 6.16 m below top) at stop 2-10 contains *Bispathodus stabilis*?, *Eotaphrus bultyncki*, *Apatognathus* sp., and *Polygnathus mehli mehli* Thompson. Samples from the Shunda at Princess Margaret Mountain contain only long ranging species: *Bispathodus stabilis, Gnathodus delicatus*, *Polygnathus communis communis*, and *P. inornatus.*

Eotaphrus bultynki ranges from the Upper *Gnathodus typicus* Zone into the lower *Scaliognathus anchoralis-Doliognathus latus* Zone (Lane *et al*., 1980). In western Canada, *Polygnathus mehli mehli* generally appears near the base of the *anchoralis-latus* Zone and ranges through that zone (Higgins *et al*., 1991). *Polygnathus longiposticus* Branson and Mehl was collected from GSC loc. C-136442 at Princess Margaret Mountain 8.0 m above the base of the Livingstone Formation. The latter species first appears in the lower Tournaisian *sulcata* Zone and normally ranges no higher than the Upper *typicus* Zone (Lane *et al*., 1980). In view of the conodont faunas collected from the underlying Pekisko Formation and overlying Livingstone Formation, the Shunda faunas can be no older than the Lower *typicus* Zone, and most are no younger than the Upper *typicus* Zone. The uppermost Shunda at Jura Creek contains *P. mehli mehli* and could be in the basal *anchoralis-latus* Zone (Richards *et al*., 1991, 1994b).

Most conodont faunas collected from the Shunda Formation at Jura Creek and Princess Margaret Mountain have low species diversity, are dominated by relatively long ranging species, and contain few specimens. Yields from this unit at stops 2-9 to 2-10 ranged from zero to 92 elements per kilogram, with the best yield from GSC locality C-195307 (25.5 to 25.8 m above base of Shunda). A 3.64 kg sample from the latter contained 335 elements dominated by *Polygnathus communis carina*. Assemblages with the highest species diversity were obtained from GSC localities C-195313 (35.56 to 35.26 m below top of Shunda) and C-195316 (6.36 to 6.16 m below top of Shunda), which yielded 6 and 8 elements per kilogram, respectively.

From stop 2-10, hike back to Highway 1A and the vehicles. On the highway proceed southwestward, passing Exshaw and the Lafarge Canada Incorporated Portland cement plant, to the southeastern end of Grotto Mountain for stop 2-11 (Fig. 19). Park on the shoulder of highway 1A above Gap Lake.

Stop 2-11. Overview of the Famennian and Carboniferous successions from Highway 1A above the Bow River and Gap Lake; examine Tournaisian carbonates in road cut along western side of highway.

A succession of Famennian and Lower Carboniferous strata, similar to that exposed along Jura Creek, is exposed on the southeastern side of Grotto Mountain (Fig. 1). The Famennian is represented by the Palliser Formation and lower Exshaw Formation. The Lower Carboniferous includes the Banff, Shunda, Livingstone, Mount Head and Etherington formations. The Pekisko Formation may also be present but can not be readily differentiated from the middle to upper Banff.

A rhythmically bedded succession of slope carbonates extending from middle member B of the Banff Formation to the lower part of the Shunda Formation is well exposed in the rock cut along the western side of the road. The interval consists of sharp-based units of bryozoan-pelmatozoan lime grainstone separated by units of lime wackestone and packstone containing abundant chert nodules. Some of the grainstone units appear to be wedge- or lens-shaped bodies

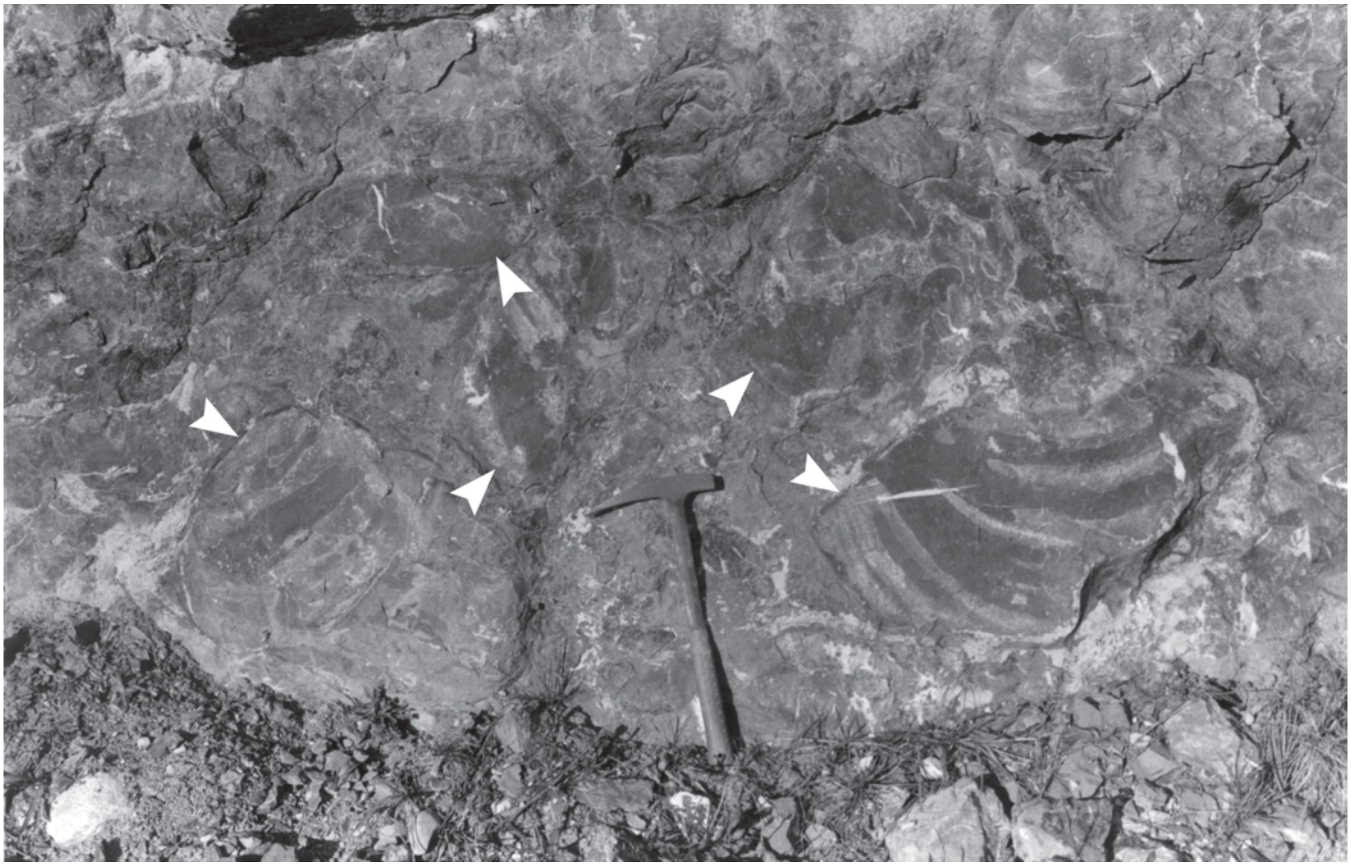

Figure 40. Submarine debris-flow deposit in Tournaisian slope facies of the Pekisko? Formation in rock cut on northwest side Highway 1A at Grotto Mountain, stop 2-11 (Fig. 19). Arrows point to blocks.

representing submarine-channel fills. Graded beds are common and most of the beds appear to be of sediment-gravity-flow origin. Local hummocky bedding and poorly-defined hummocky crossbedding indicate the occurrence of some storm beds.

Near the southwestern end of the exposure an impressive, 2.6 metre thick, submarine debris-flow deposit contains limestone blocks that are commonly more than 50 cm long and show evidence for soft-sediment deformation (Fig. 40). The debris-flow unit lies about 15.4 m below the Shunda and appears to be correlative with the Pekisko at Jura Creek.

From stop 2-11, continue along Highway 1A and drive, to Cougar Creek in Canmore for stops 2-12 to 2-18 (Fig. 41). While you are in Canmore, observe the impressive exposures of the Palliser, Banff and Livingstone formations on the northeastern side of Mount Rundle.

Day 2 (afternoon): Mississippian Platform And Ramp Carbonates And Pennsylvanian Sandstone At Cougar Creek By Canmore And At Banff, Rocky Mountain Front Ranges.

Geological setting

In the Front Ranges of the southern Rocky Mountains near the towns of Canmore and Banff, parautochthonous Lower and Upper Carboniferous strata are well displayed in the southwestward-dipping thrust sheets dissected by the Bow River and its tributaries. The objective for the afternoon of day 2 is to provide an overview of this succession by examining exposures along Cougar Creek, a southwestward flowing tributary of the Bow River northeast of Canmore (Fig. 41). Later in the day, if time permits, the Carboniferous successions on Mount Rundle and Tunnel Mountain by the city of Banff will be briefly examined from viewpoints.

The Carboniferous succession that we will examine along Cougar Creek is about 11 km west of Jura Creek and lies within the Inglismaldie Thrust Sheet of the Fairholme Range. At Tunnel Mountain and adjacent Mount Rundle, the Carboniferous is within the Rundle Thrust Sheet. Palinspastic reconstructions (courtesy of Shell Canada Limited) indicate that the Carboniferous section of the Inglismaldie Thrust Sheet by Canmore was translated 92.1 km northeastward relative to the undeformed succession on the western Interior Platform, whereas that in the Rundle Thrust Sheet at Tunnel Mountain was displaced by approximately 99.4 km toward the northeast. The succession in the Rundle sheet at Tunnel Mountain was displaced 7.3 km northeastward relative to that in the Inglismaldie sheet.

A stratigraphic interval extending from the Tournaisian upper Banff Formation to the Moscovian Kananaskis

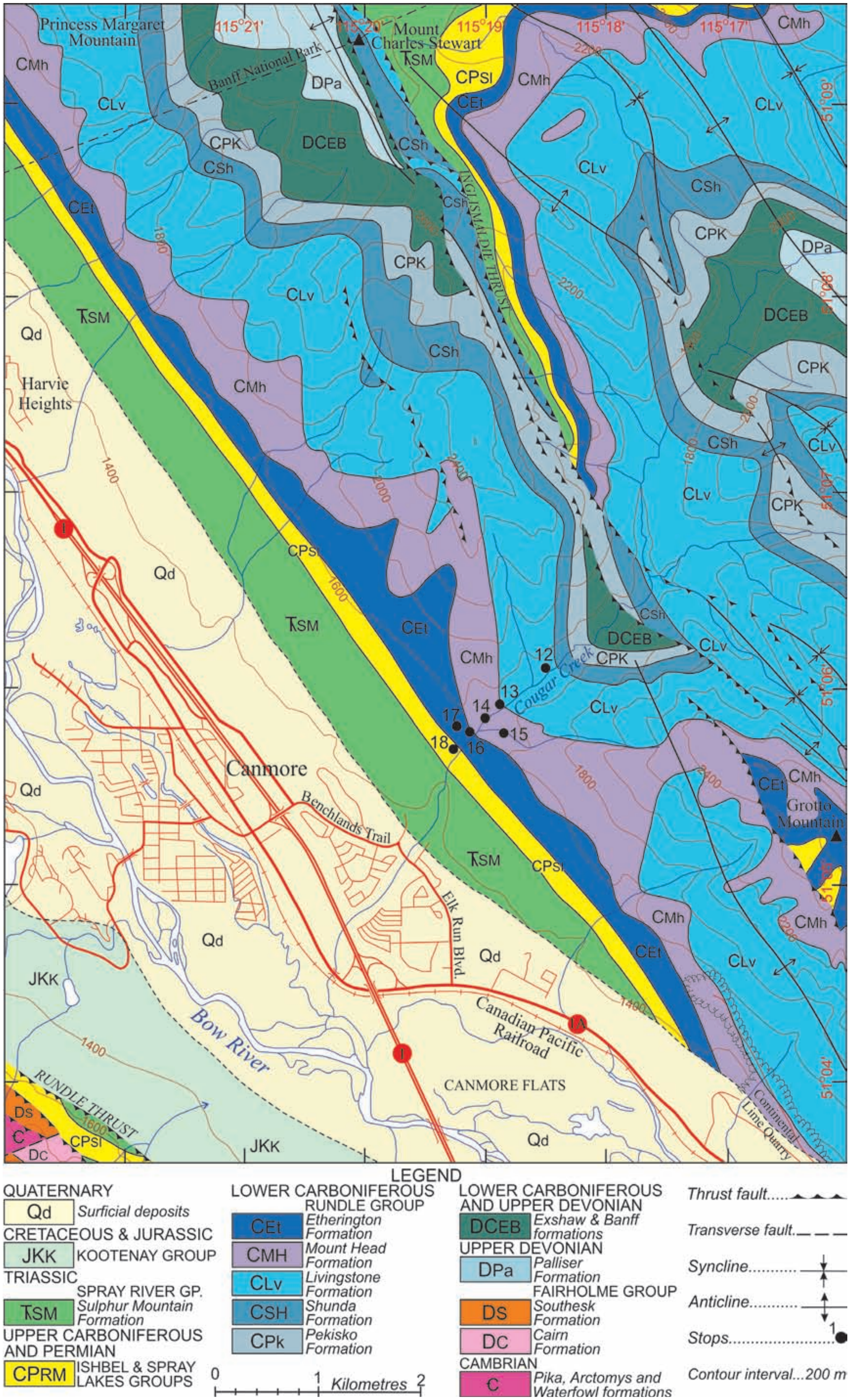

Figure 41. Geological map of the Cougar Creek region north-east of Canmore, Fairholme Range, eastern Rocky Mountains showing location of stops 2-12 to 2-18 for day 2; modified from Price (1970).


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Plate 2. All figures are scanning electron micrographs of Pa elements at X100, except Figure 15 which is at X75. All specimens are from section 90RAH8 (stops 8-10) measured in side canyon entering Jura Creek from west at point immediately north of the type section of the Exshaw Formation; 51o05’30”N, 115o09’37”W, UTM 5661500N, 628850E, zone 11u; map area NTS 82 O/3; eastern Rocky Mountains, southwestern Alberta. All specimens are hypotypes housed in the National Type Collections of Invertebrate and Plant Fossils at the Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario K1A 0E8.

Figure 1. *Eotaphrus sp.* cf. *E. bultyncki* (Grossens), lateral view, GSC 100604; GSC loc. C-195313, section at stops 8 to 10 in side canyon entering Jura Creek from west, Shunda Formation at 89.8 to 90.1 m above base, lower upper Tournaisian.

Figure 2. *Polygnathus communis communis* Branson and Mehl, upper surface view, GSC 100605; GSC loc. C-195307, section (Fig. 35) at stops 8 to 10 in side canyon entering Jura Creek from west, Shunda Formation at 25.5 to 25.8 m above base, lower upper Tournaisian.

Figures 3, 4. *Polygnathus communis carina* Hass, upper surface views, section at stops 8 to 10 in side canyon entering Jura Creek from west. 3- GSC 100606, GSC loc. C-195307; Shunda Formation at 14.4 to 14.6 m above base, lower upper Tournaisian. 4- GSC 100607, GSC loc. C-195304 (Fig. 35); Pekisko Formation at 19.0 to 18.7 m below top, lower upper Tournaisian.

Figure 5. *Bispathodus aculeatus aculeatus* (Branson and Mehl), upper surface view, GSC 100608; GSC loc. C-195305, section at stops 8 to 10 in side canyon entering Jura Creek from west, Pekisko Formation at 4.3 to 4.0 m below top, lower upper Tournaisian.

Figure 6. *Bispathodus sp. cf. B. spinulicostatus* (E. R. Branson), upper surface view, GSC 100609; GSC loc. C-195305, section at stops 8 to 10 in side canyon entering Jura Creek from west, Pekisko Formation at 4.3 to 4.0 m below top, lower upper Tournaisian (Fig. 35).

Figure 7. *Gnathodus cuneiformis* Mehl and Thomas, upper surface view, GSC 100610; GSC loc, C-195305, section at stops 8 to 10 (Fig. 35) in side canyon entering Jura Creek from west, Pekisko Formation at 4.3 to 4.0 m below top, lower upper Tournaisian.

Figures 8, 9, 10. *Gnathodus typicus* Cooper morphotype 2 Lane, Sandberg and Ziegler, upper surface views; section at stops 8 to 10 (Fig. 35) in side canyon entering Jura Creek from west, Pekisko Formation at 4.3 to 4.0 m below top, lower upper Tournaisian. 8- GSC 100611, GSC loc. C-195305. 9- GSC 100612, GSC loc. C-195305.10- GSC 100613, GSC loc. C-195305.

Figure 11. *Polygnathus inornatus* E. R. Branson, upper surface view, GSC 100614; GSC loc. C-195304, section at stops 8 to 10 (Fig. 35) in side canyon entering Jura Creek from west, Pekisko Formation at 19.0 to 18.7 m below top, lower upper Tournaisian.

Figure 12. *Gnathodus delicatus* Branson and Mehl, upper surface view, GSC 100615; GSC loc. C-195304, section at stops 8 to 10 in side canyon entering Jura Creek from west, Pekisko Formation at 19.0 to 18.7 m below top, lower upper Tournaisian.

Figures 13, 14. *Siphonodella isosticha* (Cooper), upper surface views of left and right hand elements; section at stops 8 to 10 (Fig. 35) in side canyon entering Jura Creek from west, Pekisko Formation at 19.0 to 18.7 m below top, lower upper Tournaisian. 13- GSC 100616, GSC loc. C-195304. 14- GSC 100617, GSC loc. C-195304.

Figure 15. *Siphonodella obsoleta* Hass, upper surface view, GSC 100618; GSC loc. C-195304, section at stops 8 to 10 (Fig. 35) in side canyon entering Jura Creek from west, Pekisko Formation at 19.0 to 18.7 m below top, lower upper Tournaisian.

Formation is exposed along lower Cougar Creek, but the focus of the excursion will be the interval from the top of the Viséan Livingstone Formation to the base of the Pennsylvanian Spray Lakes Group. The Carboniferous succession at Cougar Creek and Banff was deposited in eastern Prophet Trough.

Cougar Creek

The Mississippian succession at Cougar Creek is similar to that of the Jura Creek region, but the Pennsylvanian interval is substantially thicker and more complete. Like Jura Creek, the canyon along lower Cougar Creek is also a popular destination for geological field trips. The Canyon has readily accessible exposures of Carboniferous strata that are widely exposed elsewhere in the region but are either inaccessible or lie within Banff National Park, where collecting is possible only with a permit. The Mississippian Rundle Group exposed along Cougar Creek and adjacent Grotto Mountain resembles that exposed along a narrow canyon on the southeastern side of Princess Margaret Mountain (Fig. 41), where the Mississippian succession was more extensively studied for conodonts than at Cougar Creek (Higgins and Richards 1991).

Tunnel Mountain and Mount Rundle

The Lower Carboniferous succession of the Rundle Thrust Sheet at Tunnel Mountain and Mount Rundle differs significantly from that of the Inglismaldie Sheet, particularly at the level of the Banff and Mount Head formations. Between the Inglismaldie and Rundle sheets, the Pekisko and Shunda formations pass basinward into the Banff Formation, and the Wileman and Baril members of the Mount Head grade basinward into the Livingstone Formation.

The sections on Tunnel Mountain and Mount Rundle have considerable historical significance because they played an important role in the development of the regional stratigraphic nomenclature used for the Carboniferous in western Alberta. See Macqueen and Bamber (1967), Scott (1964b), and Norris (1965) for historical summaries. Kindle (1924) proposed the names Banff Formation and Rundle Formation, in ascending order, for a lower recessive argillaceous carbonate unit and overlying resistant carbonate unit at the northern end of Mount Rundle. Descriptions of the type sections for both formations were first provided by Warren (1927) and later supplemented by Beales (1950). Both Warren and Beales selected a section on the northeast side of Mount Rundle as the type Banff. However, they selected the section on the southwest side of Tunnel Mountain as the functional type section of the Rundle Formation, because the latter can not be measured on Mount Rundle. Douglas (1953, 1958) elevated the Rundle Formation to a group. Tunnel Mountain was also selected as the type section of the Rocky Mountain Formation (Warren, 1927), which was raised to a group by Raasch (1956, 1958). Scott (1964a, b) recommended that the Rocky Mountain be elevated to a super group, and this was formalized by Stewart and Walker (1980).

Stop Descriptions

To reach stop 2-12 on Cougar Creek from Highway 1A in southeastern Canmore - turn right onto Benchlands Trail, cross Highway 1 on the overpass and continue along Benchlands Trail into the housing development on the alluvial fan of Cougar Creek (Fig. 41). At the junction of Benchlands Trail and Elk Run Boulevard, turn right onto Elk Run Boulevard and head southeast for a short distance to the culvert for Cougar Creek. Park in the paved parking lot on the northwest bank of Cougar Creek. Hike up the paved trail and subsequent gravel trail on the northwest side of Cougar Creek to the entrance of the Cougar Creek canyon. Continue upstream along the canyon trail to stop 2-12, situated about 2.3 km upstream from the culvert under Elk Run Boulevard.

Stop 2-12. Upper Tournaisian to lower Viséan strata of the Lower Livingstone Formation on northwestern side of Cougar Creek, about 2.3 km upstream from the bridge. Note the thick, sharp-based, fining- and shallowing-upward cycles in the Livingstone as you hike to this stop.

At this stop, the eastern lithofacies of the Livingstone Formation are typically developed, well exposed, and dominated by bryozoan-pelmatozoan lime grainstone. Large-scale, tabular crossbedding, common at eastern occurrences of the Livingstone, is present. Similar crossbedding has been documented from shelf-edge shoals of the Great Bahamas Bank (Ball, 1967). A well-developed intergranular to vuggy porosity is also evident in the Livingstone at this stop. Most of the Livingstone of the Canmore region was deposited in upper-slope and shelf-margin settings on a vast carbonate platform (Figs. 10, 13). The predominance of pelmatozoan lime grainstone and presence of large-scale crossbedding records deposition in relatively cool water along the outer margin of the shelf-margin sand belt. In the Mississippian succession of the WCSB, the pelmatozoan grainstone belt generally developed basinward of the higher energy ooid-skeletal sand belt.

The great thickness of the Livingstone grainstone lithofacies in the region indicates that the position of the shelf-margin sand belt remained relatively stationary from the latest Tournaisian into the early Viséan (early foraminiferal zone 11), when it prograded many kilometres basinward. The thickness also indicates that latest Tournaisian to earliest Viséan subsidence rates were moderately high.

Components of the Pekisko/Shunda and Turner Valley/Wileman T-R sequences, well developed at the Moose Mountain culmination in the Rocky Mountain Foothills east of Canmore, are preserved in the Livingstone of this region, but the transgressive surface separating them has not been precisely located.

Conodont Biostratigraphy

The basal Livingstone Formation of the Exshaw to Canmore region may contain the upper Tournaisian Upper *typicus* Zone, but most of the formation in this region lies within the upper Tournaisian *Scaliognathus anchoralis-Doliognathus latus* and lower Viséan *Gnathodus texanus* zones (Higgins *et al*., 1991). The upper Livingstone at Tunnel Mountain may lie within the broad *Cavusgnathus* Zone, but conodonts at that biostratigraphic level have not been studied from the Livingstone at that locality or elsewhere in the region.

Conodonts were not recovered from this formation at Jura Creek, but a sample collected from the lower Livingstone Formation at Princess Margaret Mountain (GSC locality C-136440, 2.5 m above the base of the Livingstone) contains: *Anchignathodus penescitulus*, *Apatognathus* sp., *Eotaphrus bultyncki*, and *Polygnathus communis communis*. At 8.0 m above the base of the Livingstone (GSC locality C-136442) in the same section, *Apatognathus* sp., *Anchignathodus penescitulus*, *Polygnathus communis communis*, and *P. longiposticus* were collected. The presence of *E. bultyncki* and *P. longiposticus* places these deposits in either the Upper *typicus* or Lower *anchoralis-latus* zones and indicates a late Tournaisian age (Higgins 1985, GSC paleontological report 6-ACH-85).

At the Princess Margaret Mountain section, two assemblages assigned to the lower Viséan *anchoralis-latis* Zone were collected from GSC localities C-114902 and C-114904, at 74.3 and 111.4 m, respectively above the base of the Livingstone Formation. These two assemblages do not include the zonal name givers *Scaliognathus anchoralis* Branson and Mehl and *Doliognathus latus* Branson and Mehl, but they do include *Eotaphrus burlingtonensis* Pierce and Langenheim, which is restricted to this zone in other areas (Lane *et al*., 1980). Additionally, *Polygnathus communis communis*, and *Anchignathodus penescitulus* are present (Higgins 1985, GSC paleontological report 6-ACH-85).

Conodonts from the *texanus* Zone were extracted from several samples collected from the upper Livingstone at Princess Margaret Mountain (GSC localities C-114912, C-114911, C-114914, and C-114915 at 241.9, 261.0, 263.9 and 286.5 m, respectively above base of formation at 164.5 m). The faunas lack the zonal name-giver *Gnathodus texanus* Roundy, generally have low species diversity, and contain few specimens, because the high-energy shelf-margin deposits of the formation were generally unfavourable for conodont preservation. *Taphrognathus varians* Branson and Mehl is present together with *Anchignathodus penescitulus* and *Cloghergnathus* spp. (Higgins 1985, GSC paleontological report 6-ACH-85).

Biostratigraphy of Foraminifers and Calcareous Algae

Foraminifers and calcareous algae are relatively rare and poorly preserved in the Livingstone Formation of southwestern Alberta and have not been extensively studied from any of the Livingstone sections that will be visited on the field excursion. Microfossils of zones 8 to zone 10 are found in the Livingstone of the eastern Front Ranges. In more westerly sections, where carbonates of the lower and middle Mount Head Formation have graded laterally into the Livingstone Formation, the middle and upper parts the formation yield foraminifers and algae of zones 11 to 13 (Mamet, 1976; Mamet and Mason, 1968).

Coral Biostratigraphy

Corals are generally rare and poorly preserved throughout the Livingstone Formation. Faunas of zones IIB (upper) and IIIA (lower), found in correlative strata of the upper Shunda and Turner Valley, are poorly represented by rare occurrences of *Sychnoelasma* sp., *Vesiculophyllum* sp. and *Siphonodendron mutabile* in the lower part of the formation, overlain by *Siphonodendron* sp. cf. *S. oculinum* and *Zaphriphyllum* sp. in the upper Livingstone of eastern sections. In the more westerly Front Ranges, the upper Livingstone yields poorly developed faunas of coral zones IIIA (upper) to IIID, discussed below under the Mount Head Formation.

Stop 2-13. Uppermost Livingstone Formation and overlying Wileman, Baril, and Salter members of the Mount Head Formation, northwestern side of Cougar Creek, about 1.7 km upstream from bridge (Figs. 41, 42). The succession is most accessible at the creek level, but only the resistant carbonates of the upper Livingstone Formation and Baril Member are well exposed along the stream. The recessive Wileman and Salter members are well exposed on the northwest side of the canyon about 100 m above the stream and can be reached, if time permits, by scrambling up the wooded slope developed on the Wileman Member.

Thick-bedded, lower Viséan, bryozoan-pelmatozoan lime grainstone and dolograinstone of the upper Livingstone are abruptly overlain by recessive, silty dolostone and dolomitic siltstone of the lower Viséan Wileman Member. Thin, planar laminae and small-scale crosslaminae that are partly wave formed and accentuated by selective chertification are common in the upper Wileman. At the section measured 100 m above the stream, the Wileman is 11.49 m thick, has a broadly gradational basal contact, and contains a unit (1.77 m thick) of solution-collapse breccia derived from the dissolution of restricted-marine anhydrite.

The upper Livingstone Formation, consisting of relatively cool-water shelf-margin deposits, records the early phase of a regional regression that culminated with deposition of restricted-shelf deposits of the Wileman. In the Foothills, the Turner Valley Formation and overlying Wileman Member jointly constitute a third-order T-R sequence with the lower sequence boundary at the base of the Turner Valley. The sequence is also developed in the Front Ranges of the Canmore region. There, the transgressive surface lies in the lower to middle Livingstone but has not been precisely located because of the relatively homogeneous nature of the Livingstone and lack of precise biostratigraphic control. The RST of the sequence comprises the upper Livingstone Formation and Wileman Member. A ravinement unconformity at the base of the overlying Baril Member forms the upper sequence boundary.

The Wileman is unconformably overlain by the cliff-forming, lower Viséan Baril Member (Fig. 42), which comprises medium- to thick-bedded, skeletal grainstone grading upward into chert-rich, dolomitic lime wackestone and packstone of the overlying Salter Member. Ooid-skeletal lime grainstone is present in the basal Baril, but has not been observed higher in the unit. A recessive medial unit (2.11 m thick where measured about 100 m above the stream) of finely crystalline dolostone is also present. Medium-scale crossbedding is locally evident in the grainstone of the Baril. Lithofacies of the Baril, 31.27 m thick above Cougar Creek and 35.6 m thick at Princess Margaret Mountain, were deposited in relatively high-energy environments on the protected shelf of a rimmed carbonate platform.

The poorly exposed, gradational contact between the resistant Baril and overlying recessive Salter Member is placed at a conspicuous break in slope, above which abundant irregular masses and lenses of chert appear in the section. The Salter cannot be measured at the stream level, but at the measured section about 100 m above stop 2-2, the member is totally exposed and 21.93 m thick. At this stop, exposures of the middle Viséan Salter are mainly chert-rich, dolostone; however, a diverse array of lithofacies including ooid lime grainstone, skeletal grainstone to wackestone and fenestral, cryptalgal lime boundstone are also present. Cherty dolostone showing small-scale crosslaminae is exposed in the upper Salter at the stop. Deposition of the Salter took place on the protected shelf and restricted shelf of a carbonate platform.

The Baril and overlying Salter members constitute a third-order T-R sequence (Baril/Salter sequence). The lower sequence boundary is the ravinement unconformity at the base of the Baril, whereas the upper sequence boundary is the ravinement unconformity at the Salter/Loomis contact. A maximum flooding surface is not clearly developed. Maximum water depths appear to have been attained during deposition of the skeletal lime grainstone of unit 14 (Fig. 42), occurring in the lower part of the upper T-R subsequence of the Baril. The RST consists of the upper Baril (units 15 - 21) and the overlying restricted-marine Salter Member.

Conodont Biostratigraphy

The Wileman and possibly the Baril Member of the Mount Head contain conodont assemblages of the lower Viséan *Gnathodus texanus* Zone, but most of the formation is within the middle and upper Viséan *Cavusgnathus* Zone. Conodonts of the Mount Head sections that will be visited on the field trip have not been studied. The *Cavusgnathus* Zone is a broad biostratigraphic unit recognized in the inner shelf-margin to restricted-shelf lithofacies of the Mount Head at many localities in Alberta and east-central British Columbia (Higgins *et al.*, 1991). It has also been found locally in the lower Etherington Formation. Faunas from the Mount Head are typical of shallow-marine environments and have few specimens and low species diversity.

Coral biostratigraphy

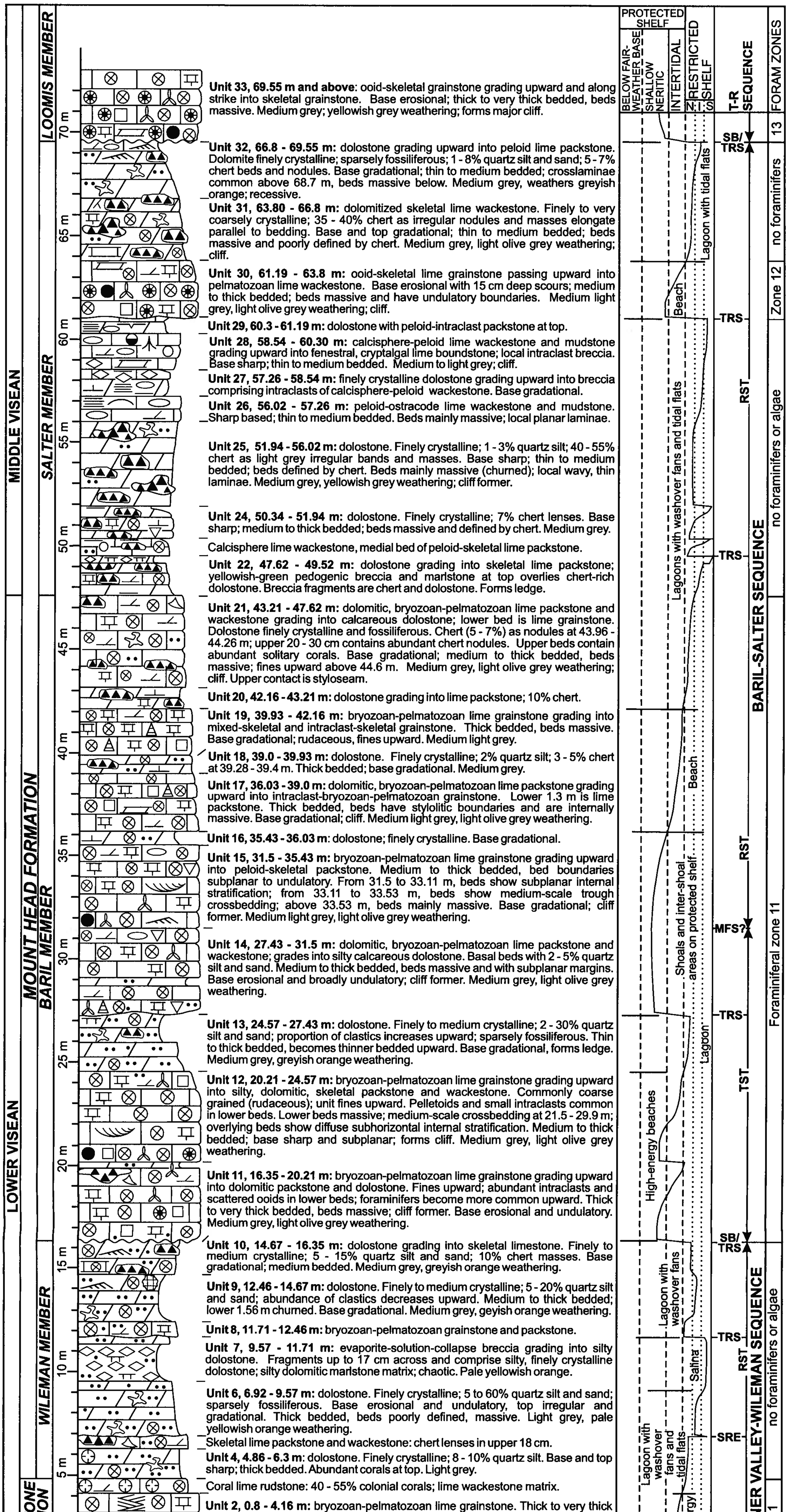
Viséan corals of zones IIIA (upper) to IV are abundant at numerous levels in the open-marine carbonates of the Mount Head Formation. Early to middle Viséan faunas of limited diversity, belonging to zones IIIA (upper) to IIIC, occur in the Baril Member and in the western, more open marine outcrops of the Wileman and Salter members. The most abundant corals in this interval are early species of *Canadiphyllum*, *Ekvasophyllum enclinotabulatum* Sutherland?, *Zaphriphyllum disseptum* Sutherland and large, unstudied ?hapsiphyllid corals. As noted above, these zones have also been recognized in western correlatives of the lower Mount Head Formation, included in the upper Livingstone Formation.

Biostratigraphy of Foraminifers and Calcareous Algae

The upper beds of the Livingstone Formation, together with the overlying Wileman and Baril members, contain foraminifers and algae assignable to lower Viséan zone 11 of Mamet and Skipp (1970). Samples from the upper 4.86 m of the Livingstone and lower 1.84 m of the Wileman Member (GSC locs. C-227601 - C-227610) at stop 2-2 contain the following microfossils: *Asphaltina macadami*, *Endothyra* sp., *Eoendothyranopsis* ex. gr. *E. spiroides*, *Eoforschia* sp., *Globoendothyra* ex. gr. *G. baileyi*, *Stacheoidella* sp., *Stacheoides* sp., and *Priscella* sp. At higher levels in the Wileman, foraminifers and algae are relatively rare and lack zone-diagnostic species. Samples (GSC locs. C-227617-227619) collected from a bed of skeletal lime packstone at 6.85 to 7.60 m above the base of the Wileman contain *Eoforschia* sp., *Septabrunsiina* sp. and *Stacheoidella* sp. Samples collected from the overlying Baril Member (GCS localities C-227627 to C-227663) contain a somewhat more diverse assemblage that is provisionally assigned to zone 11 and includes *Archaelithophyllum*? sp., *Asphaltina macadami*, “*Dasyporella*” sp., *Endothyra* sp., *Eoendothyranopsis* sp., *Eoforschia* sp., *Globoendothyra* sp., *Stacheoidella* sp., and *Stacheoides* sp.

Foraminifers assignable to zone 12 of Mamet and Skipp (1970) are common in ooid and ooid-skeletal lime grainstone of the upper Salter Member at this stop. Samples collected at GSC localities C-227691 to C-227693 (13.68 to 14.58 m above base of Salter) contain *Asphaltinella bangorensis*, *Archaeolithophyllum* sp., *Asphaltina macadami*, *Calcisphaera* sp., “*Dasyporella*” sp., *Endothyra* sp., *Eoendothyranopsis hinduensis*, *Eoendothyranopsis* ex. gr. *E. Spiroides*, *Eoforschia* sp., *Epistacheoides* sp., *Globoendothyra baileyi*, *Globoendothyra* ex. gr. *G. paula*, *Orthrisiphon saskatchewanensis*, *Orthriosiphonoides tenuiramosa*, *Orthriosiphonoides salterensis*, *Ortonella kershopensis*, *Pseudoammodiscus* sp., *Stacheoidella* sp., and *Stacheoides tenuis.*

Stop 2-14. Loomis Member and overlying lower Opal Member of the Mount Head Formation in canyon along Cougar Creek immediately downstream from stop 2-13 (Figs. 43, 44). Lithofacies of the Loomis are exposed along both sides of the canyon with the best exposure in a steep, narrow side canyon on the southeast side. Numerous joints and minor faults obscure the bedding and sedimentary fabrics on the northwest side. A northerly striking transverse fault also



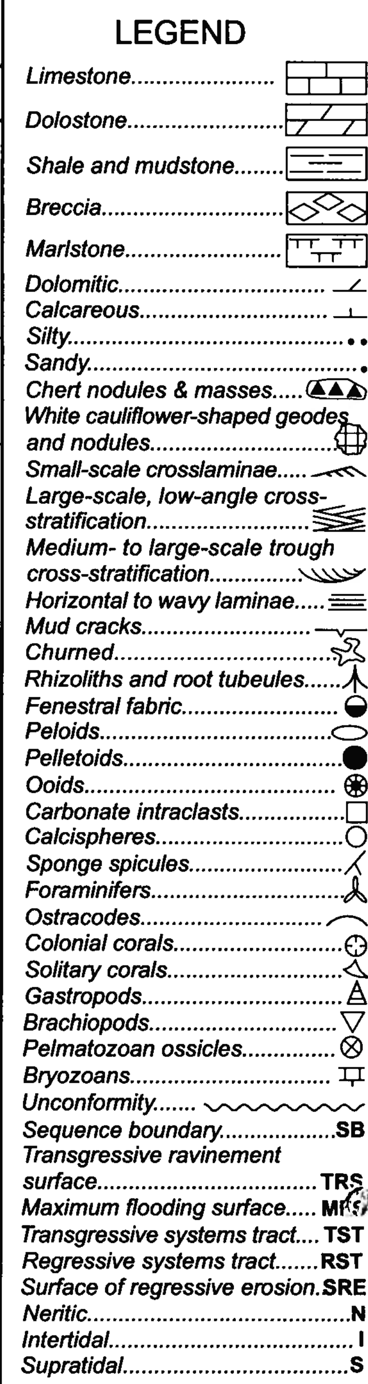


Figure 42. Columnar section showing characteristics and stratigraphic relationships of Viséan Wielman, Baril, and Salter members of the Mount Head Formation at section measured on northwest side canyon of Cougar Creek above stop 13.

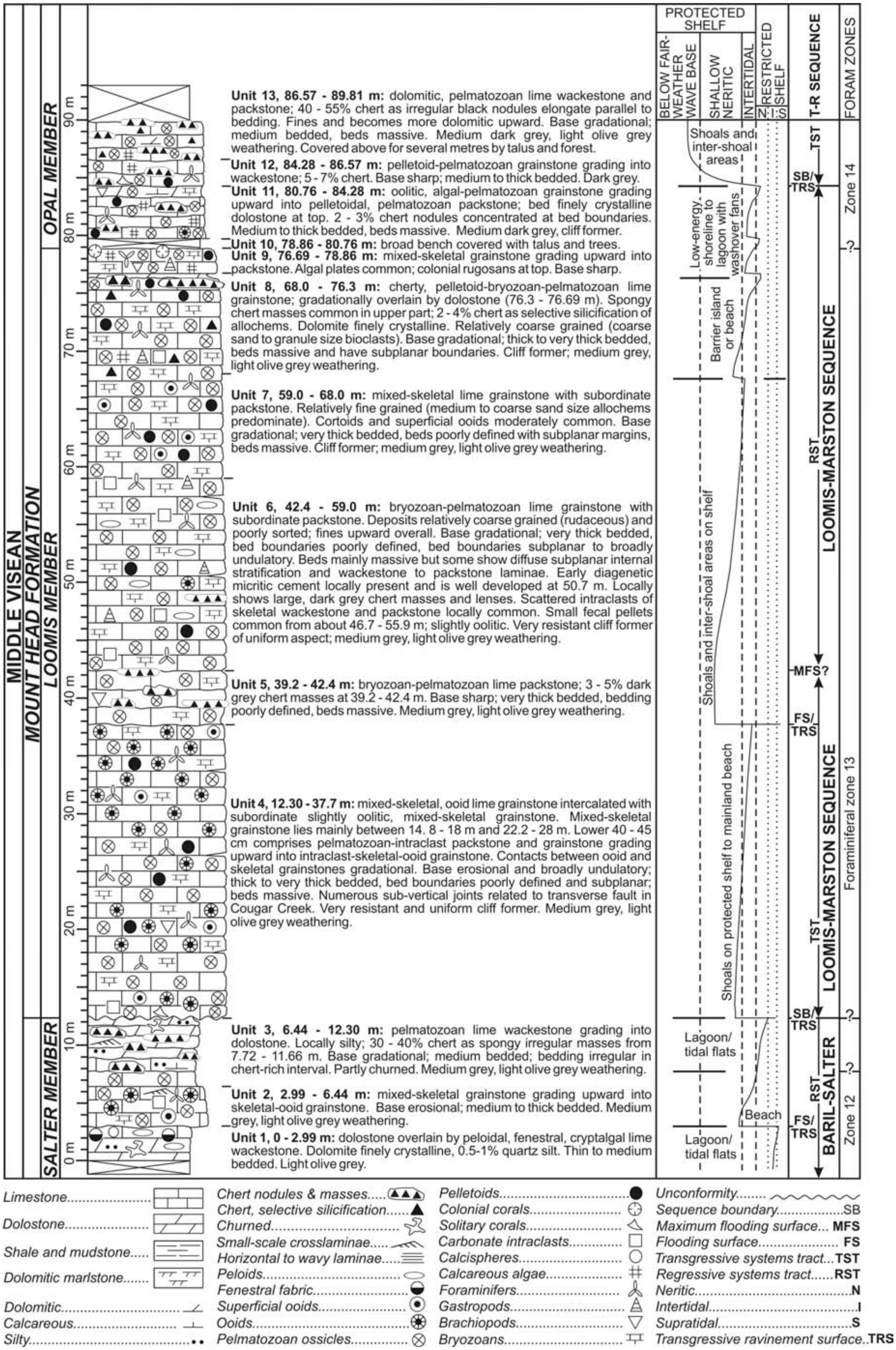


Figure 43. Columnar section showing Viséan Loomis Member on southeast side canyon of Cougar Creek at stop 2-14.

complicates the Loomis at this stop.

The cliff-forming, middle Viséan Loomis Member (about 66.6 m thick) unconformably overlies the Salter Member and is dominated by massive, thick-bedded, peloid-pelletoid-skeletal lime grainstone and packstone. Ooid lime grainstone is present in the lower Loomis on both sides of the canyon. Large nodules of chert are present in the upper Loomis, and large colonial rugose corals, including the genus *Cystolonsdaleia*, are common in the upper Loomis about 100 m above the northwest side of the creek in the footwall of the transverse fault. Nodular paleosols are widely developed in the middle part of the member in the large quarry on Grotto Mountain immediately east of Cougar Creek. At that locality, they separate a lower unit, dominated by ooid to ooid-skeletal lime grainstone from an overlying unit of cherty skeletal lime grainstone.

At stop 2-3, ooid lime grainstone in the lower part of the Loomis Member (unit 4, Fig. 43) records high-energy beach and shoal sedimentation on the protected shelf. Most of the overlying lithofacies of the Loomis appear to have been deposited in relatively low-energy settings on the outer part of the protected shelf. Such deposition is suggested by the absence of medium- to large-scale cross-stratification, the general lack of ooid grainstone and other high-energy lithofacies, predominance of open-marine bioclasts, and the occurrence of abundant pelletoids and cortoids.

The Loomis is gradationally overlain by the slightly less resistant strata of the lower Opal Member, which is structurally thickened by a minor fault and poorly exposed in the canyon of Cougar Creek. At Princess Margaret Mountain to the northwest, the Opal is 86.5 m thick. In contrast to the Loomis, the upper Viséan lowermost Opal contains abundant nodules and irregular masses of chert. Calcareous, cherty dolostone and dolomitic skeletal lime wackestone to packstone predominate in the lower Opal, which correlates with the Marston Member at Moose Mountain.

The Loomis, lower Opal, and correlative strata in the Marston Member constitute a third-order T-R sequence (Loomis/Marston sequence). At stop 2-14, the TST overlies the ravinement unconformity at the base of the Loomis and comprises the oolitic lime grainstone of the lower Loomis (unit 4, Fig. 43) and at least the lower part of the overlying section of skeletal lime grainstone (units 5 and 6). The RST comprises the upper Loomis and the lower part of the Opal Member. The medial paleosol in the Loomis at the Grotto Mountain quarry indicates the presence of two important high-order T-R subsequences.

Biostratigraphy of Foraminifers and Calcareous Algae

Above stop 2-12 (Fig. 43), foraminifers assignable to zone 13 of Mamet and Skipp (1970) occur in ooid lime grainstone and ooid-skeletal grainstone collected from the lower 1.6 m of the Loomis Member at GSC localities C-227703 to C-227707. They include: *Archaediscus* ex. gr. *A. krestovnikovi*, *Calcisphaera* sp., *Endothyra* sp., *Eoendothyranopsis scitula*, *Eoforschia* sp., *Globoendothyra* ex. gr. *G. paula*, *Koninckopora inflata*, *Koninckopora tenuiramosa*, *Orthriosiphonoides* sp., *Skipella* sp., *Stacheoides meandriformis* and *Stacheoides tenuis.*

Stop 2-15. The middle and upper units of the Opal Member along a small tributary on the southeastern side of Cougar Creek, about 1.6 km upstream from the bridge (Figs. 41, 45).

The middle Opal comprises dark grey, medium- to thick-bedded, peloid-skeletal lime grainstone with subordinate packstone and shows medium-scale trough crossbedding. The moderately resistant middle Opal is abruptly overlain by the recessive, rhythmically bedded upper Opal. Thick, massive beds of dolomitic, mixed-skeletal and bryozoan-pelmatozoan lime wackestone to packstone, intercalated with dark-grey to black shale and marlstone constitute the upper Opal.

The middle to upper Opal, the Carnarvon Member, and the recessive Daisy Creek member of the lower Etherington Formation constitute a third-order T-R sequence herein called the Opal\Carnarvon sequence. The lower sequence boundary is a major flooding surface (either a ravinement unconformity or transgressive surface) at the base of the middle Opal, whereas the upper sequence boundary is the ravinement unconformity developed on the upper paleosols of the Daisy Creek member.

The upper Opal and its correlatives in the Golata Formation of the Peace River Embayment and central Prophet Trough record the early phase of a major influx of northeasterly-derived siliciclastics. In southern Prophet Trough, the Mississippian terrigenous influx culminated with deposition of the sandstone-dominated Todhunter Member of the Etherington Formation.

Coral biostratigraphy

The upper Loomis, Opal, and Carnarvon members (zones IIID and IV) contain the richest and most diverse Mississippian coral faunas found in the southern Rocky Mountains of Alberta and British Columbia. Solitary corals of the genus *Ekvasophyllum* form a vertical succession of species (zone IIID), from *E. inclinatum* Parks in the upper Loomis and lowermost Opal, to *E. cascadense* (Warren) in the lower to middle Opal, to *E. banffense* (Warren) in the middle to upper Opal. The latter grades upward, through intermediate forms, into the genus *Faberophyllum* (zone IV), several species of which are abundant in the upper Opal and Carnarvon members. The same succession of solitary corals is found in favourable facies from Alaska to Nevada. Colonial corals are most abundant in zone IIID, within the uppermost Loomis Member and lower Opal Member. In this interval, the most commonly occurring taxa are *Siphonodendron warreni* (Nelson), *S. "whitneyi"* of Meek, *Cystolonsdaleia pennsylvanica* (Shimer), *C. shimeri* (Crickmay), *Stelechophyllum mclareni* (Sutherland), *Pleurosiphonella* sp., and *Palaeacis* sp. A less diverse fauna, representing the upper part of zone IIID in the middle and upper Opal, is dominated by *Petalaxis astraeiforme* (Warren) and also contains a few specimens

Figure 44. Salter, Loomis and Opal members of Mount Head Formation on northwestern side Cougar Creek at stop 2-14 (Fig. 41). Arrows indicate: A- approximate location of contact between middle Viséan Salter and Loomis members; B- location of contact between grainstone-dominated, middle Viséan Loomis (66.6 m thick) and overlying chert-rich carbonates of the upper Viséan Opal; C- climber on lower Loomis for scale. View is toward northwest.

Figure 45. Top of grainstone-dominated middle Opal Member (black arrows at lower left indicate top) and overlying rhythmically interbedded limestone and shale to marlstone of upper Opal at stop 2-15 (Fig. 41) in side canyon draining toward northwest into Cougar Creek.

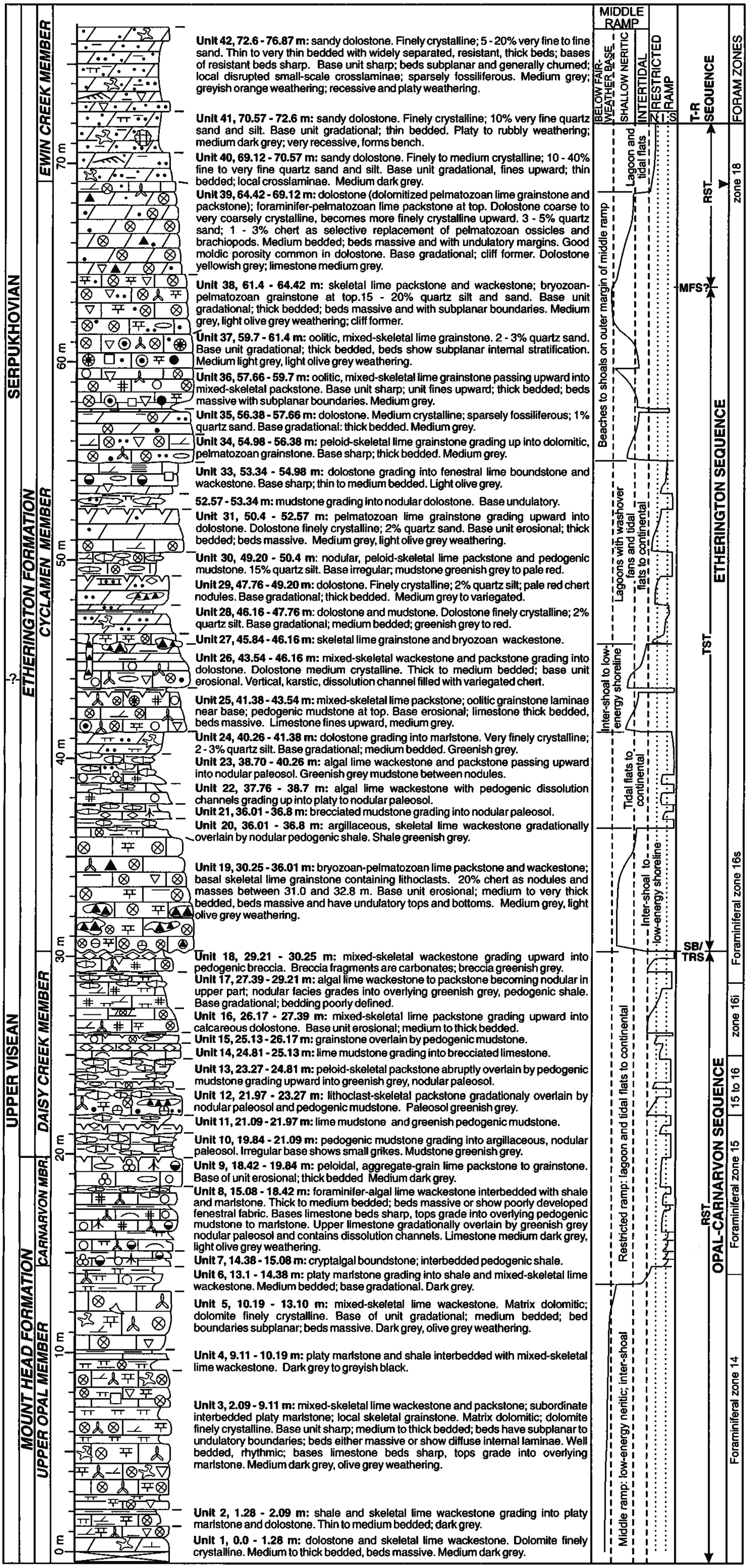
Figure 46. Daisy Creek member and overlying Cyclamen member of the cyclic upper Viséan and Serpukhovian Etherington Formation at stop 2-16 (Fig. 41) on northwest side of Cougar Creek; view is toward west. Arrows indicate: A- contact between Carnarvon Member of Mount Head Formation and overlying recessive Daisy Creek member, B- contact between Daisy Creek and overlying cliff- and ledge-forming carbonates of Cyclamen member, C- top Cyclamen and base Ewin Creek member of Etherington Formation. The Ewin Creek is well exposed in the forest above upper cliff at centre of photo.

of *S. "whitneyi"* and *Stelechophyllum* sp. The youngest colonial rugose coral in the Mount Head Formation is the distinctive, large species *Siphonodendron arizelum* (Crickmay) (zone IV), which characterizes the uppermost Opal and its lateral equivalents in the Carnarvon Member.

Stop 2-16. Uppermost Opal Member (upper 14.4 m), Carnarvon Member of the Mount Head Formation and lower Etherington Formation (Daisy Creek member and overlying Cyclamen member), lower canyon of Cougar Creek, about 1.5 km upstream from the culvert in the Cougar Creek subdivision (Figs. 41, 46, 47) The contact between the moderately resistant Carnarvon (5.46 m thick) and moderately recessive, olive-grey to black shale and mixed-skeletal lime wackestone of the underlying Opal is sharp but apparently conformable. The thick-bedded Carnarvon is mainly peloidal, foraminifer-algal lime wackestone that is rhythmically interbedded with thin recessive units of pedogenic marlstone and greenish-grey shale. Fenestral, cryptalgal lime boundstone is also locally present in the Carnarvon, which was deposited on the restricted shelf of a vast carbonate ramp.

The Carnarvon is abruptly overlain by the Daisy Creek member (10.41 m thick) of the Etherington Formation (119.17 m thick). The uppermost Carnarvon shows pedogenic alterations and its upper contact is a dissolution surface showing rundkarren (small solution grooves developed below soil). A 1.25 m thick paleosol consisting largely of limestone lithorelicts (nodules resulting from pedogenic alteration of bedded limestone) enclosed by greenish-grey mudstone constitutes the lower unit of the Daisy Creek member. The overlying Daisy Creek contains several minor unconformities separated by units containing nodular paleosols (Fig. 48) and a variety of pedogenic breccias. Glaebules are present in some of the nodular paleosols but most of the nodules appear to be lithorelicts. The unconformities are surfaces of transgressive ravinement developed on paleosols.

Typical ABC soil profiles probably developed during formation of the paleosols of the Daisy Creek member but are



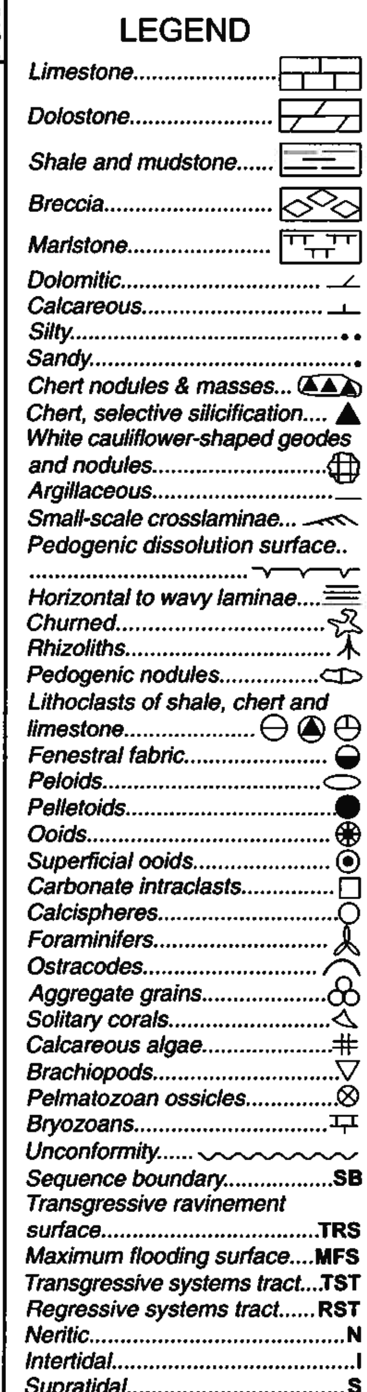


Figure 47. *Columnar section showing characteristics and stratigraphic relationships of upper Mount Head Formation and overlying lower Etherington Formation at stops 16 to 17 (Fig. 41) on Cougar Creek by Canmore, Alberta.*

truncated, preserving only parts of the B and C horizons. The B horizons abruptly to gradationally overlie the C division and comprises mudstone (commonly as granular peds), pedogenic breccia, nodular peds and columnar peds. The C division consists of deeply weathered nodular to partly brecciated bedrock. Maroon paleosols are widely preserved in the Etherington Formation but at stop 2-16 the paleosols are mainly greenish grey, thereby indicating extensive gleization (reduction in water-saturated soil). The erosion surfaces at the tops of the paleosols generally resulted from transgressive ravinement. A ravinement unconformity at the contact between the Daisy Creek and overlying Cyclamen member is particularly prominent.

The nature of the paleosols indicates that the latest Viséan climate was relatively humid. The paleosols are dominated by deposits and structures recording limestone dissolution (small karstic features and abundant lithorelicts) instead of deposits such as laminar calcrete and pisoliths that record carbonate precipitation. The paleosols record the onset of the late Paleozoic glaciations on southern Gondwana in the southern hemisphere.

The middle and upper Opal together with the Carnarvon and Daisy Creek member constitute a third-order T-R sequence (Opal\Carnarvon sequence). The lower sequence boundary (either a transgressive surface or minor ravinement unconformity) of the sequence coincides with the base of the middle Opal. Maximum water depths were apparently established during deposition of the lower black shale and marlstone of the upper Opal. The RST comprises most of the upper Opal and the overlying Carnarvon and Daisy Creek members. The upper sequence boundary, a ravinement unconformity at the base of the Cyclamen member, overlies pedogenic breccia at the top of the Daisy Creek.

A bed of lithoclastic breccia at the top of the recessive Daisy Creek member is unconformably overlain by cliff-forming carbonates of the Cyclamen member (38.85 m thick), which comprises numerous high-order T-R sequences. When completely developed, the sequences comprise a resistant lower assemblage of ooid lime grainstone and mixed-skeletal grainstone, packstone and wackestone deposited in neritic to intertidal-beach and tidal-flat settings. The lower assemblage is overlain by an upper, recessive assemblage deposited largely in supratidal environments. The upper assemblage contains a diverse array of deposits including green to maroon mudstone, nodular paleosols, and sandy dolostone showing small-scale crosslaminae.

Regionally, the Cyclamen, Ewin Creek and Todhunter (not well developed at Cougar Creek) members of the Etherington constitute a second-order T-R sequence (Etherington sequence). The lower sequence boundary lies at the base of

Figure 48. Nodular paleosol in Daisy Creek member of upper Viséan and Serpukhovian Etherington Formation at stop 2-16 on Cougar Creek. Paleosol consist of rounded lithorelicts (remnants of deeply weathered bedrock) encased in greenish grey mudstone.

the Cyclamen member, and the maximum flooding surface at Cougar Creek appears to lie in the uppermost Cyclamen member. At Cougar Creek, the RST comprises the Ewin Creek and Todhunter, which is unconformably overlain by the Bashkirian Tyrwhitt Formation. The Todhunter Member, which constitutes the upper member of the Etherington in the region, is thin and was largely removed by erosion during the latest Serpukhovian to early Bashkirian. The upper sequence boundary is the regional unconformity at the top of the Todhunter. The unconformity coincides with the boundary between the Kaskaskia sequence and overlying Absaroka tecto-stratigraphic sequence of Sloss (1963).

The Mississippian transgressive-regressive sequences that formed before the late Viséan are largely carbonate dominant and autocyclic. These sequences typically have extensive intertidal to supratidal carbonate tidal-flat facies showing metre-scale cycles and lack high-frequency, regionally developed paleosols and related disconformities. In contrast, the late Viséan and Serpukhovian sequences are typically allocyclic, high frequency, comprise mixed- carbonate-siliciclastic lithofacies and commonly have regionally developed paleosols and other supratidal deposits superimposed on neritic lithofacies in up-dip positions. The upper Mississippian sequences likely resulted from cyclic changes in the volumes of the continental ice sheets on southern Gondwana.

Conodont Biostratigraphy

Conodont faunas of the Etherington Formation are relatively poorly known and have been recovered from few localities. They have been extracted from the Cyclamen member and lower Ewin Creek member at Princess Margaret Mountain immediately north of Canmore (Fig. 41) and from the Cyclamen member at Ptarmigan Cirque above the Highwood Pass, 59 km southeast of Canmore.

The Cyclamen member and basal Ewin Creek member of the eastern Front Ranges contain conodont faunas assignable to the broad Viséan *Cavusgnathus* Zone (Higgins *et al*., 1991; Richards *et al*., 1993). Faunas from the lower Etherington are typical of shallow-marine environments and have few species and low species diversity. *Anchignathodus scitulus* (Hinde), *Apatognathus* spp., *Cavusgnathus charactus* Rexroad, *C. convexus* Rexroad, *C. unicornis* Youngquist and Miller, and *Vogelgnathus campbelli* (Rexroad) are present.

Coral Biostratigraphy

A marked change in the coral faunas of the Rundle Group occurs at the boundary between zones IV and V, which lies in the upper part of the Carnarvon Member of the Mount Head Formation (Fig. 12). The lower part of Zone V contains no species of the typical Mount Head genera *Faberophyllum*, *Ekvasophyllum*, *Canadiphyllum*, *Stelechophyllum*, and *Petalaxis*. The appearance of the genus *Siphonodendron*, represented by the two European species, *S. martini* and *S. irregulare*, marks the base of Zone V in the uppermost beds of the Carnarvon Member. *Cystolonsdaleia*, which also occurs in older beds of the Mount Head Formation, is represented by only one species, *C. stelcki*, which occurs in Zone VB, within the upper Cyclamen member and the Ewin Creek member of the upper Etherington Formation. Intervening strata of the Etherington Fm. contain corals of Zone VA, belonging to the genera *Zaphrentites*, *Schoenophyllum*, *Lublinophyllum*, *Palaeosmilia* and *Siphonophyllia*, as well as taxa belonging to at least six other rugose coral families. In contrast to older coral faunas of the Rundle Group, which are mainly endemic, those of Zone V include numerous genera and species in common with coeval faunas of North Africa and Western Europe. This similarity indicates significant faunal exchange through the Rheic Ocean, which separated Euramerica from Gondwana during mid-Carboniferous time.

Biostratigraphy of Foraminifers and Calcareous Algae

Foraminifers and calcareous algae are common and well preserved in the upper Opal Member at stop 2-5. Limestone samples (from GSC locs. C-226684 to C-226705) collected from the upper 14.4 m of the Opal contain *Aoujgalia* sp., *Archaediscus* sp., *Banffella banffensis*, *Biseriammina*? sp., *Brunsia* sp., *Calcisphaera* sp., *Consobrinella* sp., *Cribrokamaena* sp., *Earlandia* sp., *Endothyra* sp., *Endothyranopsis hirosei*, *Eoendothyranopsis* ex. gr. *E. ermakiensis*, *Eoendothyranopsis scitula*, *Eoendothyranopsis thompsoni*, *Eoforschia* ex. gr. *E. moelleri*, *Epistacheoides connorensis*, *Globoendothyra* ex. gr. *G. paula*, *Issinella* sp., *Koninckopora inflata*, *Koninckopora mortelmansi*, *Lugtonia*? sp., *Mediocris* sp., *Opalella* (a new genus to be named), *Priscella* sp., *Pseudoammodiscus* sp., *Skippella* sp., *Stacheoides meandriformis* sp., *Stacheoides tenuis*, and *Tuberitina* sp., assigned to upper Viséan zone 14.

Foraminifers and algae are also relatively common in the thin Carnarvon Member. Limestone samples collected from the Carnarvon at GSC localities C-226708 to C-226721 contain *Asphaltina* sp., *Banffella banffensis*, *Biseriammin*a sp., *Cribrokamaena* sp., *Earlandia* sp., *Endothyra* sp., *Endospiroplectammina* sp., *Endothyranopsis* sp., *Eoendothyranopsis* ex. gr. *E. ermakiensis*, *Eoendothyranopsis robustus*, *Eoendothyranopsis thompsoni*, *Eoforschia* sp., *Globoendothyra* ex. gr. *G. globulus*, *Koninckopora inflata*, *Koninckopora mortelmansi*, *Opalella* sp., *Palaeomicrocodium* sp., *Pokornynella* sp., *Pseudoammodiscus* sp., *Skippella* sp., *Stacheoides* sp. and *TeT-Rataxis* sp., assigned to upper Viséan zone 15. The lower 2.13 m of the overlying Daisy Creek member (GSC locs. C-226722 to C-226726) contains a similar assemblage.

The section from 2.96 m to 4.04 m above the base of the Daisy Creek member contains microbiota that are transitional between those that normally occur in the upper Carnarvon and those characteristic of the lower Etherington. Usually the Carnarvon/Etherington contact is sharp with the elimination of many foraminifers of zone 15 (e.g. *Koninckopora*, *Opalella*) and subsequent arrival of zone 16 elements (*Eostaffella, Pseudoendothyra, Neoarchaediscus*). At Cougar Creek, a few *Eoendothyranopsis* occur up to 4.06 m above

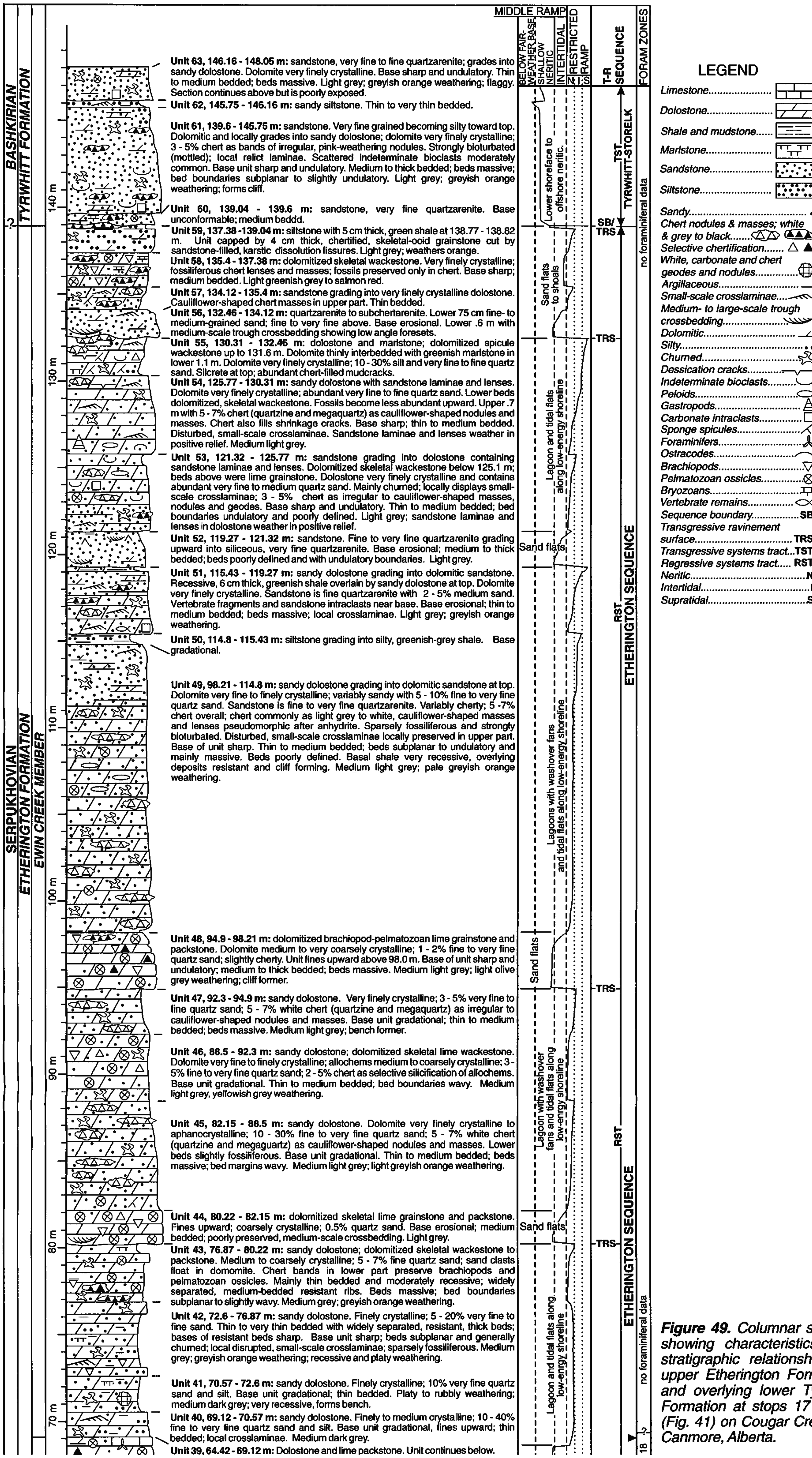


***Figure 49.** Columnar section showing characteristics and stratigraphic relationships of upper Etherington Formation and overlying lower Tyrwhitt Formation at stops 17 to 18 (Fig. 41) on Cougar Creek by Canmore, Alberta.*

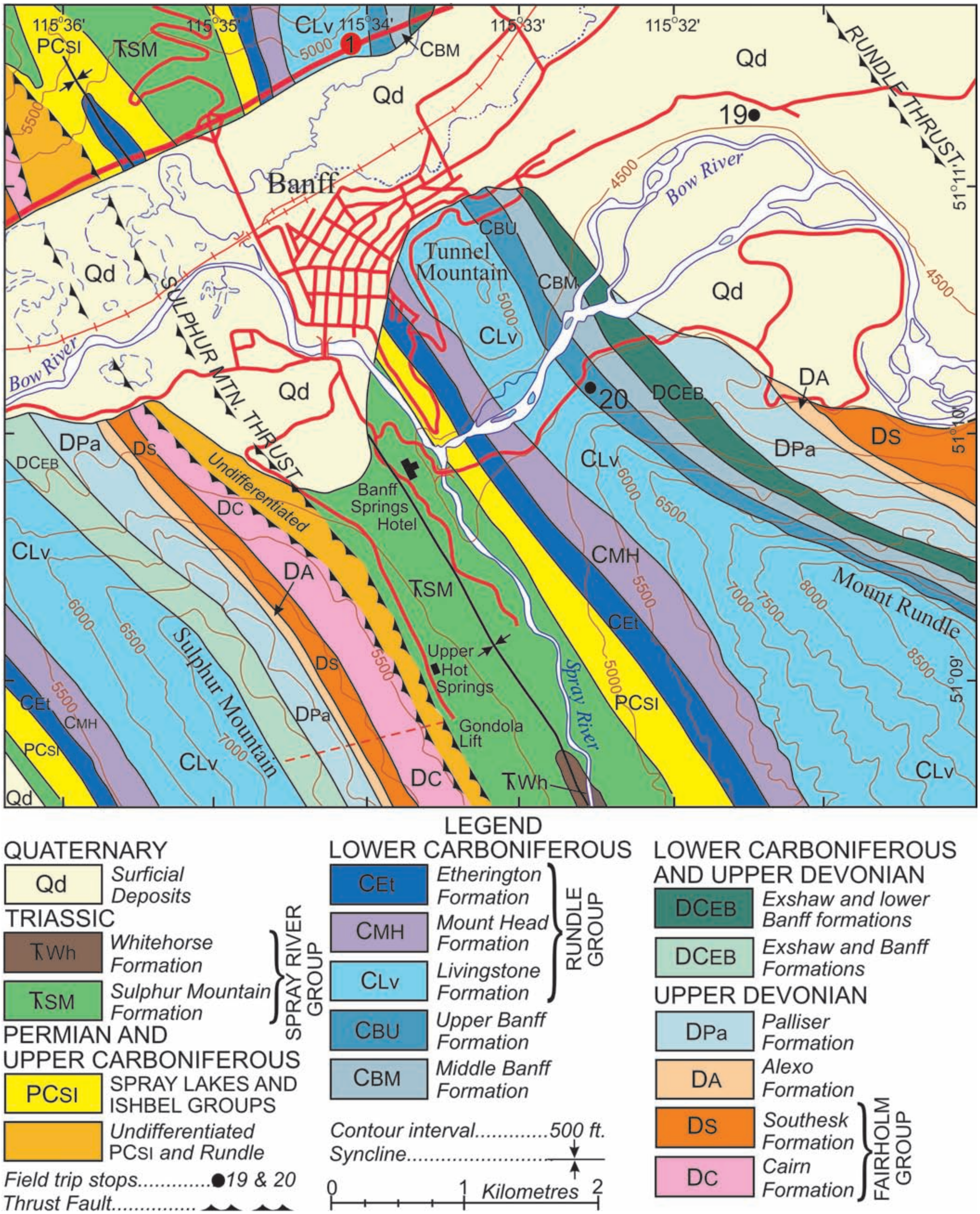


Figure 50. Geological map of the Tunnel Mountain region by the town of Banff in Banff National Park, Alberta. Map shows location of stops 2-19 to 2-20 for day 2 (from Price and Mountjoy, 1972).

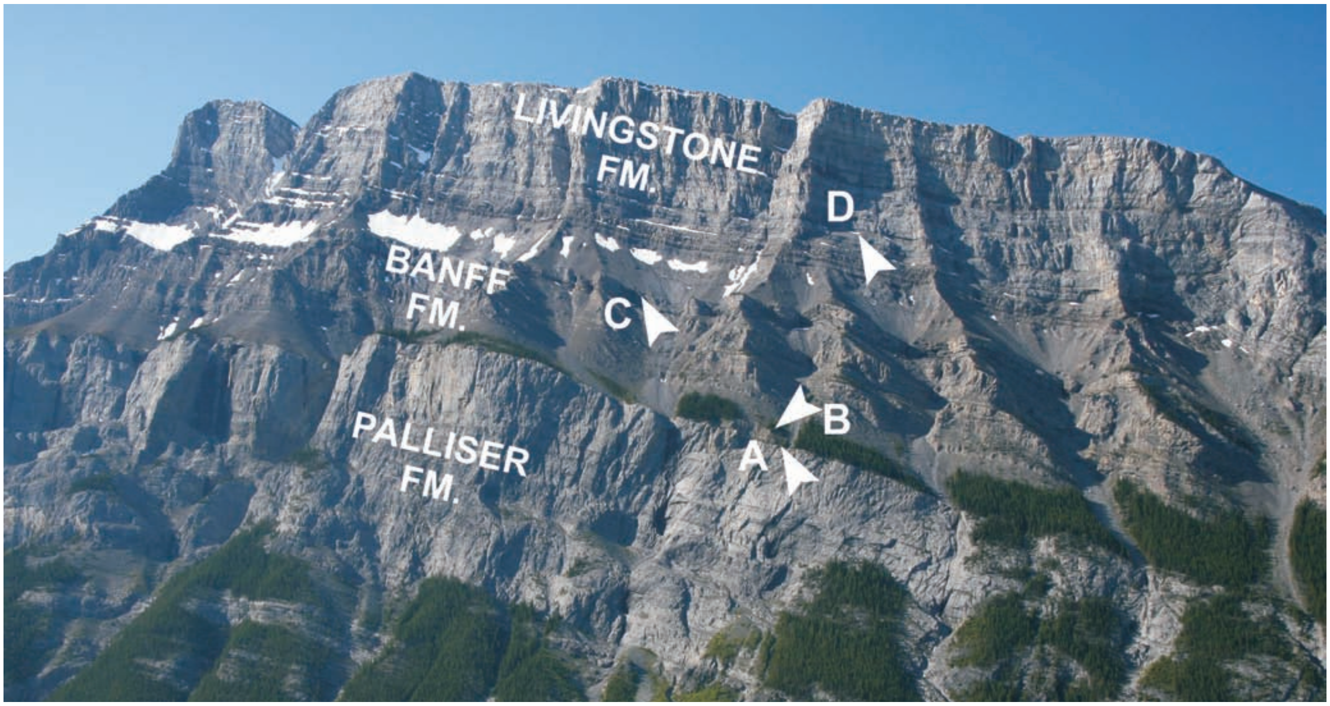


Figure 51. View of northeastern side of Mount Rundle from stop 2-19 (Fig. 50) at the hoodoos above north side Bow Valley. Arrows indicate: A- top of ramp carbonates of Famennian Palliser Formation and base of Famennian to Tournaisian Exshaw Formation, B- top Exshaw and base of type section of Tournaisian Banff Formation (512 m thick), C- top of middle Banff (horizon correlates with base of Pekisko Fm. at Jura Creek), D- top of Banff type section and base of grainstone-dominated Livingstone Formation. Well bedded strata in upper part of Banff Fm. are silty dolostone.

Figure 52. View of type section of Rundle Group on Tunnel Mountain from stop 2-20 (Fig. 50) above access road to Banff Springs Golf Course. Arrows indicate: A- historical location of contact between Banff and Livingstone formations, B- top Livingstone Formation and base Salter Member of Mount Head Formation, C- contact between Salter and Loomis members of Mount Head, D- approximate location of contact between the Loomis and Opal members of the Mount Head, E and F- alternate locations for Banff/Rundle contact. View is toward northwest.

the base of the Daisy Creek. The lower Daisy Creek also contains a mixture of Carnarvon and Etherington microfacies. In conclusion, the lower Daisy Creek at stop 2-5 is somewhat older than at most locations. During deposition of the upper Carnarvon, several episodes of alternating subaerial weathering and marine deposition produced deposits (Fig. 48) that are generally confined to the Etherington.

The upper 5.15 m of the Daisy Creek member at stop 2-5 contains a microbiota assigned to upper Viséan zone 16. Samples collected at GSC localities C-226732 to C-226739 in contain *Archaediscus* sp., *Calcisphaera* sp., *Earlandia* sp., *Endothyra* ex. gr. *E. bowmani*, *Globoendothyra* sp., *Kamaenella* sp., *Eostaffella* sp., primitive *Neoarchaediscus* sp., *Pseudoammodiscus* sp., and *Zellerinella* sp.

Foraminifers and algae are not common in most of the Cyclamen member. The lower Cyclamen contains microbiota assigned to uppermost Viséan zone 16s and an assemblage assigned to zone 18 was collected near the Cyclamen/Ewin creek contact. Samples from zone 16s in the lower Cyclamen contain *Archaediscus koktjubensis, Archaediscus krestovnikovi*, *Calcisphaera* sp., *Earlandia* sp., *Endothyra* ex. gr. *E. bowmani*, *Fasciella* sp., *Globoendothyra* ex. gr., *G. globulus*, *Mediocris* sp., *Neoarchaediscus* sp., *Planoendothyra* sp., *Priscella* sp., *Tetrataxis* sp., *Ungdarella* sp. and *Zellerinella* sp. A sample from Serpukhovian zone 18 was collected 0.1 m below the top of the Cyclamen and contains *Archaediscus* sp., *Asteroarchaediscus* sp., *Biseriella* sp., *Calcisphaera* sp., *Earlandia* sp., *Eostaffella* sp., *Eostaffellina* sp., *Fasciella* sp., *Neoarchaediscus* sp., *Planospirodiscus* sp., *Pseudoammodiscus* sp., *Pseudoendothyra* sp., *Pseudoglomospira* sp., and *Ungdarella* sp.

To reach stop 2-17, take game trails up the tree-covered slope developed on top of the Cyclamen member on the northwest side of Cougar Creek to a point where the recessive lower dolostone of the Ewin Creek member is well exposed above the upper cliff of the Cyclamen. The locality is about 75 m above the creek.

Stop 2-17. Lower Carboniferous (Serpukhovian) Ewin Creek member (69.92 m thick) of the Etherington Formation about 75 to 125 m above northwest side of Cougar Creek (Fig. 49).

The recessive lower part of the Ewin Creek member gradationally overlies the cliff-forming limestone and dolostone of the Cyclamen member. The lower Ewin Creek is mainly platy, strongly bioturbated dolostone rhythmically interbedded with beds of resistant, massive silty dolostone, but friable siliciclastic mudstone is present near the base of the member. Slightly higher in the succession, a sharp-based fining-upward unit of dolomitized bryozoan-pelmatozoan grainstone and packstone is present. To see the remainder of the member, continue up the slope and westward along the break in slope developed below the outcrop of the Ewin Creek to the top of Cougar Creek canyon. Above its lower recessive beds, the Ewin Creek becomes more resistant upward and is mainly partly bioturbated, sparsely fossiliferous sandy dolostone showing disturbed small-scale crosslaminae (wave and current formed). The sandy laminae commonly weather in positive relief. Sandstone beds are locally present and become more abundant upward. Chert nodules, geodes, and irregular to botryoidal masses resembling cauliflowers are common. The chert minerals present include quartzine (commonly pseudomorphic after sulphates), megaquartz and chalcedonite.

The Ewin Creek member is a shallowing-upward succession overall, as indicated by an upward gradation from strongly bioturbated dolostone and subordinate bryozoan-pelmatozoan dolograinstone to sandy dolostone showing abundant mud cracks indicating subaerial exposure.

Stop 2-18. Unconformable contact between the Serpukhovian Todhunter Member of the Etherington and overlying Bashkirian Tyrwhitt Formation of the Pennsylvanian Spray Lakes Group at stream level in the canyon of Cougar Creek (Fig. 49).

At this stop, the upper Ewin Creek member of Etherington is dominated by restricted-shelf lithofacies that locally show mud cracks and stromatolites. The uppermost part of the Etherinton Formation is, however, a high-order T-R sequence that is assigned to the Todhunter Member and comprises deposits of somewhat more open-marine aspect. Along the northwestern rim of the canyon, where the Etherington section was measured (Fig. 49), the upper T-R sequence is 6.58 m thick and includes a lower sharp-based, 1.66 m thick, fining-upward unit of shoreline sandstone showing planar stratification and medium- to small-scale cross-stratification. The overlying 3.3 m of the sequence is mainly greenish-grey to light maroon, sandy to silty dolostone containing grey to salmon-red chert lenses with pelmatozoan ossicles, brachiopods and bryozoans. The uppermost 1.66 m is siltstone and greenish grey shale capped by a 4 cm thick bed of certified, skeletal-ooid grainstone. The upper chert bed is partly brecciated and cut by dissolution fissures containing sandstone with abundant medium- to coarse-grained quartz sand. At the level of Cougar Creek, the upper T-R sequence of the Etherington is somewhat thicker but resembles the deposits above.

The boundary between the Lower and Upper Carboniferous is a regional unconformity in most of the World including western North America (Richards *et al*., 2002a). At some localities in the Canadian Rockies, beds of breccia and conglomerate are present at the base of the Spray Lakes Group, but at stop 2-18 the sandstone-filled fissures represent the basal Pennsylvanian deposits. The lower part of the overlying Bashkirian Tyrwhitt Formation consists of strongly bioturbated, very fine to fine grained, dolomitic sandstone of neritic (lower shore face) aspect. Deposits showing hummocky cross stratification and large starved ripples are locally present higher in the formation.

Return to the vehicle for the trip to the Tunnel Mountain region (Fig. 50) in Banff National Park. To drive to stop 2-19, take Highway 1 into Banff National Park and exit at the road

(Banff Avenue) to the town of Banff. Drive southwest on Banff Avenue and turn left onto Tunnel Mountain Road at motels east of town; stop at the Hoodoos overlook.

Stop 2-19. Overview of the Bow Valley, Mount Rundle, and Tunnel Mountain from the Hoodoos overlook by the Tunnel Mountain Road (Figs. 50, 51).

In the Rundle Thrust Sheet on northeastern side of Mount Rundle, the well bedded, argillaceous slope carbonates and subordinate fine-grained siliciclastics of the type section of the Banff Formation (512 m thick) overlie the poorly exposed upper Famennian and lower Tournaisian Exshaw Formation (24.82 m thick), which in turn overlies the cliff-forming Famennian Palliser Formation. The Banff Formation named by Kindle (1924) is conformably overlain by the cliff-forming upper Tournaisian to middle Viséan Livingstone Formation (mainly lime grainstone of upper-slope and shelf-margin origin). The type section of the Banff was first described by Warren (1927). Between the McConnell Thrust Sheet at Jura Creek and the type section of the Banff, the Pekisko Formation and overlying Shunda Formation have passed basinward into the middle and upper Banff, respectively.

Return to vehicles and drive to stop 2-20 above the Banff Springs Golf Course slightly west of the clubhouse and 1.0 km east of the bridge over the Spray River. To reach the stop, cross the Bow River on Banff Avenue. Then drive toward the west end of the Banff Springs Golf Course via Spray Avenue, Rundle, and River Avenue. Cross the Spray River on Aspen Avenue (golf course road) and continue toward the east along the paved road to a gravel parking area on the south side of the road. Climb a short distance up the ridge to obtain a good view of Tunnel Mountain.

Stop 2-20. View of Rundle Group on southwest side of Tunnel Mountain (Fig. 52) from ridge on northeast side of Mount Rundle above the Banff Springs Golf Course.

The section on Tunnel Mountain and its continuation along the Bow River at the west end of the mountain was designated as the type section of the Rundle Formation by Warren (1927). The Rundle, elevated to a group by Douglas (1958), comprises the Livingstone (311.2 m thick), Mount Head (245.3 m thick), and Etherington (135.8 m thick) formations, in ascending order. A section extending from the upper Banff Formation to the lower Etherington Formation is well exposed along the lower cliffs of the mountain. The uppermost Mount Head and Etherington are moderately well exposed along the north bank of the Bow River. In this section, the Mount Head comprises the Salter, Loomis, Opal and Carnarvon members, in ascending order. Between Cougar Creek and Tunnel Mountain, the Wileman and Baril members, well developed at the former locality, have graded basinward into the upper Livingstone Formation.

Return to vehicles for final stops of the day (Pennsylvanian Spray Lakes Group) at Tunnel Mountain and along the north side of the Bow River by Bow Falls. To reach these stops, cross the Bow River on Banff Avenue then turn right onto Buffalo Street. Continue to junction with Tunnel Mountain Drive and the small parking area above Bow Falls.

References

Ahr, W.M. 1973. The carbonate ramp: an alternative to the shelf model. Transactions Gulf Coast Association of Geological Societies, 23rd Annual Meeting, Houston, p. 221-225.

Ball, M.M. 1967. Carbonate sand bodies of Florida and the Bahamas. Journal of Sedimentary Petrology, v. 37, p. 556-591.

Bamber, E.W. and Mamet, B.L. 1978. Carboniferous biostratigraphy and correlation, northeastern British Columbia and southwestern District of Mackenzie. Geological Survey of Canada, Bulletin 266, 65 p.

__________and Waterhouse, J.B. 1971. Carboniferous and Permian stratigraphy and paleontology, northern Yukon, Canada. Bulletin of Canadian Petroleum Geology, v. 19, p. 29-250.

Barclay, J.E., Krause, F.F., Campbell, R.I. and Utting, J. 1990. Dynamic casting and growth faulting: Dawson Creek Graben Complex, Carboniferous-Permian Peace River Embayment, western Canada. Bulletin of Canadian Petroleum Geology, v. 38A, p. 155-145.

Baxter, S. and von Bitter, P.H. 1984. Conodont succession in the Mississippian of southern Canada. *In*: Part 2: biostratigraphy. P.K. Sutherland and W.L. Manger (eds.). Neuvième Congrès International de Stratigraphie et de Géologie du Carbonifère, Compte Rendu, v. 2, p. 253-264.

Beales, F.W. 1950. The late Paleozoic formations of southwestern Alberta (preliminary account). Geological Survey of Canada, Paper 50-27, 72 p.

Beaumont, C. 1981. Foreland basins. Geophysical Journal of the Royal Astronomical Society, v. 65, p. 291-329.

Bond, G.C. and Kominz, M.A. 1991. Disentangling middle Paleozoic sea level and tectonic events in cratonic margins and cratonic basins of North America. Journal of Geophysical Research - Solid Earth and Planets. v. 96 section B4, p. 6619-6639.

Chatellier, J-Y. 1988. Carboniferous carbonate ramp, the Banff Formation, Alberta Canada. Bulletin des Centres de Recherches Exploration-Production Elf-Aquitaine, v. 12, p. 569-599.

Christopher, J.E. 1961. Transitional Devonian-Mississippian formations of southern Saskatchewan. Saskatchewan Mineral Resources, Report 66, 103 p.

Dixon, J., Dietrich, J.R. and McNeil, D.H. 1992. Upper Cretaceous to Holocene sequence stratigraphy of the Beaufort-Mackenzie and Banks Island areas, northwest Canada. Geological Survey of Canada, Bulletin 407, 90 p.

Douglas, R.J.W. 1953. Carboniferous stratigraphy in the southern foothills of Alberta. Alberta Society of Petroleum Geologists, 3rd Annual Field Conference Guidebook, p. 66-88.

__________1958. Mount Head map-area, Alberta. Geological Survey of Canada, Memoir 291, 241 p.

Douglas, R.J.W., Gabrielse, H., Wheeler, J.O., Stott, D.F. and Belyea, H.R. 1970. Geology of western Canada. *In*: Geology and Economic Minerals of Canada. R.J.W. Douglas (ed.). Geological Survey of Canada, Economic Geology Report no. 1, p. 366-488.

Embry, A.F. 1993. Transgressive-regressive (T-R) sequence analysis of the Jurassic succession of the Sverdrup Basin, Canadian Arctic Archipelago. Canadian Journal of Earth Sciences, v. 30, p. 301-320.

__________and Johannessen E.P. 1992. T-R sequence stratigraphy, facies analysis and reservoir distribution in the uppermost Triassic-Lower Jurassic succession, western Sverdrup Basin, Arctic Canada. *In*: Arctic Geology and Petroleum. T.O. Vorren, E. Bergsager, O.A. Dahl-Stamnes, E. Holter, B. Johansen, E. Lie and T.B. Lund (eds.). Norwegian Petroleum Society (NPF), Special Publication no. 2, p. 121-146.

Evenchick, C.A., Parrish, R.R. and Gabrielse, H. 1984. Precambrian gneiss and late Proterozoic sedimentation in north-central British Columbia. Geology, v. 12, p. 233-237.

Flemings, P.B. and Jordan, T.E. 1989. A synthetic stratigraphic model of foreland basin development. Journal of Geophysical Research, v. 94, p. 3851-3866.

Flajs, G. and Feist, R. 1988. Index conodonts, trilobites and environment of the Devonian-Carboniferous boundary beds at La Serre (Montagne Noir, France). Courier Forschungsinstitut Senckenberg, v. 100, p. 53-107.

Galloway, W.E. 1989. Genetic stratigraphic sequences in basin analysis II: application to northwest Gulf of Mexico Cenozoic basin. American Association of Petroleum Geologists Bulletin, v. 73, no. 2, p. 143-154.

Goebel, K.A. 1991. Paleogeographic setting of Late Devonian to Early Mississippian transition from passive to collisional margin, Antler Foreland, eastern Nevada and western Utah. *In*: Paleozoic Paleogeography of the Western United States - II. J.D. Cooper and C.H. Stevens (eds.). Pacific Section Society Economic Paleontologists and Mineralogists, v. 1, p. 401-418.

Gordey, S.P. 1988. Devono-Mississippian clastic sedimentation and tectonism in the Canadian Cordilleran Miogeocline. *In*: Devonian of the World. N.J. McMillan, A.F. Embry and D.J. Glass (eds.). Canadian Society of Petroleum Geologists. Memoir 14, v. 2, p. 1-14.

__________, Abott, J.G., Tempelman-Kluit, D. J. and Gabrielse, H. 1987. “Antler” clastics in the Canadian Cordillera. Geology, v. 15, p. 103-107.

Higgins, A.C., Richards, B.C. and Henderson, C.M. 1991. Conodont biostratigraphy and paleoecology of the uppermost Devonian and Carboniferous of the Western Canada Sedimentary Basin. *In*: Ordovician to Triassic Conodont Paleontology of the Canadian Cordillera. M.J. Orchard and A.D. McCracken (eds.). Geological Survey of Canada, Bulletin 417, p. 215-251.

Johnson, J.G., Klapper, G. and Sandberg, C.A. 1985. Devonian eustatic fluctuations in Euramerica. Geological Society of America Bulletin, v. 96, p. 567-587.

Johnston, D.I. and Chatterton, D.E. 1991. Famennian conodont biostratigraphy of the Palliser Formation, Rocky Mountains, Alberta and British Columbia, Canada. *In*: Ordovician to Triassic Conodont Paleontology of the Canadian Cordillera. M.J. Orchard and A.D. McCracken (eds.). Geological Survey of Canada Bulletin 417, p. 163-183.

Jordan, T.E. and Flemings, P.B. 1991. Large-scale stratigraphic architecture, eustatic variation, and unsteady tectonism: a theoretical evaluation. Journal of Geophysical Research, v. 96, p. 6681-6699.

Kindle, E.M. 1924. Standard Paleozoic section of the Rocky Mountains near Banff, Alberta. Pan-American Geologist, v. 42, p. 113-124.

Lane, H.R., Sandberg, C.A. and Ziegler, W. 1980. Taxonomy and phylogeny of some Lower Carboniferous conodonts and preliminary standard post- *Siphonodella* zonation. Geologica et Palaeontologica, v. 14, p. 117-164.

Macauley, G., Penner, D.G., Procter, R.M. and Tisdall, W.H. 1964. Chapter 7, Carboniferous. *In*: Geological History of Western Canada. R.G. McCrossan and R.P. Glaister (eds.). Alberta Society of Petroleum Geologists, p. 89-102.

Macqueen, R.W. and Bamber, E.W. 1967. Stratigraphy of Banff Formation and lower Rundle Group (Mississippian), southwestern Alberta. Geological Survey of Canada, Paper 67-47, 37 p.

__________and Sandberg, C.A. 1970. Stratigraphy, age, and inter-regional correlations of the Exshaw Formation, Alberta Rocky Mountains. Bulletin of Canadian Petroleum Geology, v. 18, p. 32-66.

Macdonald, D.E. 1987. Geology and resource potential of phosphates in Alberta. Alberta Geological Survey, Alberta Research Council, Earth Science Report87-1, 65 p.

Mamet, B.L. 1967. The Devonian-Carboniferous boundary in Eurasia. *In*: International Symposium on the Devonian System, Calgary, 1967. D.H. Oswald (ed.). Alberta Society of Petroleum Geologists, v. 2, p. 995-1007.

__________1976. An atlas of microfacies in Carboniferous carbonates of the Canadian Cordillera. Geological Survey of Canada, Bulletin 255, 131 p.

__________1984. Carboniferous small foraminifers and stratigraphy. *In*: Biostratigraphy. P.K. Sutherland and W. L. Manger (eds.). Neuvième Congrès International de Stratigraphie et de Géologie du Carbonifère, 1979. Compte Rendu, no. 2, p. 3-18.

__________and Bamber, E.W. 1979. Stratigraphic correlation chart of the lower part of the Carboniferous, Canadian Cordillera and Arctic Archipelago. *In*: Paleontological Characteristics of the Main Subdivisions of the Carboniferous. S.V. Meyen, V.V. Menner, E.A. Reitlinger, A.P. Rotai and M.N. Solovieva (eds.). Huitième Congrès International de Stratigraphie et de Géologie Carbonifère, 1975, Compte Rendu, v. 3, p. 37-49.

__________, Bamber, E.W. and Macqueen, R.W. 1986. Microfacies of the Lower Carboniferous Banff Formation and Rundle Group, Monkman Pass map-area, northeastern British Columbia. Geological Survey of Canada, Bulletin 353, 93 p.

__________and Mason, D. 1968. Foraminiferal zonation of the Lower Carboniferous Connor

Lake section, British Columbia. Bulletin of Canadian Petroleum Geology, v. 16, p. 147-166.
__________and Skipp, B.1970. Lower Carboniferous calcareous foraminifera: preliminary zonation and stratigraphic implications for the Mississippian of North America. *In*: Sixième Congrès International, de Stratigraphie et de Géologie du Carbonifère, Sheffield 1967. Compte Rendu, 3, p. 1129-1146.
McGugan, A. and Rapson, J.E. 1963. Permian stratigraphy and nomenclature, western Alberta and adjacent regions. *In*: Sunwapta Pass area, D.E. Jackson (ed.). Edmonton Geological Society Guidebook, 5th Annual Field Trip, p. 52-64.
__________, Rapson-McGugan, J.F., Mamet, B.L. and Ross, C.A. 1968. Permian and Pennsylvanian biostratigraphy, and Permian depositional environments, petrography and diagenesis, southern Canadian Rocky Mountains. *In*: Canadian Rockies, Bow River to North Saskatchewan River, Alberta. H. Hornford (ed.). Canadian Society of Petroleum Geologists 16th Annual Field Conference, Guidebook, p. 48-66.
McIlreath, I.A. and James, N.P. 1978. Facies models 13: Carbonate slopes. Geoscience Canada, v. 5, p. 189-199.
Meijer Drees, N.C. and Johnston, D.I. 1994. Type section and conodont biostratigraphy of the Upper Devonian Palliser Formation, southwestern Alberta. Bulletin of Canadian Petroleum Geology, v. 42, p. 56-62.
Moore, P.F. 1988. Devonian geohistory of the western interior of Canada. *In*: Devonian of the World. N.J McMillan, A.F. Embry and D.J. Glass (eds.). Canadian Society of Petroleum Geologists, Memoir 14, v. 1, p. 67-83.
Morrow, D.W. and Geldsetzer, H.H.J. 1988. Devonian of the eastern Canadian Cordillera. *In*: Devonian of the World. N.J. McMillan, A.F. Embry and D.J. Glass (eds.). Canadian Society of Petroleum Geologists, Memoir 14, v. 1, p. 85-121.
Mortensen, J.K. and Jilson, G.A. 1985. Evolution of the Yukon-Tanana terrane: evidence from southeastern Yukon Territory. Geology, v. 13, p. 806-810.
__________, Montgomery, J.R. and Fillipone, J. 1987. U-Pb zircon, monazite, and sphene ages for granitic orthogneiss of the Barkerville terrane, east-central British Columbia. Canadian Journal of Earth Sciences, v. 24, p. 1261-1266.
Norris, D.K. 1965. Stratigraphy of the Rocky Mountain Group in the southeastern Cordillera of Canada. Geological Survey of Canada, Bulletin 125, 82 p.
Okulitch, A.V. 1985. Paleozoic plutonism in southeastern British Columbia. Canadian Journal of Earth Sciences, v. 22, p. 1409-1424.
Pamenter, C.B. 1956. *Imitoceras* from the Exshaw Formation of Alberta. Journal of Paleontology, v. 30, p. 965-966.
Paproth, E. and Streel, M. 1984. Precision and practicability: On the definition of the Devonian-Carboniferous boundary. Courier Forschungsinstitut Senckenberg, v. 67, p. 255-258.
Paproth, E., Feist, R., and Flajs, G. 1991. Decision on the Devonian-Carboniferous boundary stratotype. Episodes, v. 14, p. 331-336.
Parrish, J.T. 1982. Upwelling and petroleum source beds with reference to Paleozoic. American Association of Petroleum Geologists Bulletin, v. 66, p. 750-774.
Parrish, R.R. 1992. Miscellaneous U-Pb zircon dates from southeast British Columbia. *In*: Radiogenic Age and Isotopic Studies: Report 5. Geological Survey of Canada Paper 91-2, p. 143-153.
Peterhänsel, A. and Pratt, B.R. 2008. The Famennian (Upper Devonian) Palliser platform of western Canada - architecture and depositional dynamics of a post-extinction epeiric giant. In: Dynamics of Epeiric Seas. B.R. Pratt and C. Holmden (eds.). Geological Association of Canada Special Paper 48, p. 247-281.
Poole, F.G. and Sandberg, C.A. 1991. Mississippian paleogeography and conodont biostratigraphy of the western United States. In: Paleozoic Paleogeography of the Western United States - II. J.D. Cooper and C.H. Stevens (eds.). Pacific Section, Society of Economic Paleontologists and Mineralogists, v. 1, p. 107-136.
Porter, J.W., Price, R.A. and McCrossan, R.B. 1982. The Western Canada Sedimentary Basin. Philosophical Transactions of the Royal Society of London, v. A 305, p. 169-192.
Posamentier, H.W., Jervey, M.T. and Vail, P.R. 1988. Eustatic controls on clastic deposition I - conceptual framework. *In*: Sea-level Changes: an Integrated Approach. C.K. Wilgus, B.S. Hastings, H. Posamentier, J.C. Van Wagoner, C.A. Ross and C.G.St.C. Kendall (eds.). Society of Economic Paleontologists and Mineralogists, Special Publication no. 42, p. 109-124.
__________ and Vail, P. R. 1988. Eustatic controls on clastic deposition II -sequence and systems tract models. *In*: Sea-level Changes: an Integrated Approach. C.K. Wilgus, B.S. Hastings, H. Posamentier, J. Van Wagoner, C.A. Ross and C.G.St.C. Kendall (eds.). Society of Economic Paleontologists and Mineralogists, Special Publication no. 42. p. 125-154.
Price, R.A. 1970. Geology - Canmore (east half), Alberta. Geological Survey of Canada, Map 1265A.
__________ 1970. Geology - Canmore (west half), Alberta. Geological Survey of Canada, Map 1266A.
__________ and Mountjoy, E.W.1972. Geology - Banff (east half), Alberta - British Columbia. Geological Survey of Canada, Map 1294A.
Quinlan, G. M. and Beaumont, C. 1984. Appalachian thrusting, lithospheric flexure, and the Paleozoic stratigraphy of the eastern interior of North America. Canadian Journal of Earth Sciences, v. 21, p. 973-996.
Raasch, G. O. 1956. The Permian Rocky Mountain Group in Alberta. Alberta Society of Petroleum Geologists, Sixth Annual Field Conference and Guide Book, p. 114-119.
__________1958. Upper Paleozoic section at Highwood Pass, Alberta. *In*: Jurassic and Carboniferous of Western Canada. A.J. Goodman (ed.). American Association of Petroleum Geologists, John Andrew Allan Memorial Volume, p. 190-215.
Read, J.F. 1982. Carbonate platforms of passive (extensional) continental margins: types, characteristics and evolution. Tectonophysics, v. 81, p. 195-212.

Richards, B.C. 1989. Upper Kaskaskia Sequence: uppermost Devonian and Lower Carboniferous, Chapter 9. *In*: Western Canada Sedimentary Basin, a Case History. B.D. Ricketts (ed.). Canadian Society of Petroleum Geologists, p. 165-201.

__________, Barclay, J.E., Bryan, D., Hartling, A., Henderson, C.M. and Hinds, R.C. 1994a. Chapter 14 - Carboniferous strata of the Western Canada Sedimentary Basin. *In*: Geological Atlas of the Western Canada Sedimentary Basin. G.D. Mossop and I. Shetson (eds.). Canadian Society of Petroleum Geologists and Alberta Research Council, p. 221-250.

__________, Bamber, E.W., Henderson, C.M., Higgins, A.C., Johnston, D.I., Mamet, B.L. and Meijer Drees, N.C. 1994b. Uppermost Devonian (Famennian) and Lower Carboniferous (Tournaisian) at Jura Creek and Mount Rundle, southwestern Alberta. Geological Survey of Canada, Open File 2866, p. 1-79.

__________, Bamber, E.W., Higgins, A.C. and Utting, J. 1993. Carboniferous, Subchapter 4E. *In*: Sedimentary Cover of the Craton in Canada. D.F. Stott and J.D. Aitken (eds.). Geological Survey of Canada, Geology of Canada no. 5, p. 202-271 (also Geological Society of America, The Geology of North America, v. D-1).

__________, Henderson, C.M., Higgins, A.C., Johnston, D.I., Mamet, B.L. and Meijer Drees, N.C. 1991. The Upper Devonian (Famennian) and Lower Carboniferous (Tournaisian) at Jura Creek, southwestern Alberta. *In*: A Field Guide to the Paleontology of Southwestern Canada. P.L. Smith (ed.). Paleontology Division of the Geological Association of Canada, p. 35-81.

__________and Higgins, A.C. 1988. Devonian-Carboniferous boundary beds of the Palliser and Exshaw formations at Jura Creek, Rocky Mountains, southwestern Alberta. *In*: Devonian of the World. N.J. McMillan, A.F. Embry and D.J. Glass (eds.). Canadian Society of Petroleum Geologists, Memoir 14, v. 2, p. 399-412.

__________, Lane, H.R. and Brenckle, P.L. 2002a. The IUGS Mid-Carboniferous (Mississippian-Pennsylvanian) Global Boundary Stratotype Section and Point at Arrow Canyon, Nevada, USA. *In*: Carboniferous and Permian of the World. L.V. Hills, C.M. Henderson and E.W. Bamber (eds.).Canadian Society of Petroleum Geologists, Memoir 19, p. 802-831.

__________, Ross, G.M. and Utting, J. 2002b.U - Pb geochronology, lithostratigraphy and biostratigraphy of tuff in the upper Famennian to Tournaisian Exshaw Formation: evidence for a mid-Paleozoic magmatic arc on the northwestern margin of North America. *In*: Carboniferous and Permian of the World. L.V. Hills, C.M. Henderson and E.W. Bamber (eds.). Canadian Society of Petroleum Geologists, Memoir 19, p. 158-207.

Ricketts, B.D. 1989. Introduction, chapter 1. *In*: Western Canada Sedimentary Basin, a case History. B.D. Ricketts (ed.). Canadian Society of Petroleum Geologists, p. 3-8.

Root, K.G. 2001. Devonian Antler fold and thrust belt and foreland basin development in the southern Canadian Cordillera: implications for the Western Canada Sedimentary Basin. Canadian Society of Petroleum Geologists, v. 49, p. 7-36.

Ross, C.A. and Bamber, E.W. 1978. Middle Carboniferous and Early Permian fusulinaceans from the Monkman Pass area, northeastern British Columbia. *In*: Contributions to Canadian Paleontology. Geological Survey of Canada, Bulletin, 267, p. 25-41.

Rubin, C.M., Miller, M.M. and Smith, G.M. 1990. Tectonic development of Cordilleran mid-Paleozoic volcano-plutonic complexes; evidence for convergent margin tectonism. *In*: Paleozoic and Early Mesozoic Paleogeographic Relations; Sierra Nevada, Klamath Mountains, and Related Terranes. D.S. Harwood and M.M. Miller (eds.). Geological Society of America, Special Paper 255, p. 1-16.

Sandberg, C.A, Ziegler, W., Leuteritz, K. and Brill, S.M. 1978. Phylogeny, speciation, and zonation of *Siphonodella*(Conodonta, Upper Devonian and Lower Carboniferous). Newsletters in Stratigraphy, v. 7, p. 102-120.

Sando, W.J. and Bamber, E.W. 1985. Coral zonation of the Mississippian System in the western interior province of North America. United States Geological Survey, Professional Paper 1334, 61 p.

Savoy, L.E.. 1992. Environmental record of Devonian-Mississippian carbonate and low-oxygen facies transitions, southernmost Canadian Rocky Mountains and northwest Montana. Geological Society of America Bulletin, v. 104, p. 1412-1432.

__________and Harris, A.G. 1993. Conodont biofacies in a ramp to basin setting (latest Devonian and earliest Carboniferous) in the Rocky Mountains of southernmost Canada and northern Montana. United States Geological Survey, Open File Report 93-184.

Schindewolf, O.H. 1959. Adolescent cephalopods from the Exshaw Formation of Alberta. Journal of Paleontology, v. 33, p. 971-976.

Scott. D.L. 1964a. Stratigraphy of the lower Rocky Mountain Supergroup in the southern Canadian Rocky Mountains. PhD thesis, University of British Columbia, Vancouver, B.C., 133 p.

__________1964b. Pennsylvanian stratigraphy. Bulletin of Canadian Petroleum Geology, v. 12, Flathead Valley Guidebook Issue, p. 460-493.

Selby, D. and Creaser, R.A. 2005. Direct radiometric dating of the Devonian-Mississippian time-scale boundary using Re-Os black shale geochronometer. Geology, v. 33 (7), p. 545-548.

Sloss, L.L. 1963. Sequences in the cratonic interior of North America. Geological Society of America, Bulletin, v. 74, p. 93-114.

__________1964. Tectonic cycles of the North American craton. *In*: Symposium on Cyclic Sedimentation. D.F. Merriam (ed.). State Geological Survey of Kansas, Bulletin, 169, v. II, p. 449-460.

Smith, M.T. and Gehrels, G.E. 1992. Structural geology of the Lardeau Group near Trout Lake, British Columbia: implications for the structural evolution of the Kootenay Arc. Canadian Journal of Earth Sciences, v. 29, p. 1305-1319.

__________, Dickinson, W.R. and Gehrels, G.E. 1993. Contractional nature of Devonian-Mississippian

Antler tectonism along the North American continental margin. Geology, v. 21, p. 21-24.
Stewart, W.D. and Walker, R.G. 1980. Eolian coastal dune deposits and surrounding marine sandstones, Rocky Mountain Supergroup (Lower Pennsylvanian), southeastern British Columbia. Canadian Journal of Earth Sciences, v. 17, p. 1125-1140.
Stockmal, G.S., Beaumont, C. and Boutilier, R. 1986. Geodynamic models of convergent margin tectonics: transition from rifted margin to overthrust belt and consequences for foreland-basin development. American Association of Petroleum Geologists Bulletin, v. 70, p. 181-190.
Struik, L.C. 1987. The ancient western North American margin: an alpine rift model for the east-central Canadian Cordillera. Geological Survey of Canada, Paper 87-15, 19 p.
Tempelman-Kluit, D.J. 1979. Transported cataclasite, ophiolite and granodiorite in Yukon: evidence of arc-continent collision. Geological Survey of Canada, Paper 79-14, 27 p.
Trapp, E., Kaufmann, B., Mezger, K., Korn, M., and Weyer, D. 2004. Numerical calibration of the Devonian-Mississippian boundary: Two new U-Pb isotope dilution-thermal ionization mass spectrometry single-zircon ages from Hasselbachtal (Sauerland, Germany). Geology, v. 32, p. 857-860.
Vail, P.R., Mitchum R.M.Jr. and Thompson, S.III. 1977. Seismic stratigraphy and global changes of sea level, part 4: global cycles of relative changes of sea level. *In*: Seismic Stratigraphy - Applications to Hydrocarbon Exploration. C.E. Payton (ed.). American Association of Petroleum Geologists, Memoir 26, p. 83-97.
Van Wagoner, J.C., Posamentier, H.W., Mitchum, R.M., Vail, P.R., Sarg, J.F., Loutit, T.S. and Hardenbol, J. 1988. An overview of the fundamentals of sequence stratigraphy and key definitions. *In*: Sea-level Changes: an Integrated Approach. C.K. Wilgus, B.S. Hastings, H.W. Posamentier, J.C. Van Wagoner, C.A. Ross, and C.G.St.C. Kendall (eds.). Society of Economic Paleontologists and Mineralogists, Special Publication no. 42, p. 39-45.
Warren, P.S. 1927. Banff area, Alberta. Geological Survey of Canada, Memoir 153, 94 p.
Wheeler, J.O., Brookfield, A.J., Gabrielse, H., Monger, J.W.H., Tipper, H.W., and Woodsworth, G.J. 1988. Terrane map of the Canadian Cordillera. Geological Survey of Canada, Open File 1894, Scale 1:2,000,000.
White, W.H. 1959. Cordilleran tectonics in British Columbia. American Association of Petroleum Geologists Bulletin, v. 43, p. 60-100.
Wilson, J.L. 1975. Carbonate facies in geologic history. Springer-Verlag, New York, 471 p.
.Ziegler, W. 1962. Taxonomie und Phylogenie Oberdevonischer Conodonten und ihr stratigraphische Bedeutung. Hessisches Landesamt Bodenforschung Abhandlungen, v. 38, 166 p.
__________1971. Conodont stratigraphy of the European Devonian. *In*: Symposium on Conodont Biostratigraphy. W.C. Sweet and S.M. Bergstrom (eds.). Geological Society of America, Memoir 127, p. 227-284.
__________and Sandberg, C.A. 1984. *Palmatolepis*-based revision of upper part of standard Late Devonian conodont zonation. *In*: Conodont Biofacies and Provincialism. D.L. Clark (ed.). Geological Society of America, Special Paper 196, p. 179-194.
__________and Sandberg, C.A. 1990. The Late Devonian standard conodont zonation. Courier Forschungsinstitut Senckenberg, v. 121, 115 p.

Stop 2-21; We will finish the day with a short stop at Bow Falls parking lot

Cross the Bow River along the Banff Springs golf course to see Upper Carboniferous and Permian rocks including the sub-Kasimovian unconformity (51.16580 N; 115.55761 W; 1401 m), sub-Permian unconformity and sub-Middle Permian unconformity and compare these tectonic events with those in Nevada (Figs 53, 54 and 55).

Discuss Pennsylvanian to Lower Triassic stratigraphy, unconformities, and the Permian – Triassic extinction.

Figure 53. Red line shows position of sub-Lower Kasimovian unconformity within the Kananaskis Formation. Foreshore deposits above. This unconformity correlates with the C6 unconformity of Synder (Fig. 54).

Figure 55. Red lines shows position of P3 (lower) and P4 (upper) unconformities; the upper level separates the Johnston Canyon Formation from the overlying Ranger Canyon Formation.

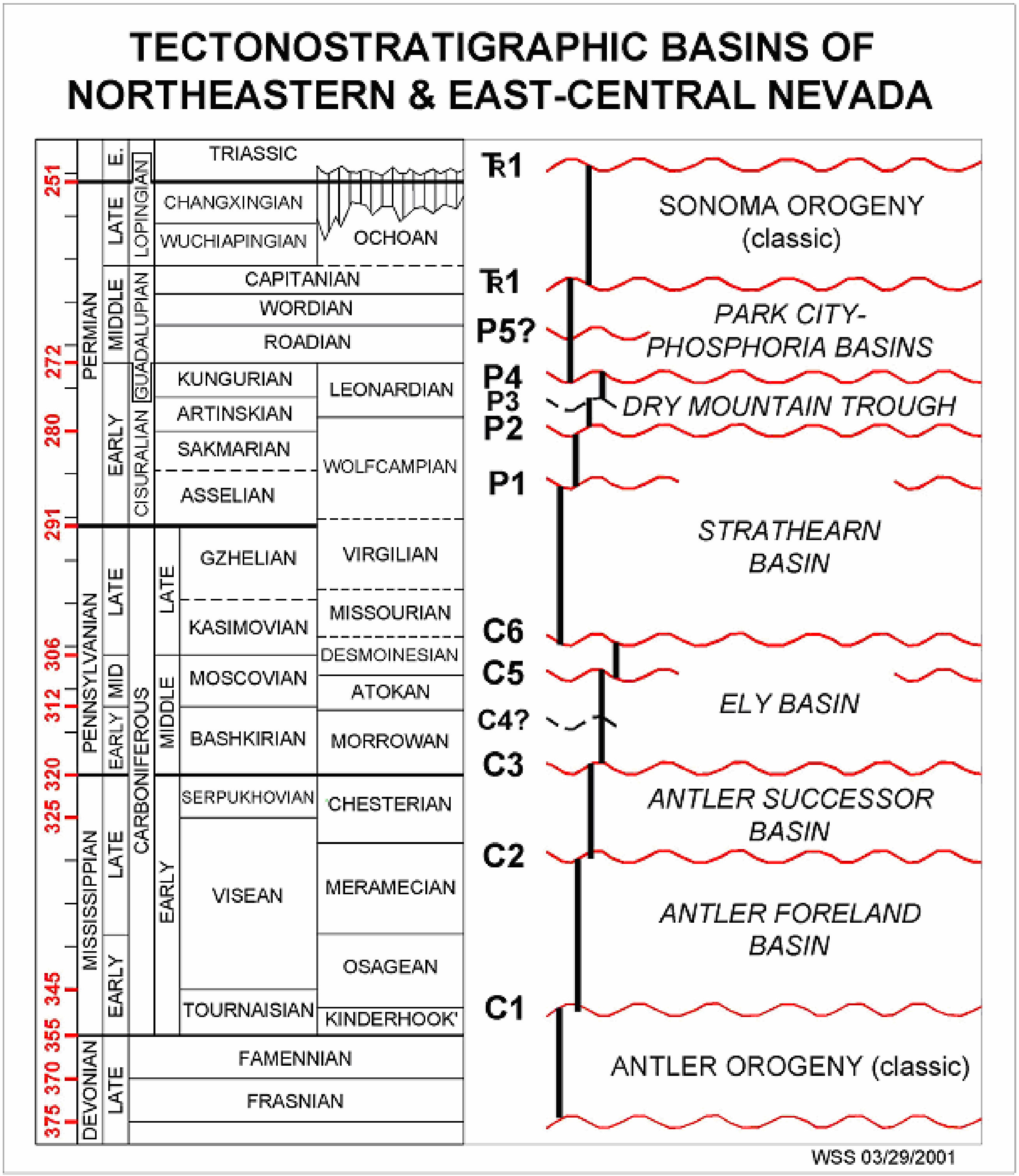


Figure 54. The unconformities shown in this figure by Walter Synder of Boise State University are correlatable from Nevada to Western Canada. The C6 unconformity includes a major compressive event in Nevada as seen at Carlin Canyon where a significant angular unconformity can be seen. The C6 boundary is the most significant in Western Canada and is usually represented by a significant basal conglomerate.

Day 3: Leave Banff Centre on a 300 km journey bound for Tonquin Lodge in Jasper via the Icefields Parkway.

Before we get on the bus we will walk around the corner to see the Tunnel Mountain roadcut section of Upper Carboniferous to Lower Triassic strata comparable to what saw on our last stop yesterday.

Stop 3-1. Tunnel Mountain viewpoint of Banff Springs Hotel (Figs. 3.1 to 3.5).

We will discuss Pennsylvanian to Lower Triassic stratigraphy, unconformities, and the Permian – Triassic extinction.

The Tunnel Mountain viewpoint section offers a fantastic photo opportunity taken by most tourists to Banff of the Banff Springs Hotel and Bow Falls. It also offers and excellent geologic story as two major unconformities, one minor unconformity, and the greatest of all extinction events are seen at this locality. Rocks at this section are exposed in the Rundle Thrust Sheet.

The Kananaskis Formation, which represents the youngest formation of the Spray Lakes Group, is preserved south of 52 degrees 10 minutes north in the Rockies of southeastern BC and southwestern Alberta, is up to 51 metres thick, and thins eastward owing to stratigraphic condensation and sub-Permian truncation. The Kananaskis is mostly silty and sandy dolostone grading into dolomitic siltstone and sandstone with minor chert nodules, thin chert beds, and novaculite. Intraformational chert breccia is characteristic of the Upper Kananaskis in some eastern sections that pass westward into an unbrecciated chert facies. A marine origin for the Kananaskis is recorded by common occurrence of fusulinaceans and brachiopods in the chert and rare conodonts in the dolostone. These fauna indicate at least an Early Moscovian age. The subsequent regressive deposits are not preserved as most of the sedimentary basin was exposed beneath the sub-Permian unconformity.

A thin Permian facies of sequence 3 rests unconformably on the Kananaskis Formation and is characterized by black spicular chert, platy phosphatic siltstone, and minor pelmatozoan wackestone. Rhythmic bedding, abundant phosphorite, and the absence of shallow marine sedimentary structures may indicate slope or basinal depositional environments, however, an alternative starved-shelf interpretation seems more likely. Numerous upper bedding surfaces have a nodular appearance and popcorn textured chert which may represent hardgrounds. In the Banff region they are referred to as the Johnston Canyon Formation. The phosphatic nature of this unit, its thinness, and the lack of sequence 2 strata all point to a starved shelf setting in a topographically high region. The Johnston Canyon and Ross Creek formations of sequence 3 are disconformably overlain by the Roadian-Wordian Ranger Canyon Formation of sequence 4. This disconformity has been referred to as the "intra-Permian disconformity".

Below is your author at the sub-Permian unconformity at Tunnel Mountain. My hand is at the boundary between

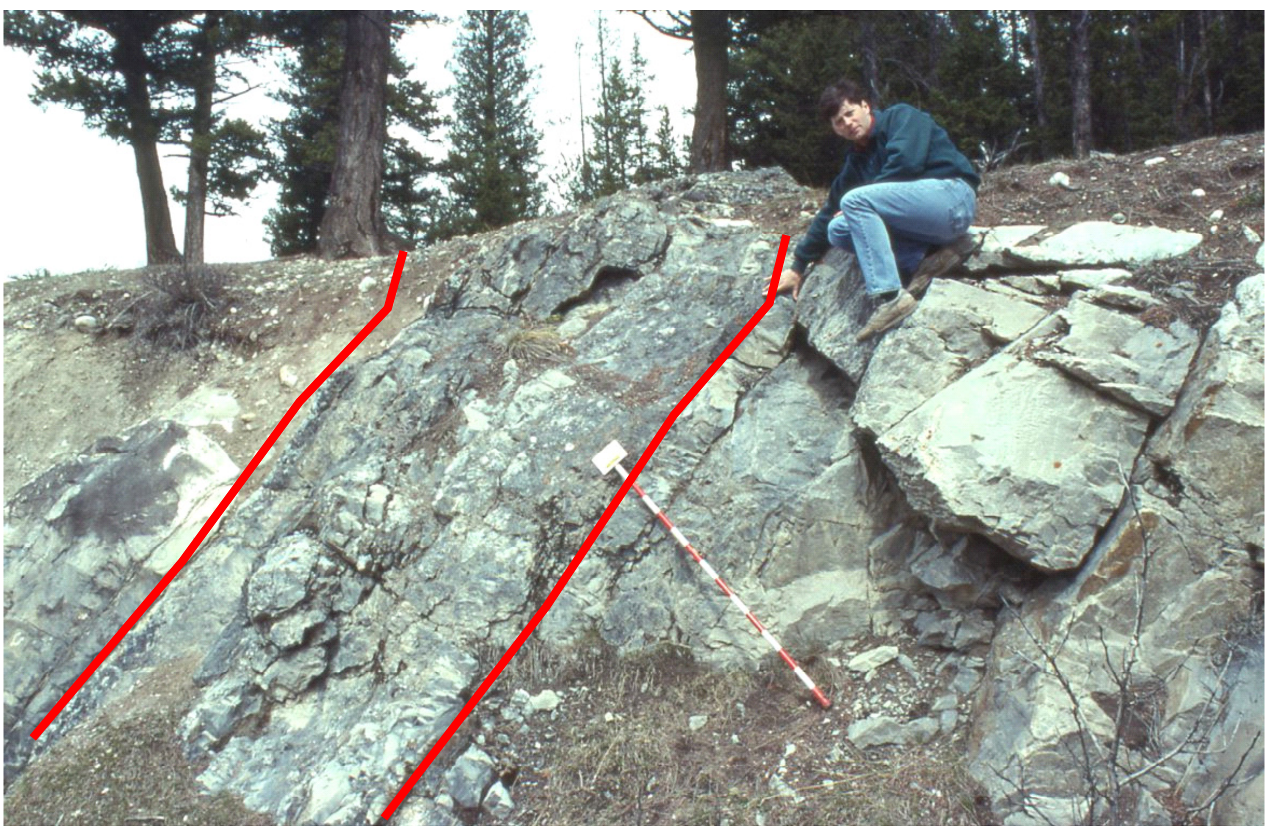


Fig. 3-1. Red lines shows position of P1 (lower) and P2 (upper) unconformities; the lower level separates the Johnston Canyon Formation from the underlying Kananaskis Formation.

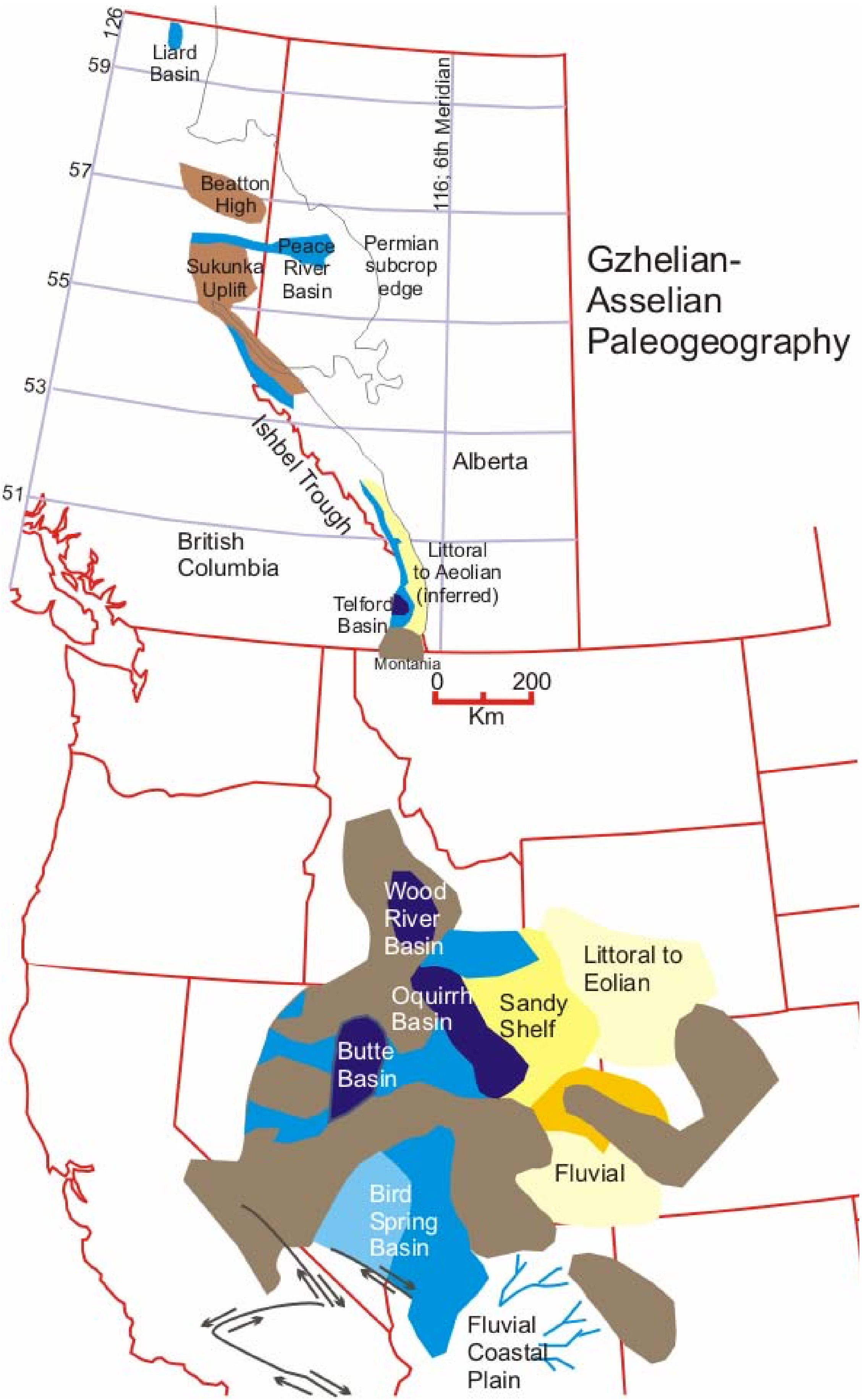


Fig. 3-2. Paleogeography for strata between C6 and P1.

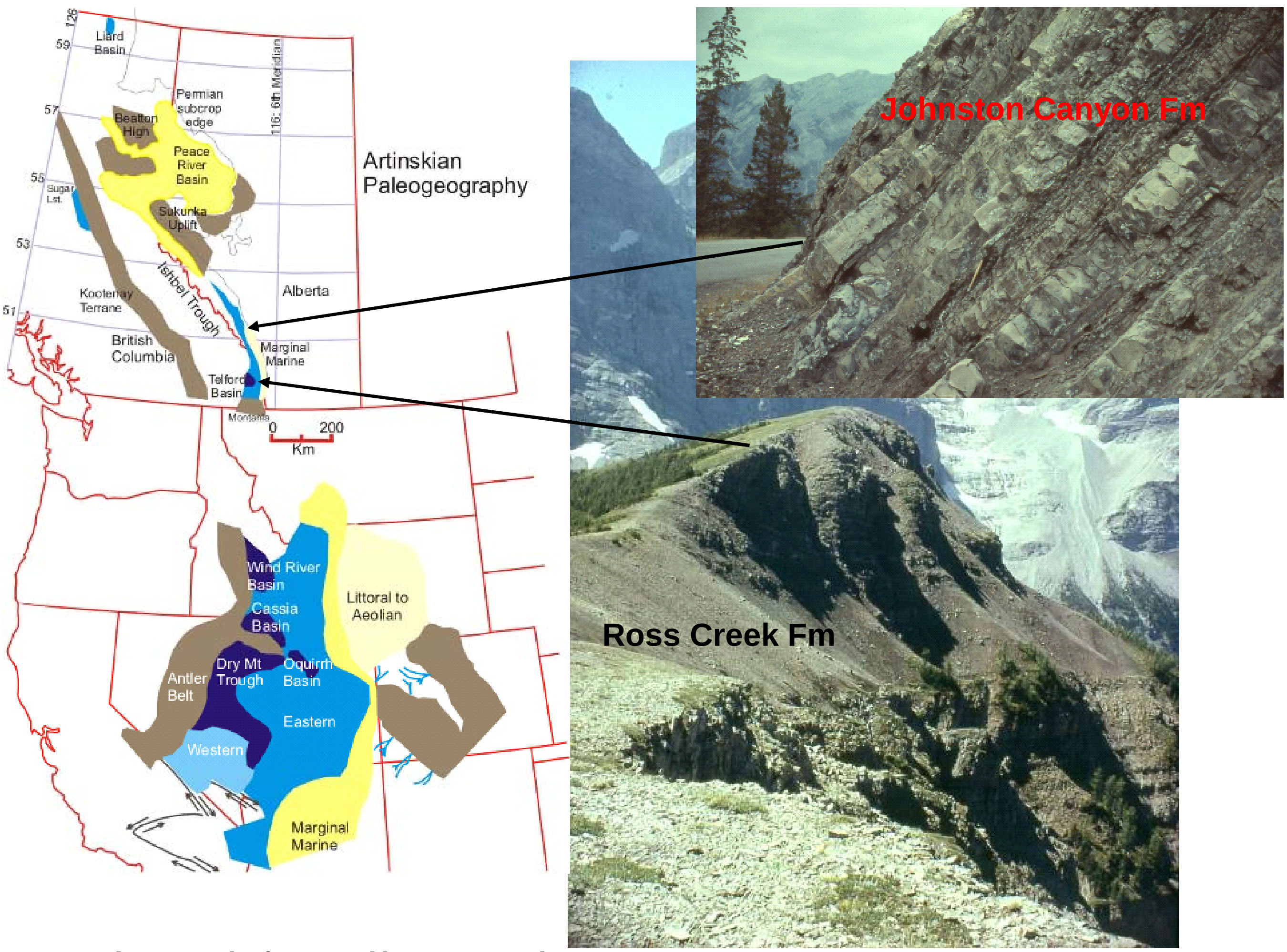


Fig. 3.3. Paleogeography for interval between P2 and P4.

Kasimovian strata below and Upper Asselian above. About 15 to 20 million years are missing at this point.

To the left is the intra-Permian unconformity (base of resistant ledge) representing the contact between the Johnston Canyon and Ranger Canyon. The top of the resistant ledge corresponds to the Permian-Triassic boundary.

Strata of sequence 4, which constitute a transgressive sequence above this intra-Permian disconformity, are consistent in lithology and thickness from southeastern BC to the southern Mackenzie Fold Belt. In the southern Rockies (south of Jasper), the interval comprises a relatively thin but widespread sequence of blue-grey chert, silicified sandstone and phosphatic siltstone referred to as the Ranger Canyon Formation. In the type area at Banff, the thickness of the Ranger Canyon varies from less than one metre to 45 m, but is generally about 10 m (McGugan and Rapson, 1963). The ages of these three formations are poorly known (Logan and McGugan, 1968), but data from conodont (Henderson and McGugan, 1986), rare brachiopod, and elasmobranch fish occurrences indicate Roadian and Wordian. Significant stratigraphic condensation has been postulated for this thin interval (MacRae and McGugan, 1977) because of the considerable time span that it represents.

The extent of the unconformity separating the Upper

Fig. 3-4. Red line shows contact between Ranger Canyon and Johnston Canyon formation next to the Bow River.

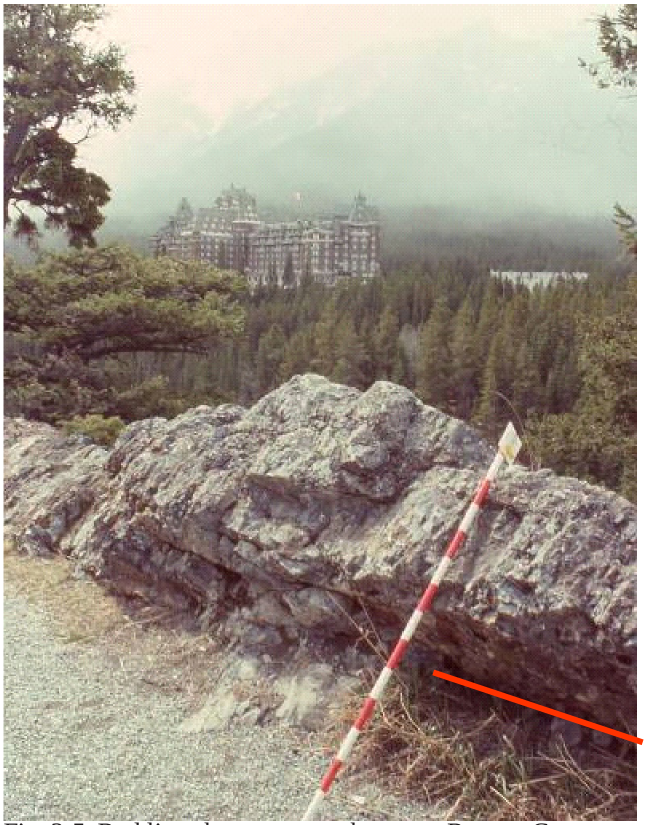


Fig. 3-5. Red line shows contact between Ranger Canyon and Johnston Canyon formation at the Tunnel Mt Road viewpoint of the Banff Springs Hotel.

Permian Ranger Canyon Formation from the overlying Sulphur Mountain Formation (Spray River Group is unknown, but is on the order of a few million years. The Sulphur Mountain Formation consists of marine shale and siltstone that is very soft and recessive and therefore controls the position of the Bow River. Although it is not obvious from this location, the contact between the Ranger Canyon and Sulphur Mountain formations corresponds to the greatest of all extinction events, the Permian-Triassic extinction event about 250 Ma ago. It has been estimated that perhaps as many as 96% of all species living near the end of the Permian became extinct. The extinction took place during an interval of intense physical change on the earth with the amalgamation of Pangea and major lowstands of sea-level. This extinction event raises many questions. Was the extinction abrupt and catastrophic or were faunal disappearances spread over several million years (probably the latter)? Was the extinction diachronous (evidence is accumulating that it was)? The boundary rocks reveal evidence of marine anoxia or increased salinity or rapid cooling or warm and arid conditions. In other words, the nature of the boundary differs from one region to another so it is important to consider the paleogeography for the time. In this area, there is evidence that the Permian-Triassic boundary (as defined in China by first appearance of Hindeodus parvus) is located in the basal part of the Sulphur Mountain Formation (Henderson, 1997) and not at the contact with the Ranger Canyon Formation. This would imply that the anoxic event, indicated by the black pyritic shales lacking trace fossils in the basal Sulphur Moutain, occurred during the latest Permian, pointing to diachroneity of the boundary extinctions. This interval is also representative of a transition from ice-house conditions to green-house conditions; the influence of the large continental landmass of Pangea may have been important at this time. Doug Erwin (1993) referred to the causes of the P-T extinction as the "Murder on the Orient Express" scenario, where everyone, in this case everything, is responsible for the event.

32 km on our right is the Sawback Range

Devonian to Permian units dip steeply in the hanging wall of the Sawback Thrust as bare rock and the Triassic Sulphur Mountain Formation is tree covered on the western slope.

37 km Castle Mountain viewpoint; 1422 m 51.22630 115.82452

Classic three layer sequence with Middle Cambrian Cathedral, Stephen, and Eldon formations sitting on Lower Cambrian Gog Group, all brought to the surface by the Castle Mountain thrust (summit 2766 m) and relatively flat lying. These Main Range thrusts contrast with the west dipping panels of the Front Ranges that we saw yesterday and that we just saw in the Sawback Range. We are currently at an elevation about 1400 m. It is the Stephen Formation that is laterally equivalent to the Burgess Shale Formation to the west. As we approach we will notice that the rocks change from west dipping panels of Devonian and Carboniferous limestone to relatively flat lying panels of resistant Middle Cambrian limestone. This zone represents the transition from the Front Ranges to the Eastern Main Ranges of the Rocky Mountains.

Castle Mountain (Figs. 3.6, 3.7) was known as Mount Eisenhower for a few years. However, enough people kept calling it Castle Mountain that several years ago its name was officially switched back to Castle Mountain. It has recently become the focal point for a native land claim. The Siksika nation claims that it was the focal point for several rituals, as well as being an obvious landmark.

At Castle Mountain (formerly Mount Eisenhower) we see the castellated peaks of the Eldon Formation near the top. Underlying the Eldon is a thin recessive zone of shale called the Stephen Formation (marked by a thin ribbon of snow in the middle of the mountain) which represents the lateral equivalent of the Burgess Shale Formation. Other formations underlying the Stephen include the Middle Cambrian Cathedral and Mount Whyte formations, the Lower Cambrian Gog Group and the Upper Precambrian Miette Group. All of these rocks were brought to the surface by the Castle Mountain thrust.

Fig. 3.6.

Fig. 3.7

66.5 km Junction of Highway 93 and #1
We head north on the Icefield's Parkway from this point.

Views on the left (west) include (Fig. 3.8 and 3.9)

80.8 km; Pulpit Peak (2725 m): Cathedral Limestone and

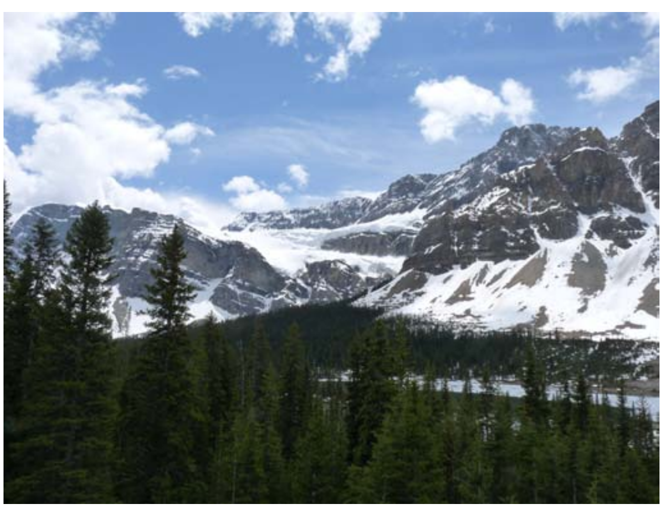


Fig. 3.8

Fig. 3.9

Dolostone. The rocks of this range are called the Waputik (Stoney for mountain goat) (Fig. 3.8). Range and the peak ridge represents the continental divide between Pacific and Atlantic

95.9 km; Hector Lake viewpoint: Named for James Hector a Scottish physician and geologist on the Palliser expedition. The peak next to it is called Andromache, who was a Trojan princess and wife of the Greek warrior called Hector. The rocks are all Middle Cambrian. Mt Hector is locally referred to its shape as "Snoopy on his doghouse".

99 km: Crowfoot Glacier (pull off) (Fig. 3.9). You only see the lower point of it and it is named for its resemblance to a crow's foot. The toes are melting away by climate warming. The glacier lies on Cathedral Formation carbonate rocks.

101 km: Bow Lake (pull off); Headwaters of the Bow River which flows through Calgary. You can see the Bow Glacier and part of the Watpa Icefield (Fig. 3.10).

106.6 km: Peyto Lake viewpoint. The delta in the lake

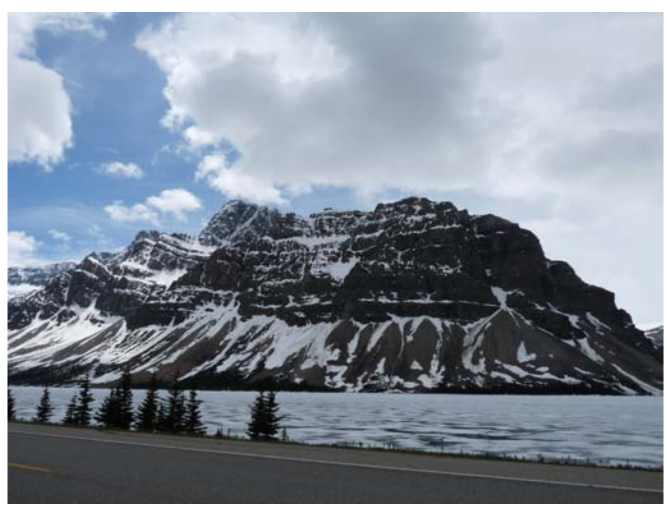


Fig. 3.10

Fig. 3.11

has prograded about 1/3 of the length since the Wisconsinian Iceage ended about 11,000 years ago. This glacial melt from Peyto Glacier gives the lake its colour. The rock flour hangs in suspension in the water and scatters the blue-green wavelengths of light giving the intense colour. Excessive rock flour gives a greyer appearance (Figs. 3.11, 3.12).

115.1: Snowbird Glacier. Bird is diving headfirst down the mountain. The ice has carved a cirque and is not melting as much because of high snowfall in this area. The bird's wings are on the Cathedral and the tail on the Stephen Shale.

Fig. 3.12

125.3; Viewpoint of Howse Peak across lower Waterfowl Lake and a little ice age terminal moraine and Mt. Chephren (the black pyramid a classic horn; most of it is Gog and the upper 1/3 is Mount Whyte and Cathedral formations. Anywhere along this roadway you may see wildlife like this Black Bear chowing down on this tree (Fig. 3.13).

131.6: Mt. Murchison (3333 m; Fig 3.14); Massif on the right (east): One of the larger mountains in the Rockies in terms of area (68 square km), it has 9 distinct summits. Footwall and

Fig. 3.13

east of the Simpson Pass thrust; it is therefore younger than the rocks on the left. The massif includes Sullivan shale, lower cliff is Lyell Dolostone, then Bison Creek (lst and shale) and upper cliff is Mistaya capped by Upper Cambrian to Lower Ordovician Survey Peak Formation. It was named after Sir Roderick Murchison of Silurian and Permian fame.

140 km Mt Wilson (short stop at the Crossing 1445 m 51.97316 116.74635); Murchison to south and Wilson to north (Fig. 3.15)): As you descend toward Saskatchewan River Crossing the mountain for viewing the Late Cambrian and Ordovician carbonates is seen to the north (Mt. Wilson). Each cliff slope defines a formation. The rocks dip to the NE and the opposite on the other side (Mt. Wilson syncline). After we leave the Crossing on the right is Mt Wilson and the top of the cliffs are the Mt Wilson Formation quartzites.

156.2 km Lyell Formation roadcuts on right: Mt Saskatchewan Peak on the left is 3342 m.

160 km: braided North Saskatchewan River

171.7 km Palliser Formation (the Weeping Wall); to the

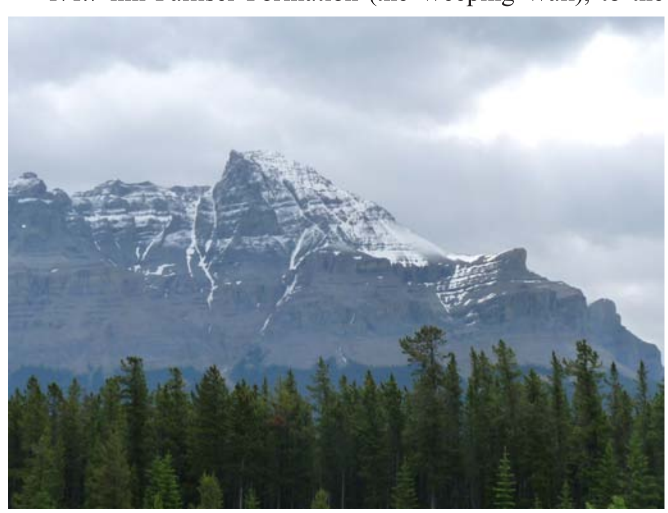


Fig. 3.14

Fig. 3.15

north we can see the Mt. Wilson syncline. See the view to the south of the Palliser to Livingstone succession as we climb the Big Bend.

176.2 km Big Bend (pull off; 1605 m 52.17654 117.05599): Cirrus Mt (3160 m) viewpoint; A fantastic view (Fig. 3.16)! Classic Rocky Mountain sequence of Palliser, Banff and Livingstone formations (Upper Devonian to Mississippian). This is a spectacular view that has graced many magazine covers and the cover of our guidebook. Exfoliating Palliser beds on left after the pull off.

Fig. 3.16

183.6 km; Hilda Peak (3060 m) to northwest (on the left). Road elevation is 2011 m.

192.0 km Icefield's Centre: (1980 m 52.21802 117.22582); Here we will take a short hike along the lateral moraine of the Athabasca Glacier (Fig. 3.17) which represents a tongue of the Columbia Icefields. This hike is short, but bear in mind you are at 2000 metres so if you have any heart ailments you should pace yourself accordingly. This lateral moraine marks the height of the glacier around 1840 during the peak of the Little Ice Age. It has been melting back ever since. The snow

Fig 3.17

dome of the Columbia Icefield represents a triple junction of continental divides (the only place on North America where such a point exists). This "divide" or hydrographic apex separates Pacific, Arctic and Atlantic drainages.

192.2 km; Sunwapta Pass at 2035 m

Figs 3.18 – 3.20 show the Cambrian stratigraphy, global paleogeography and local paleogeography and will be dis-

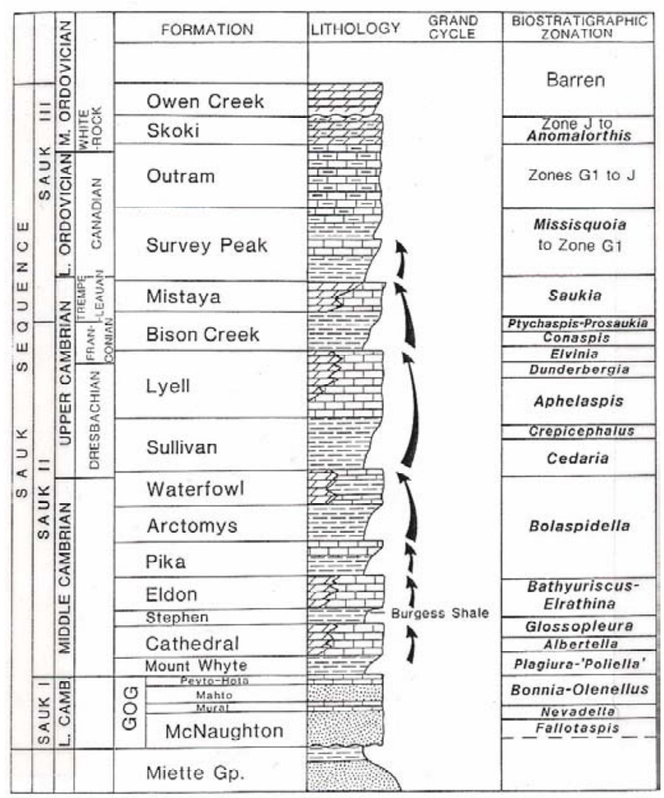


Fig. 3.18. Upper Cambrian to Lower Ordovician stratigraphy showing the Grand Cycles.

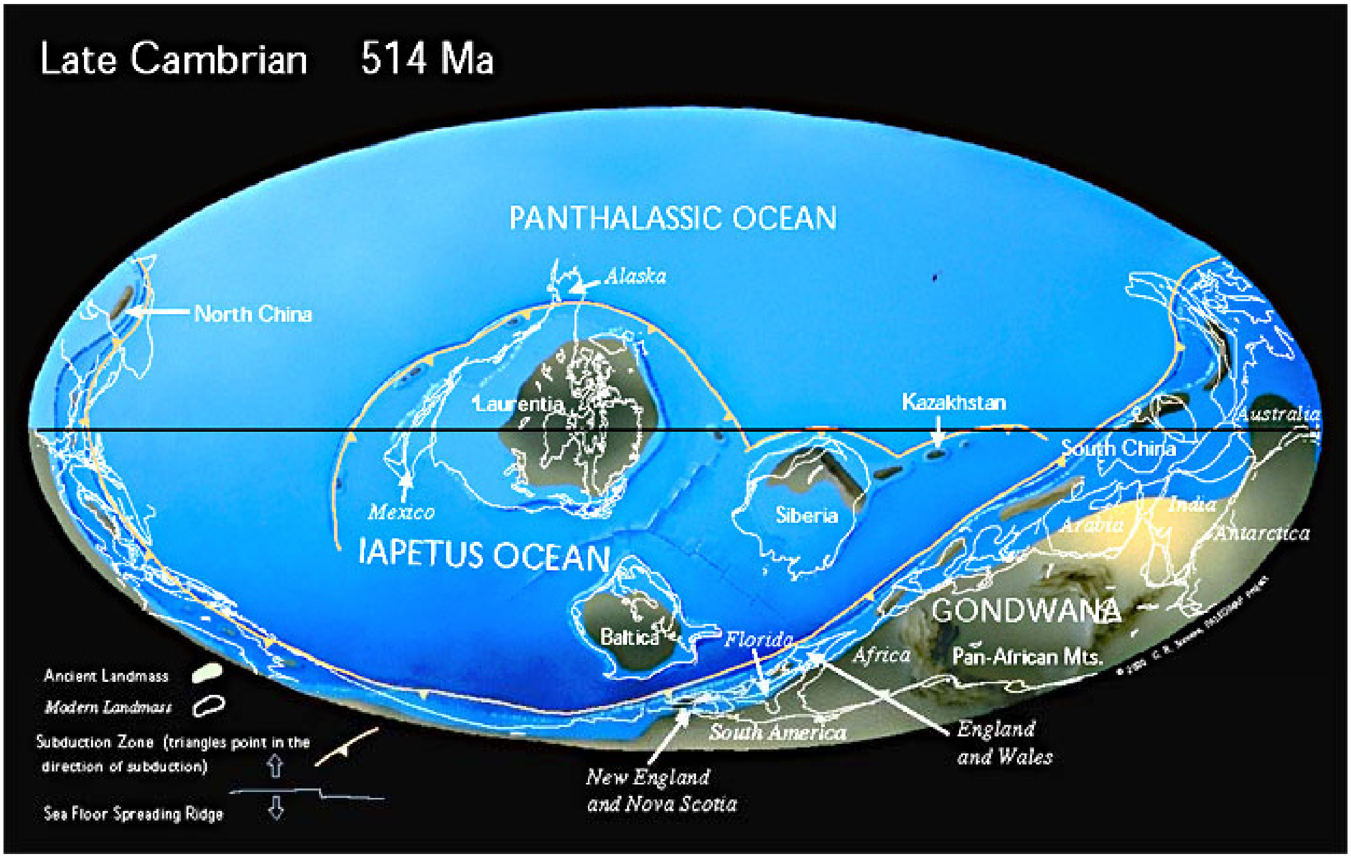


Fig. 3.19. Paleogeography from Chris Scotese website showing that Western Canada was at the equator during Late Cambrian.

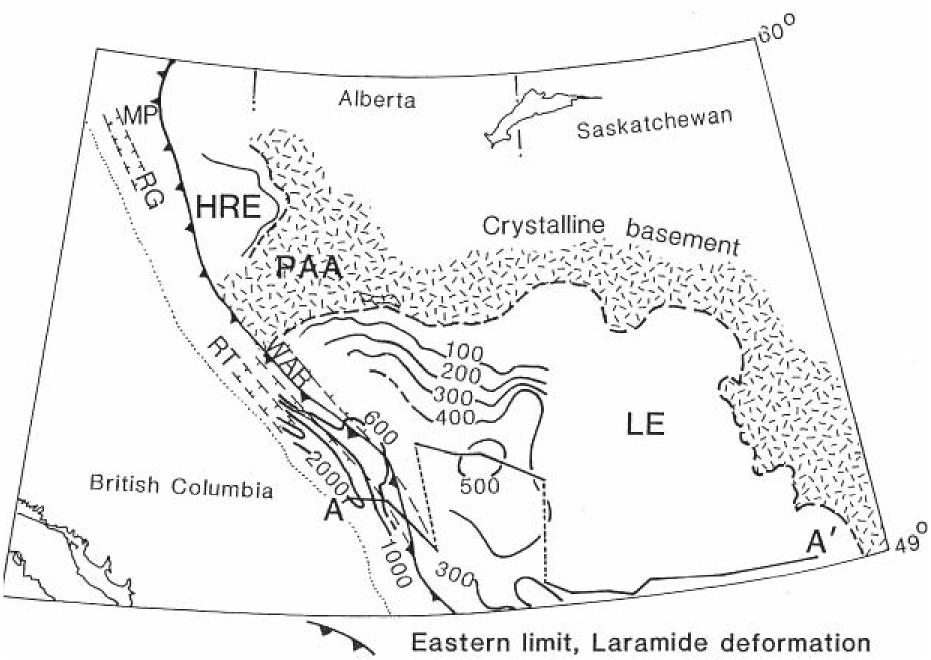


Fig. 3.20. Local paleogeography showing Peace River Arch and embayments that witnessed Middle Cambrian transgressions.

cussed during the day.

208.8 km; Sunwapta River is braided and flows into the Athabasca River and eventually to the Arctic Ocean.

235 km: Endless Chain Ridge is composed of reddish weathering Gog Quartzite.

242 km; Sunwapta Falls (1398 m); A tough limestone/dolostone layer in the Snake Indian Formation forms the cap over which the Sunwapta River falls in a spectacular cascade.

Jasper and Tonquin Lodge at 300.5 km (end of day).

Day 4; We leave Jasper on a 560 km return journey to Calgary along Highway 13 and #40 Forestry Trunk Road south and #22 Highway.

Stop 4-1. (22.6 km) Cold Sulphur Springs: Sub-Devonian unconformity;

Upper Cambrian Lynx overlain by Upper Devonian Flume and Maligne. There are 110 million years missing at this sharp contact, which is a result of Late Silurian arching of the West Alberta Ridge (Figs. 4.1 to 4.6).

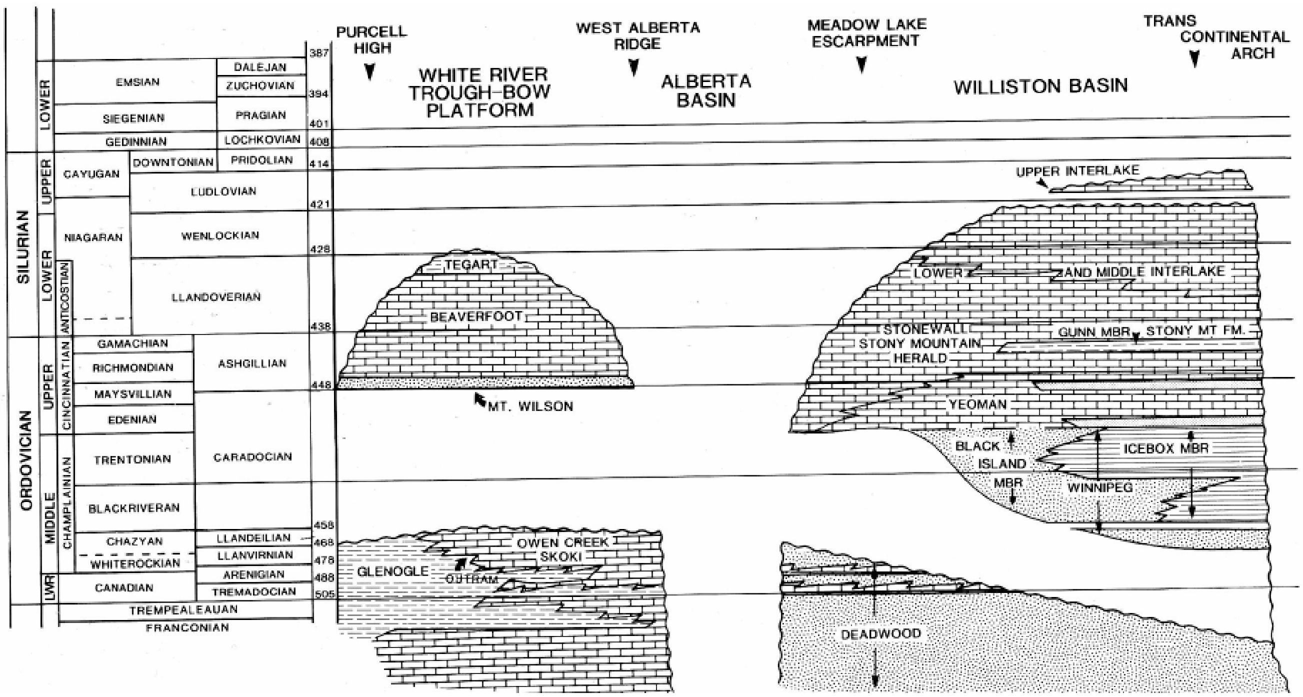


Figure 4.1. A major deformation event resulted in arching and a major unconformity between Cambrian-Ordovician and Upper Devonian formations.

Figure 4.3. Closeup of surface seen in 4.2.

Figure 4.2. Greg Dean is pointing at unconformity separating Upper Cambrian Lynx and Upper Devonian Flume formations.

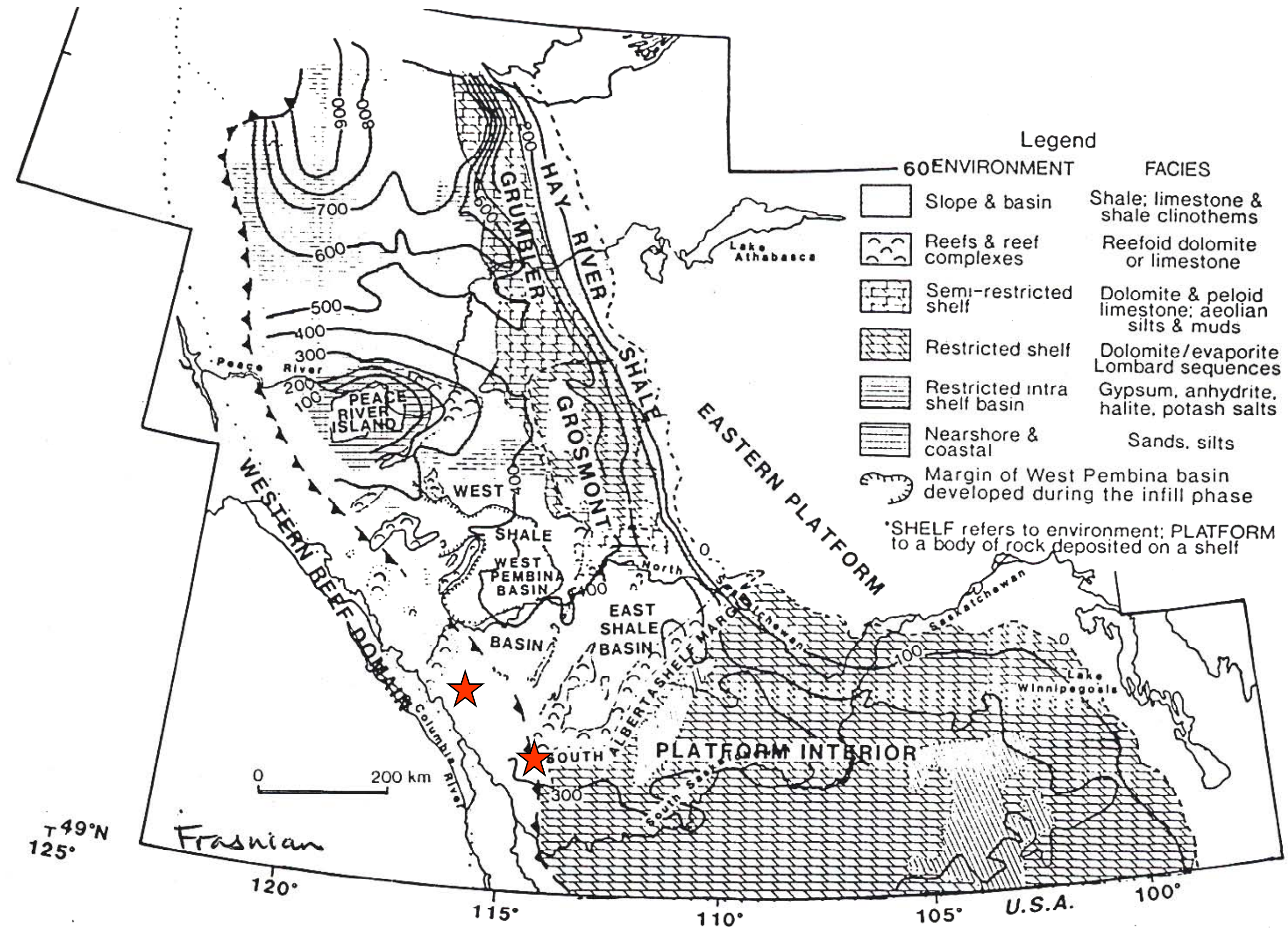


Figure 4.4. Upper Devonian paleogeography in Western Canada. The southern star is the Grassi Lakes area seen in Day 1 and the northern star is our current position..

Figure 4.5. Glacially rounded surfaces on the Flume Formation.

Figure 4.6. Recessive shale and siltstone of Maligne (above rear of vehicle) overlies the Flume Formation.

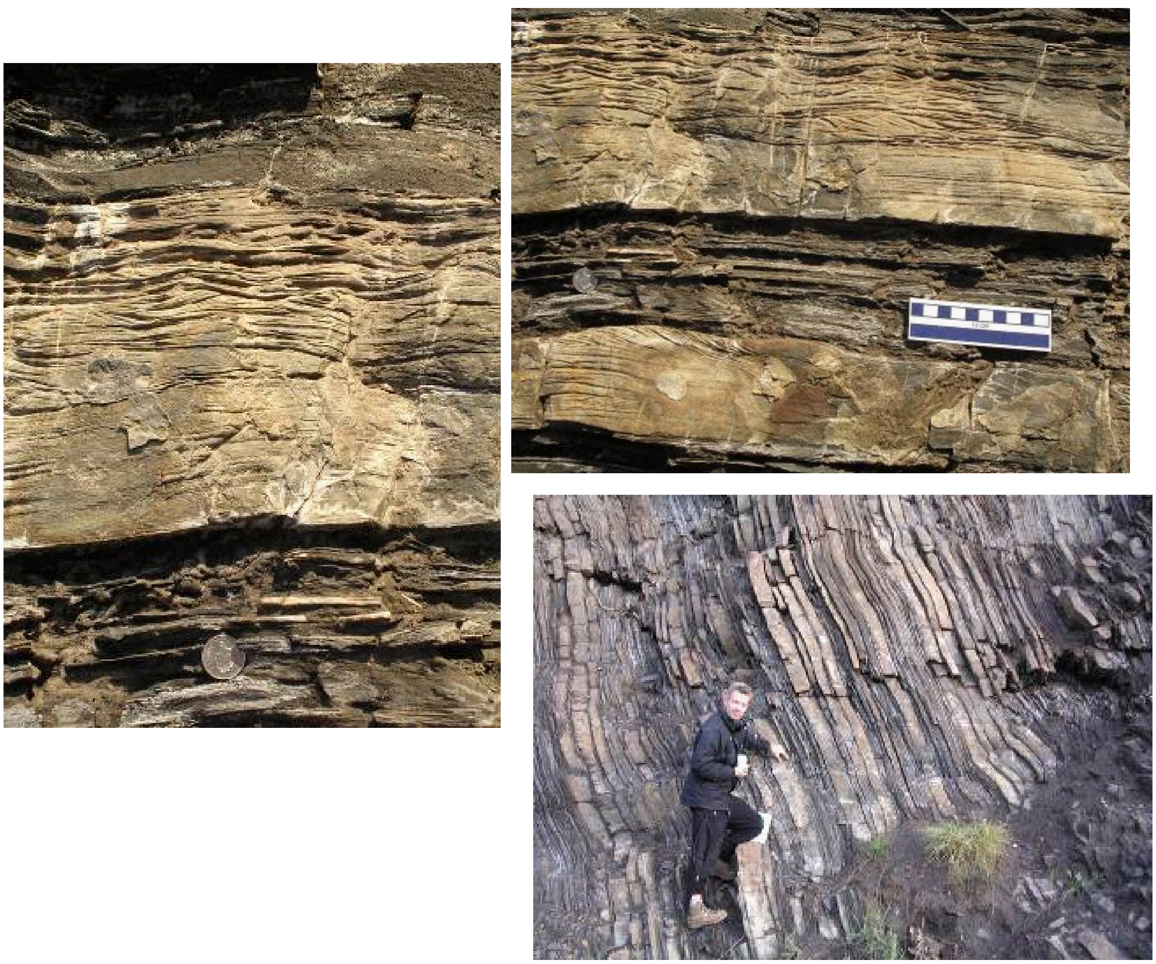


Figure 4.7. BCDE turbidites in Sulphur Mountain Fm.

Over the next 1 km we cross a thrust fault as the next west dipping rocks that we will see are the uppermost Permian to Lower Triassic Sulphur Mountain Formation. Here we see some excellent examples of turbidites (Fig. 4.7) (53.05143 N; 118.07305 W; 1012 m) that represent one of two major reservoir plays in the Peace River Basin.

Next we see Sub-Upper Permian unconformity (not exposed = contact between Sulphur Mountain and Ranger Canyon Formation) and sub-Middle Permian unconformity where Middle Permian Ranger Canyon chert overlies Visean Mount Head Formation dolostone (23.7 km) with a thin conglomerate marking the contact (Fig. 4.8).

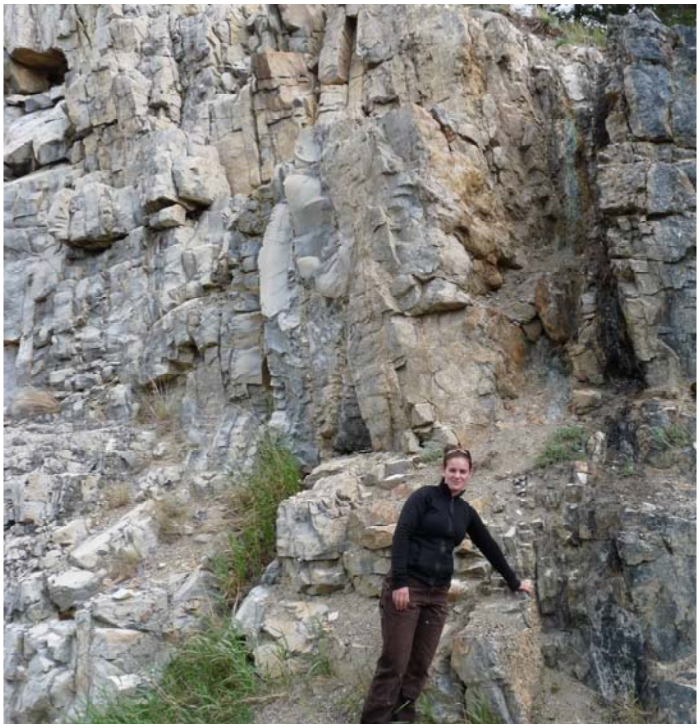


Figure 4.8. Kate Zubin-Stathopoulos points at contact between Mississippian Mount Head and Middle Permian Ranger Canyon Fm..

70 km; turn south on to #40.

107 km; Luscar Coal

Figure 4.?... tbp

Figure 4.9. Big trucks at the Luscar Coal Mine.

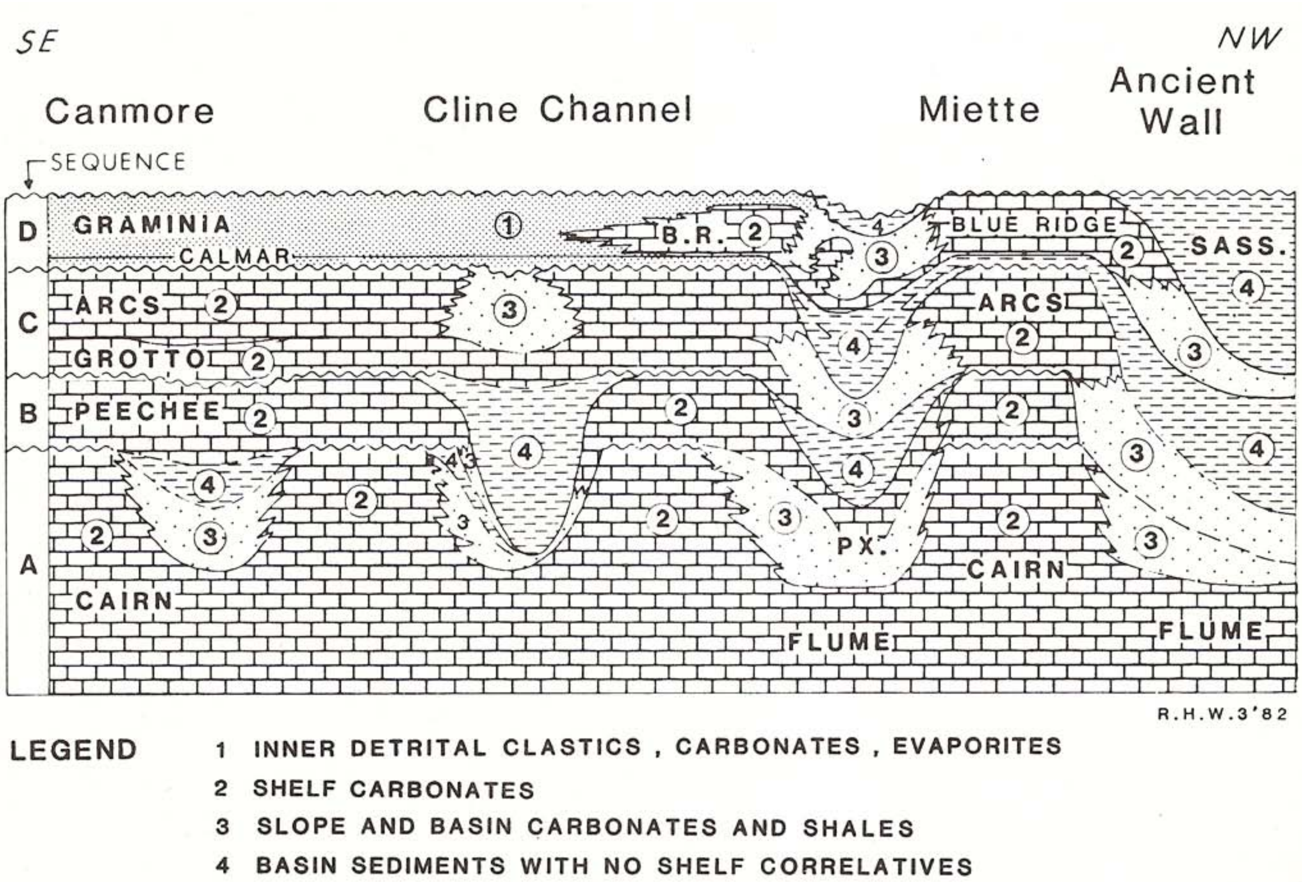


Figure 4.?... tbp

Stop 4-2. Whitehorse Creek Campground 129 km.

McLeod River section of the Lower Triassic Sulphur Mountain Formation. We travel by the Cardinal River Operation of the Elk Valley Coal and its monster trucks. This Jurassic-Cretaceous boundary coal is used among other things for thermal generation of electricity. We park at the Whitehorse Creek campground and hike 985 metres to the only carbonate unit of the Lower Triassic – the Mackenzie

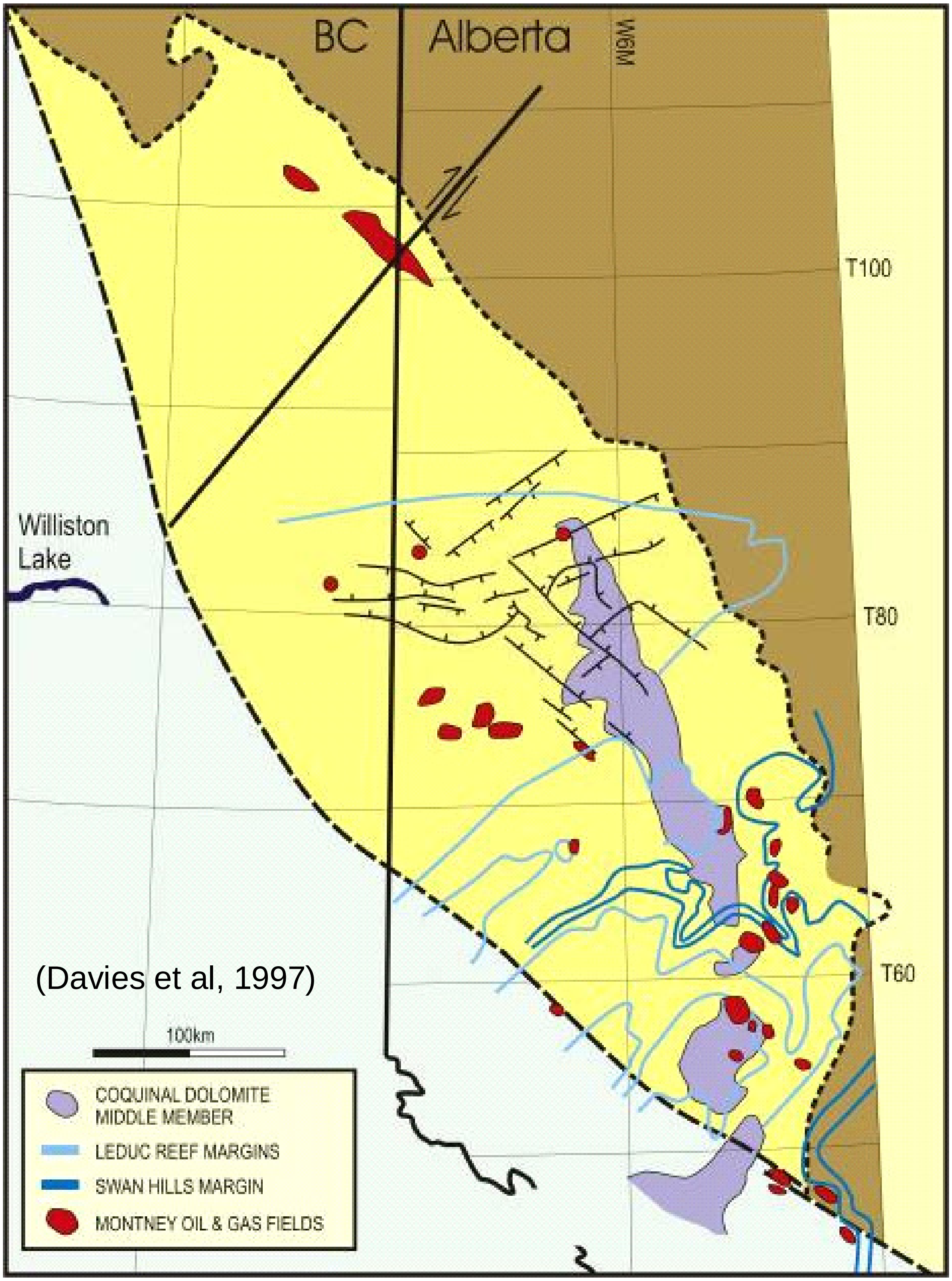


Figure 4.10. Triassic rocks in the Peace River Basin represent hydrocarbon plays in a coquina unit and in turbidites down-dip to the west.

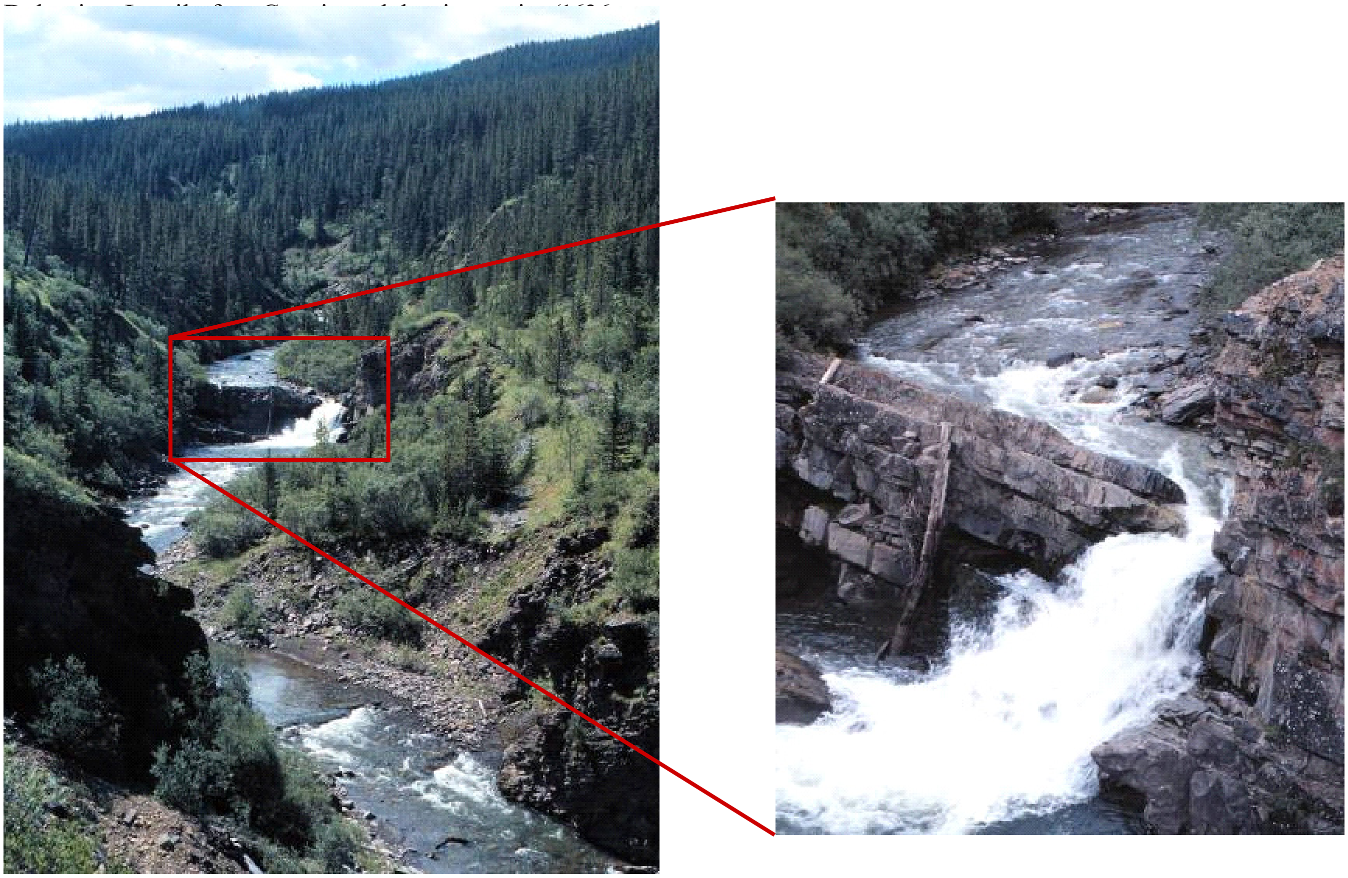


Figure 4.11. Lower Triassic along McLeod River.Insert shows the top of the Dienerian succession.

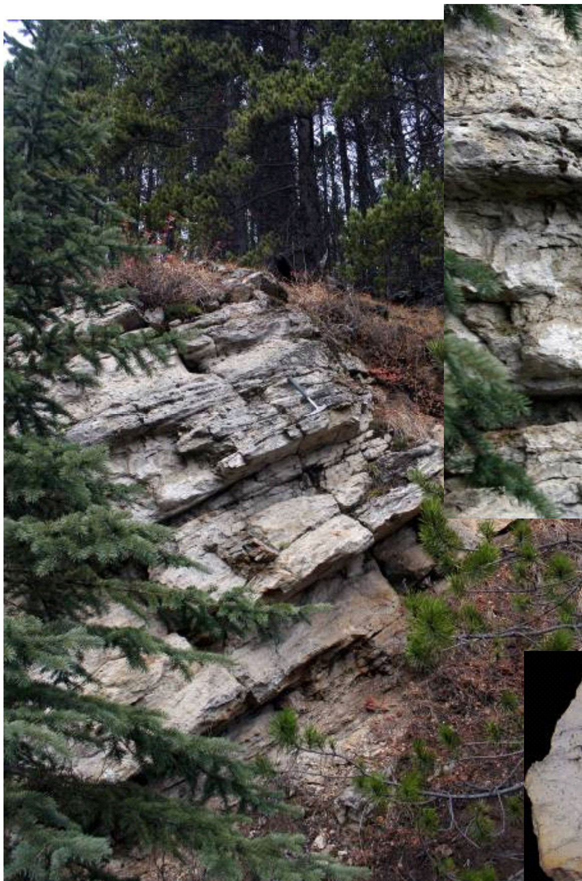
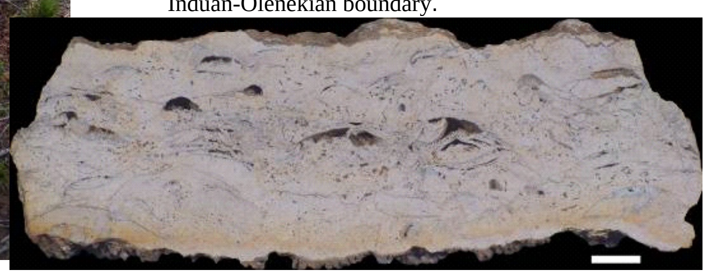


Figure 4.12. Mackenzie Dolomite Lentil or Coquina dolomite unit includes the Induan-Olenekian boundary.



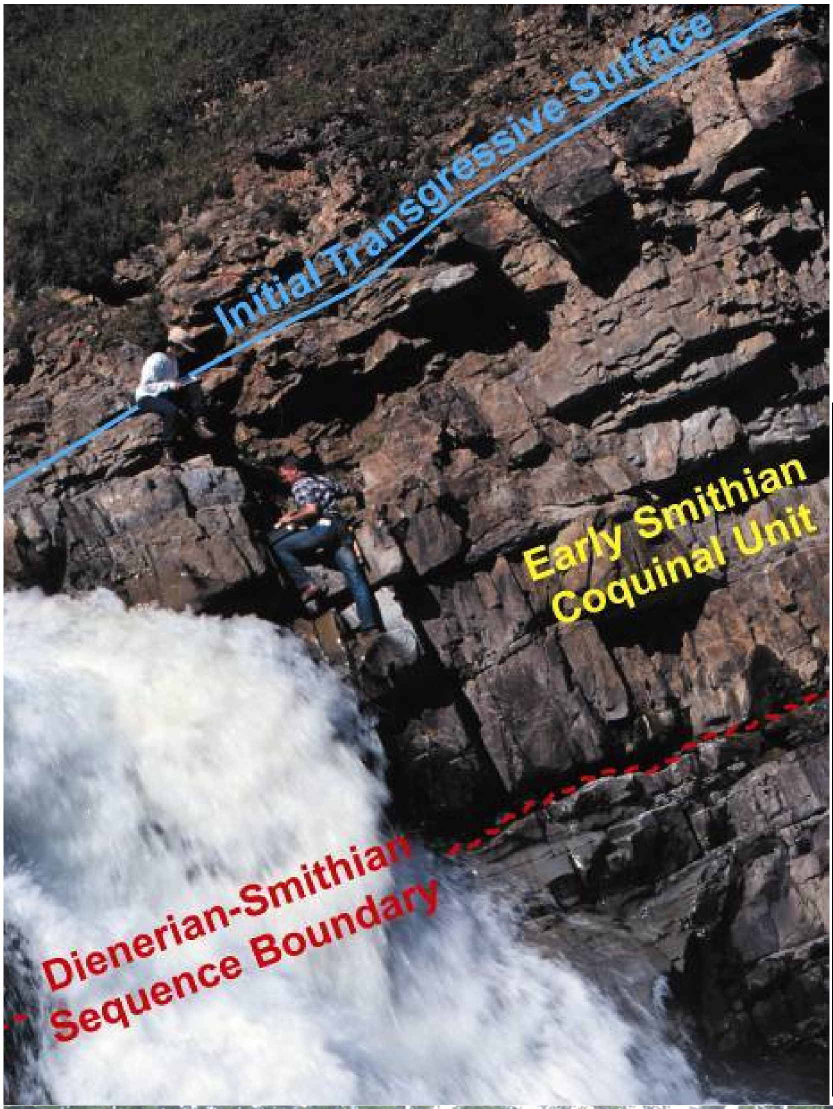


Figure 4.13. Sequence boundary is either at the base of the coquina or within the coquina. Geologists are gamma logging and results are below.

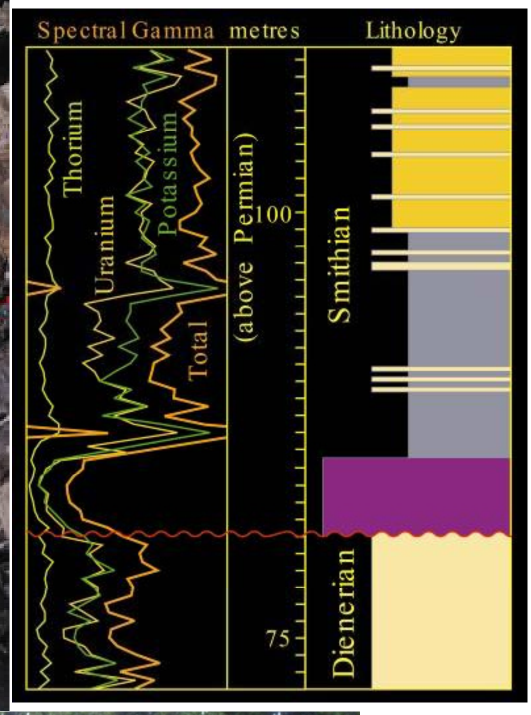


Figure. 4.14.Sequence boundary is probably toward the top of the Coquina.

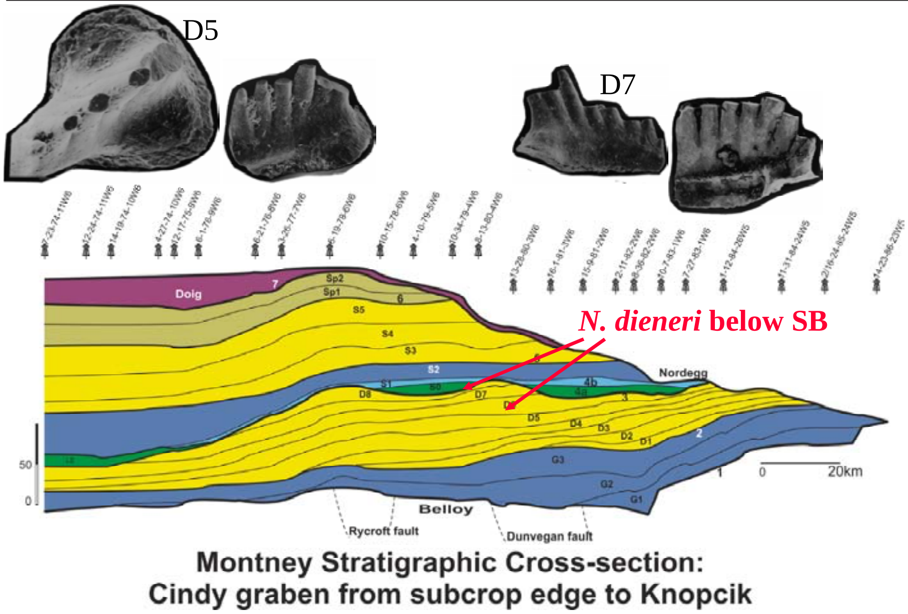


Figure 4.15. Condonts from upper Dienerian including basal coquina.

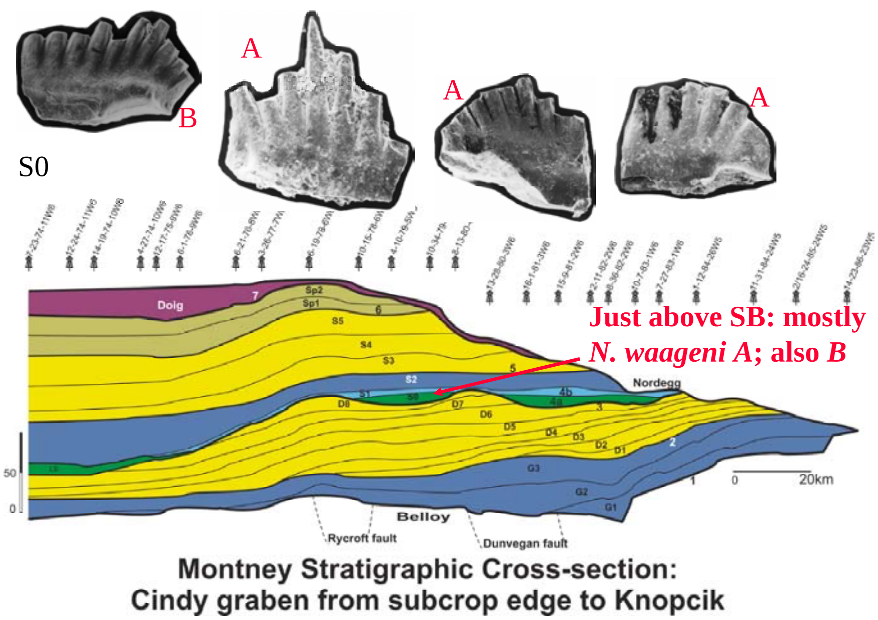


Figure 4.16. Conodonts from upper coquina are similar to those seen at Opal Creek.

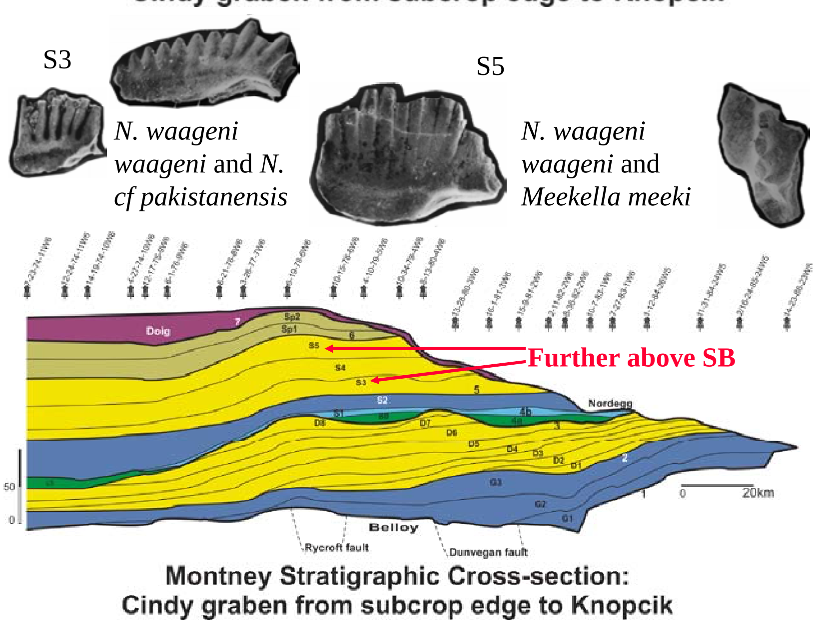


Figure 4.17. Younger Smithian conodonts from the subsurface.

Now we travel for at least two hours through foothills territory with a number of lumber operations. Turn south on #40 at 166 km. The scenery will be somewhat dull until we get within 10 km of our next and last stop at Nordegg (280 km). Sit back and relax or nap and enjoy your lunch.

Stop 4-3. (280 km): Nordegg: D-C boundary section of Palliser and Exshaw formations.

Upper Devonian (Famennian) And Early Mississippian (Tournaisian) Carbonates And Black Shale Along The Nordegg Railroad Cut, Western Rocky Mountain Foothills S.W. Alberta

Geological setting

In the western Rocky Mountain Foothills near the village of Nordegg, the upper Famennian to lower Tournaisian Exshaw Formation is well exposed in a succession extending from the upper Palliser Formation into the lower part of the Tournaisian Banff Formation along an abandoned railroad cut (figs. 4.18, 4.19). The objective for the afternoon of day 4 is to provide an overview of the lithostratigraphy and conodont biostratigraphy of this succession. The Famennian and Tournaisian strata lie within the Brazeau Range and Brazeau thrust sheet about 5.3 km northeast of Nordegg. The Famennian Palliser Formation was deposited on the western Alberta Shelf. Deposition of the Exshaw and overlying Banff Formation (Fig. 4.20) took place in eastern Prophet Trough.

From the intersection of Highway 11 and the paved road heading south into Nordegg, drive 4.3 km east along Highway 11. Turn south from the highway onto a gravel road that heads toward the southeast and continue east along that road for about .6 km. Stop at the gate or barricade on the road and hike the remaining distance to the abandoned railway cut at a point where an abandoned bridge crossed the cut.

Stop 4-4. Upper Palliser Formation along the eastern side of the railroad cut (Fig. 4.21).

Along the railroad cut, about 42 m of the upper Palliser Formation are well exposed and a few scattered outcrops of the underlying Palliser are also evident. The succession is overturned toward the northeast (attitude of beds at top Palliser-120°/65°W). At Jura Creek and elsewhere in the Bow Valley region that we visited on days one and two of the field trip, the Palliser comprises the Morro Member and overlying Costigan Member (Fig. 4.20). In the Nordegg railroad cut, however, the Palliser can not be readily divided into members. The local presence of fenestral fabrics and thinly laminated deposits of

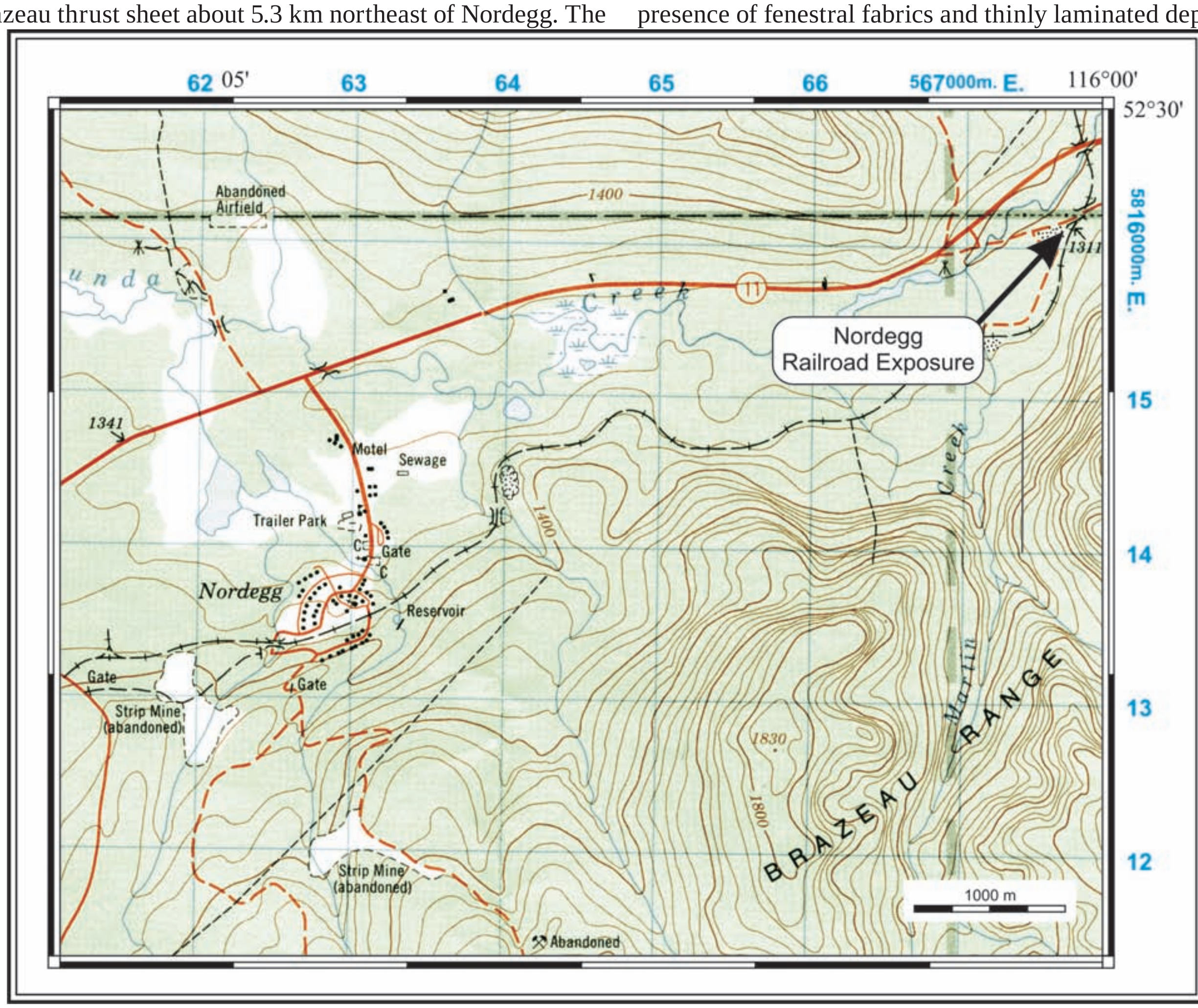


Figure 4.18. Map showing location of Nordegg railroad cut.

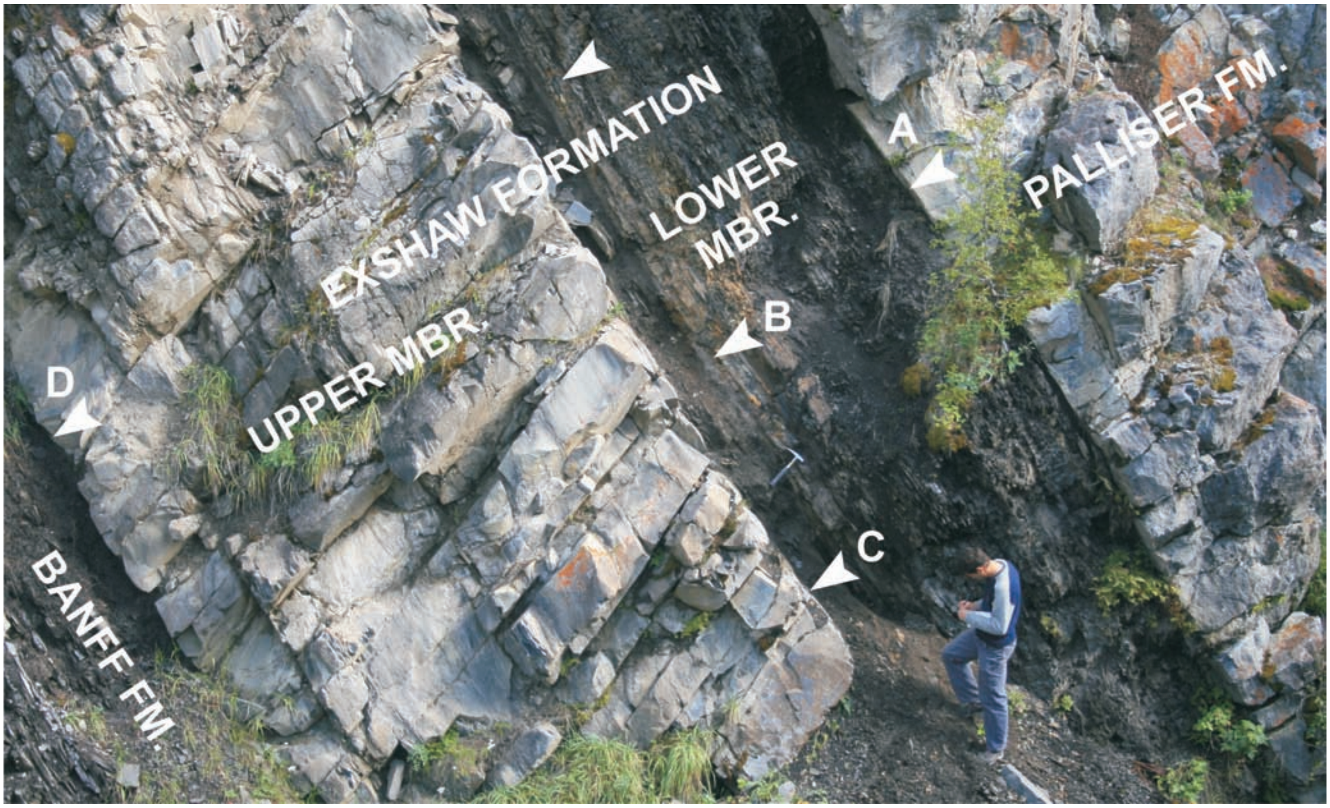


Figure 4.19. Palliser, Exshaw and Banff formations at Nordegg railroad cut western Rocky Mountain Foothills, S.W. Alberta. Section is overturned toward the northeast; view is toward southeast. Arrows indicate: A- top Famennian limestone of Palliser Formation and base upper Famennian to lower Tournaisian? lower member (2.18 m thick) of Exshaw Formation, B- approximate location of bentonitic tuff bed, C- base upper member (4.17 m thick) of Exshaw, and D- top Exshaw and base of lower Tournaisian shale and marlstone of Banff Formation.

restricted-marine aspect in the lower part of the outcrop (below the upper 35 m of the Palliser as shown in Figure 4.21) suggest the lower Costigan is present in the lower part of the section but the overlying deposits resemble those of the Morro Member.

The upper transgressive unit of the Costigan, which is well developed in the Bow Valley region, may be present at Nordegg but is not typically developed. Stratigraphically above the 35-metre level in the section, the Palliser is dominated by burrow-mottled lime wackestone and packstone resembling that of the upper Morro Member along Jura Creek. These upper deposits are of more open-marine aspect than the underlying strata and may represent the upper transgressive unit of the Costigan.

Conodonts are well preserved and relatively abundant in the upper Palliser at Nordegg (Plate 1). The conodonts have been studied by Johnston and Chatterton (1991), Savoy *et al*. (1999) and Johnston and Chatterton (2001). Figure 4.22 shows the established ranges of taxa in the upper 12 metres of the Palliser. The Interval from 12.3 to 3.8 m below top Palliser is assigned to the Uppermost *marginifera* to Lower *trachytera* Zones. The Uppermost Palliser contains an assemblage assignable to the Upper *marginifera* to Middle *expansa*? zones.

In the upper Palliser at this stop, the local occurrence of oncoliths and the predominance of burrow-mottled to massive peloid-skeletal lime packstone containing crinoid ossicles and other open-marine fossils indicates deposition in the photic zone but below fair-weather wave base in middle-ramp, neritic environments. Deposition in such a setting is also indicated by the general absence of lime grainstone and wave-formed sedimentary structures. The presence of deposits of restricted-marine aspect in the lower part of the outcrop (below the upper 35 m of the Palliser in Figure 4.21) indicates deposition in lagoonal to high-intertidal environments on the restricted shelf.

Stop 4-5. Exshaw Formation and lower Banff Formation along the eastern side of the railroad cut (Figs. 4.19, 4.23).

At stop 4-2, the Exshaw Formation is well exposed along both sides of the railroad cut but the exposure on the east side is substantially better; therefore, the Exshaw section (Fig. 4.23) was measured along that side. The base of the Exshaw is sharp, showing 2 to 6 cm of relief as dished-shaped depressions, and is probably erosional. The lower contact looks like a dissolution surface and is tentatively interpreted to be a submarine erosion surface or surface of non-deposition rather than a subaerial unconformity. However, the upper transgressive unit of the Costigan is not clearly developed at the locality and hiatus between the Exshaw and Palliser may be more substantial than shown on Figure 4.20.

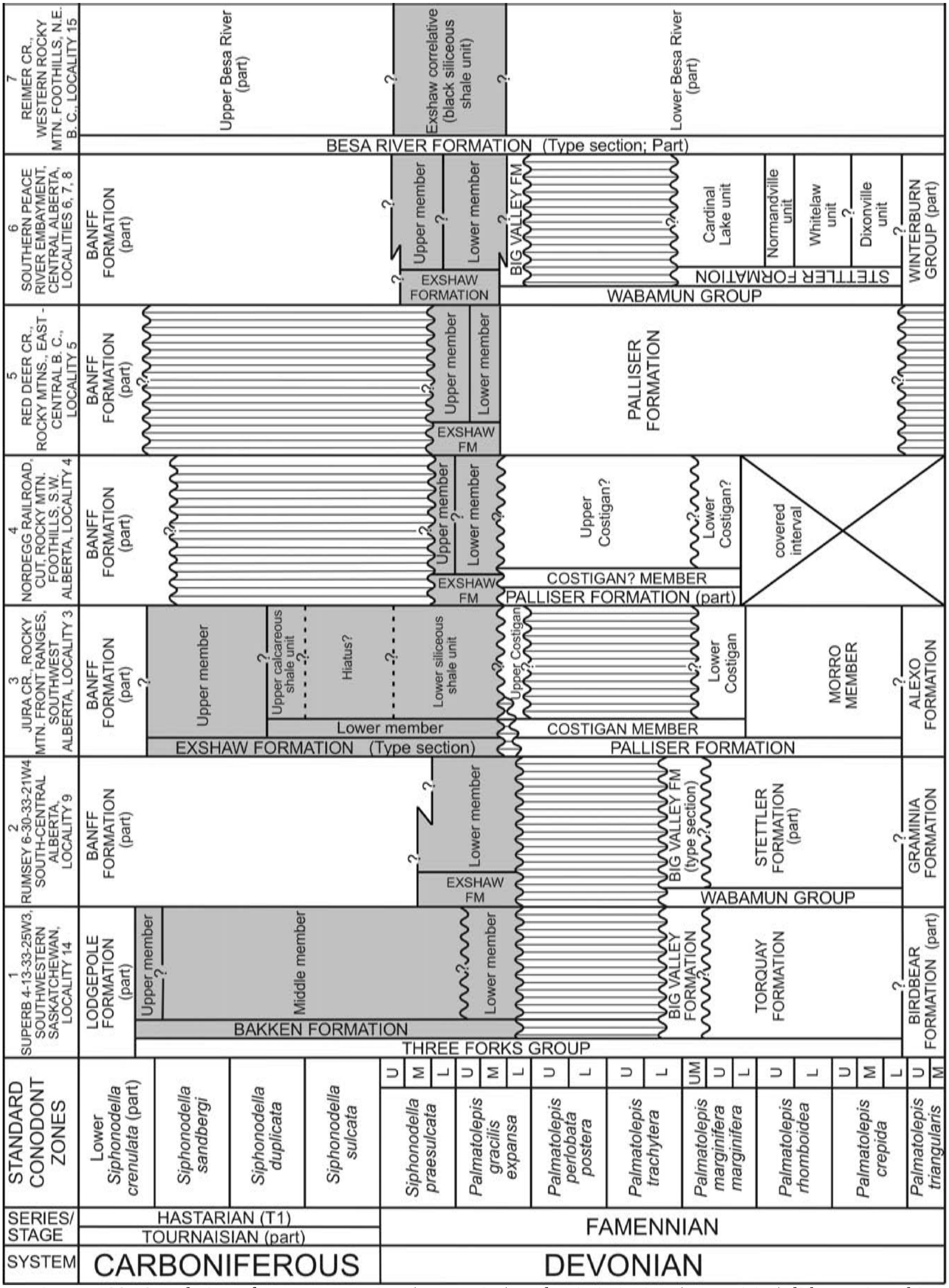


Figure 4.20. Correlation of Upper Devonian (Famennian) and Mississippian (Tournaisian) lithostratigraphic units in the Western Canada Sedimentary Basin with standard chronostratigraphic units and conodont zones (from Richards et al., 2002).

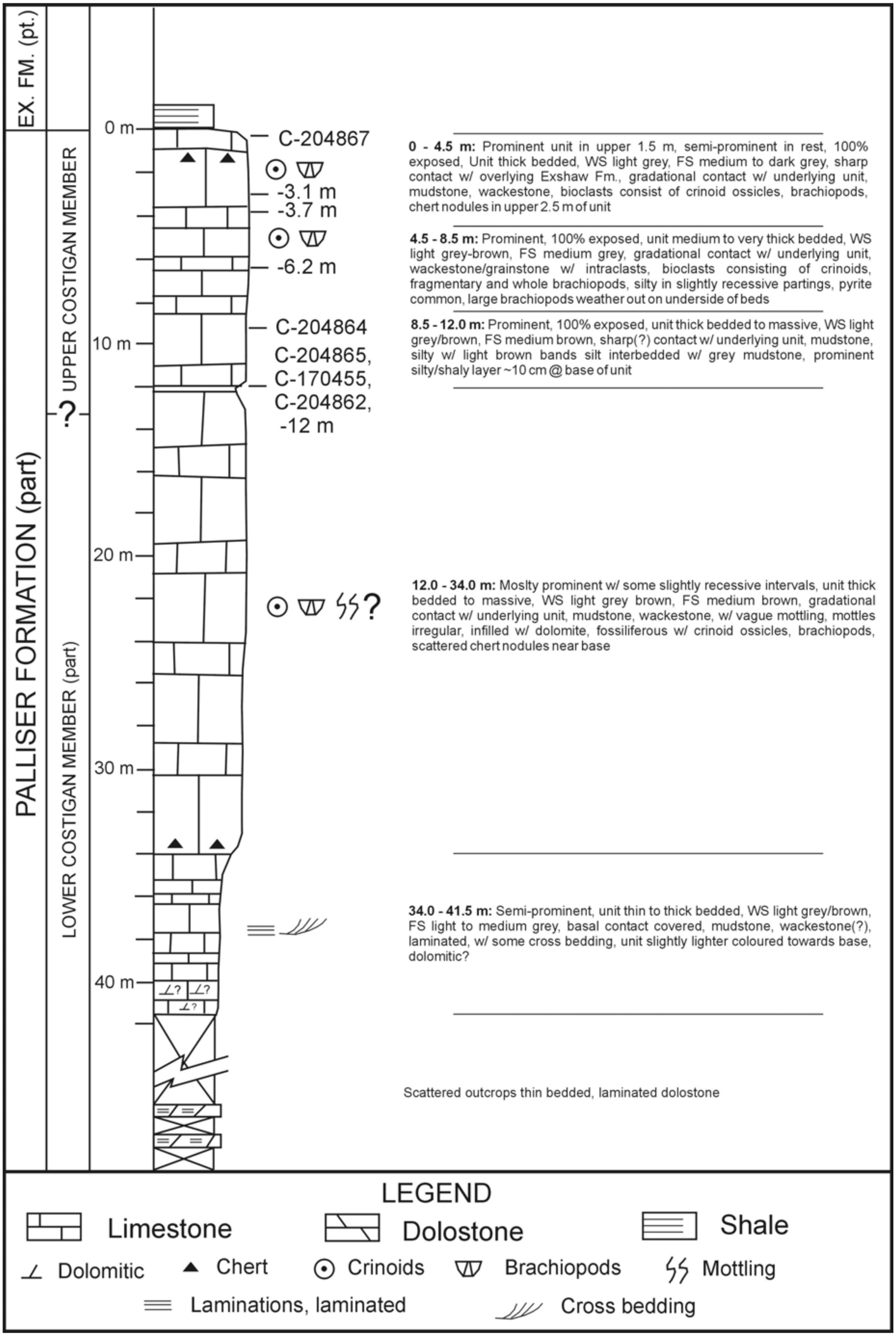
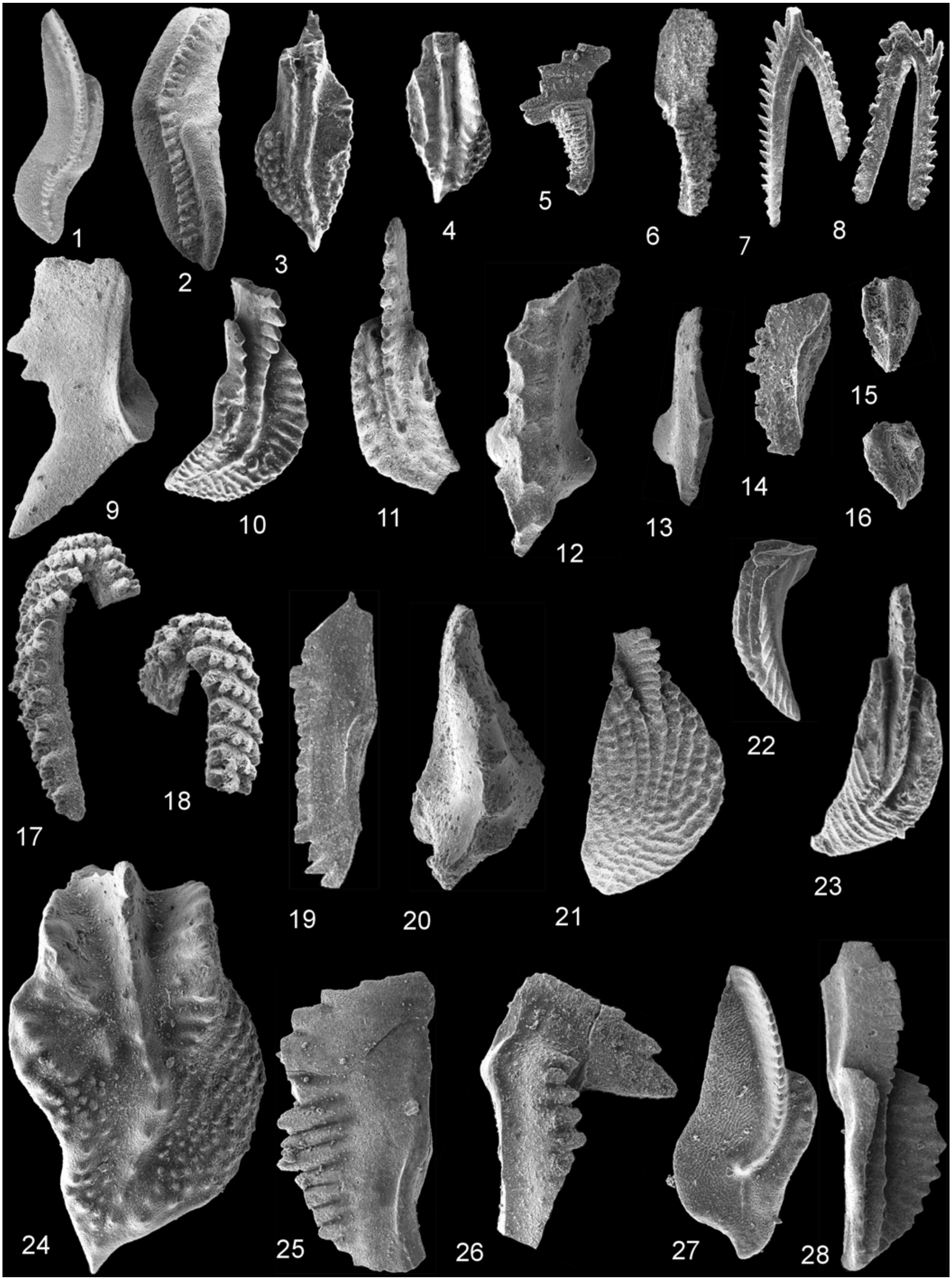


Figure 4.21. Stratigraphic column showing upper Palliser Formation at Nordegg railroad cut.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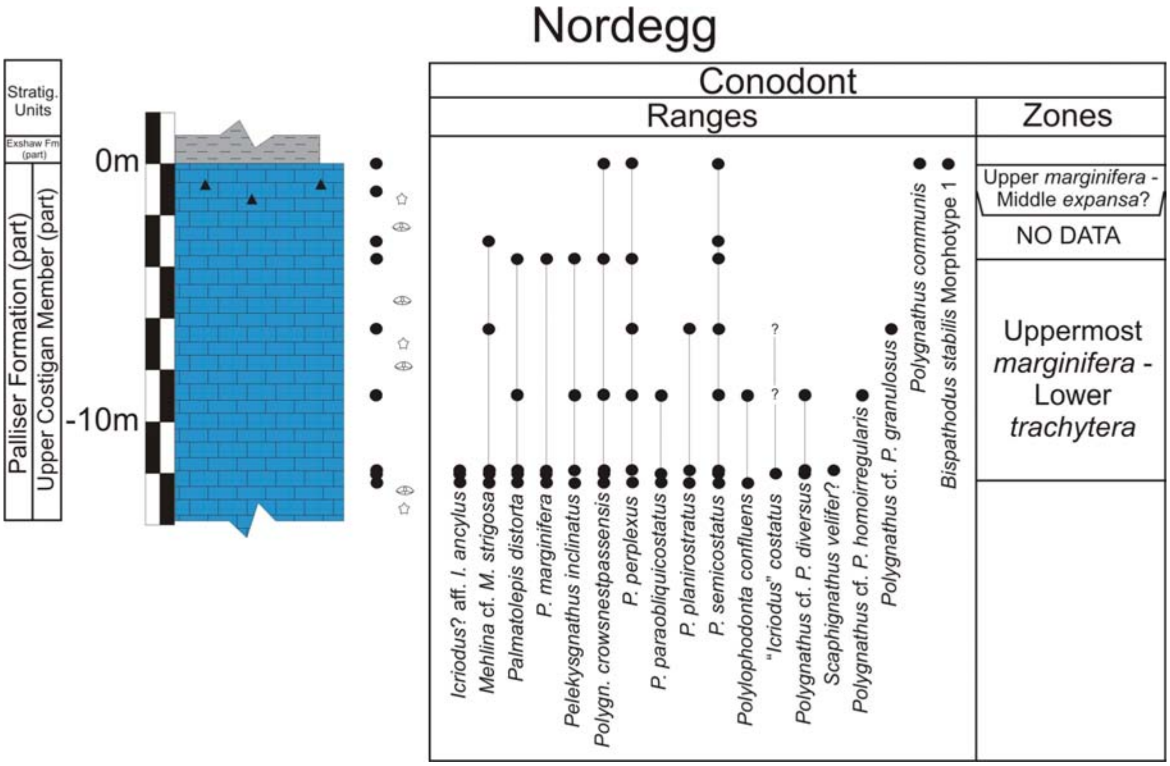

Figure 4.22 (above). Range chart showing established ranges of conodont species from the upper part of the Famennian Palliser Formation at Nordegg, S.W. Alberta.

Plate 1 (right): Representative conodonts from the upper Palliser Formation at Nordegg, Alberta. All are P_1 elements and upper views, unless indicated otherwise. SEM photographs in 1-4, 7-11, 17, 18, 21, 23 and 27 by BDE Chatterton. GSC = Geological Survey of Canada.

1, 2?. *Palmatolepis distorta* Branson and Mehl. 1, GSC type no. 100259, previously illustrated by Johnston and Chatterton (1991, Pl. 1, fig. 3; 2001, Pl. 7, fig. 5), 2, P_2 element?, both specimens X54 and from 12 m below top of Palliser Formation.

3, 4. *Polygnathus perplexus* Thomas. Both X60 and from 3.7 m below top of Palliser Formation.

5, 6. *Polygnathus* cf. *P. diversus* Helms. 5, lateral view, P_2 element, 6, oblique upper view, both specimens X60 and from GSC locality no. C-204865, 11.9 m below top of Palliser Formation.

7, 8. *Apatognathus sp.* ramiform elements, both specimens X54 and from 12 m below top of Palliser Formation.

9. *Pelekysgnathus inclinatus* Thomas. I element, lateral view, X54, 12 m below top of Palliser Formation.

10, 11. *Polygnathus planirostratus* Dreesen and Dusar. 10, oblique upper view, Morphotype 2 of Dreesen and Dusar, X30, 11, Morphotype 1 of Dreesen and Dusar, X54, both from 12 m below top of the Palliser Formation.

12. *Icriodus? sp.* aff. *I. ancylus* Sandberg and Dreesen. oblique upper view, I element, X60, GSC locality no. C-170455, 12 m below top of Palliser Formation.

13, 20?. *"Icriodus" costatus* (Thomas). I element, X60, GSC locality no. C-170455, 12 m below top of Palliser Formation, 20, I element, X60, GSC locality no. C-204864, 8.9-9.0 m below top of Palliser Formation.

14. *Bispathodus stabilis* (Branson and Mehl) Morphotype 1 of Ziegler et al. lateral view, X60, GSC locality no. C-204867, 0.0-0.1 m below top of Palliser Formation.

15, 16. *Polygnathus communis* Branson and Mehl. 16, lower view, both X60 and from GSC locality no. C-204867, 0.0-0.1 m below top of Palliser Formation.

17, 18. New genus, new species? ramiform elements?, both X54 and from 12 m below top of Palliser Formation.

19, 25. *Mehlina sp.* cf. *M. strigosa* (Branson and Mehl). lateral views, both X60 and from GSC locality no. C-204865, 11.9 m below top of Palliser Formation.

21. *Polylophodonta confluens* Ulrich and Bassler. X54, 12 m below top of Palliser Formation.

22. *Polygnathus paraobliquicostatus* Johnston and Chatterton. oblique upper view, X60, GSC locality no. C-204864, 8.9-9.0 m below top of Palliser Formation.

23. *Polygnathus semicostatus* Branson and Mehl. X60, 12 m below top of Palliser Formation.

24. *Polygnathus sp.* cf. *P. homoirregularis* Ziegler. X60, GSC locality no. C-204864, 8.9-9.0 m below top of Palliser Formation.

26. *Scaphignatus velifer* Helms? lateral view, X60, GSC locality no. C-204865, 11.9 m below top of Palliser Formation.

27. *Palmatolepis marginifera* Helms. X54, GSC type no. 107005, 12 m below top of Palliser Formation, previously illustrated by Johnston and Chatterton (2001, Pl. 14, fig. 14).

28. *Polygnathus crowsnestpassensis* Johnston and Chatterton. oblique upper view, X60, GSC locality no. C-204863, 12.0-12.05 m below top of Palliser Formation.

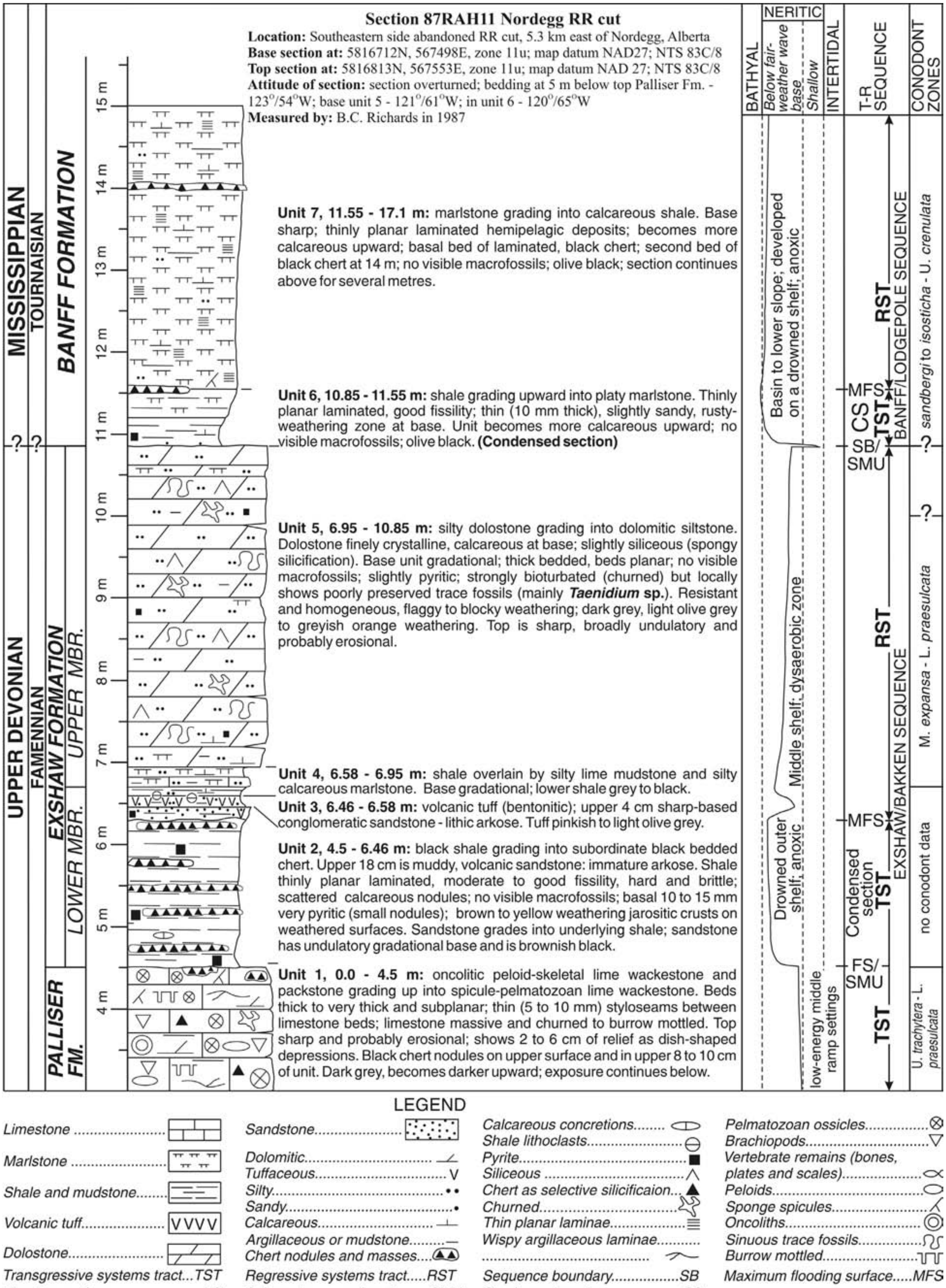

Figure 4.23. Columnar section showing characteristics and stratigraphic relationships of the upper Famennian to lower Tournaisian? Exshaw Formation and overlying lower Banff Formation at the Nordegg railroad cut, S.W. Alberta (from Richards et al., 2002).

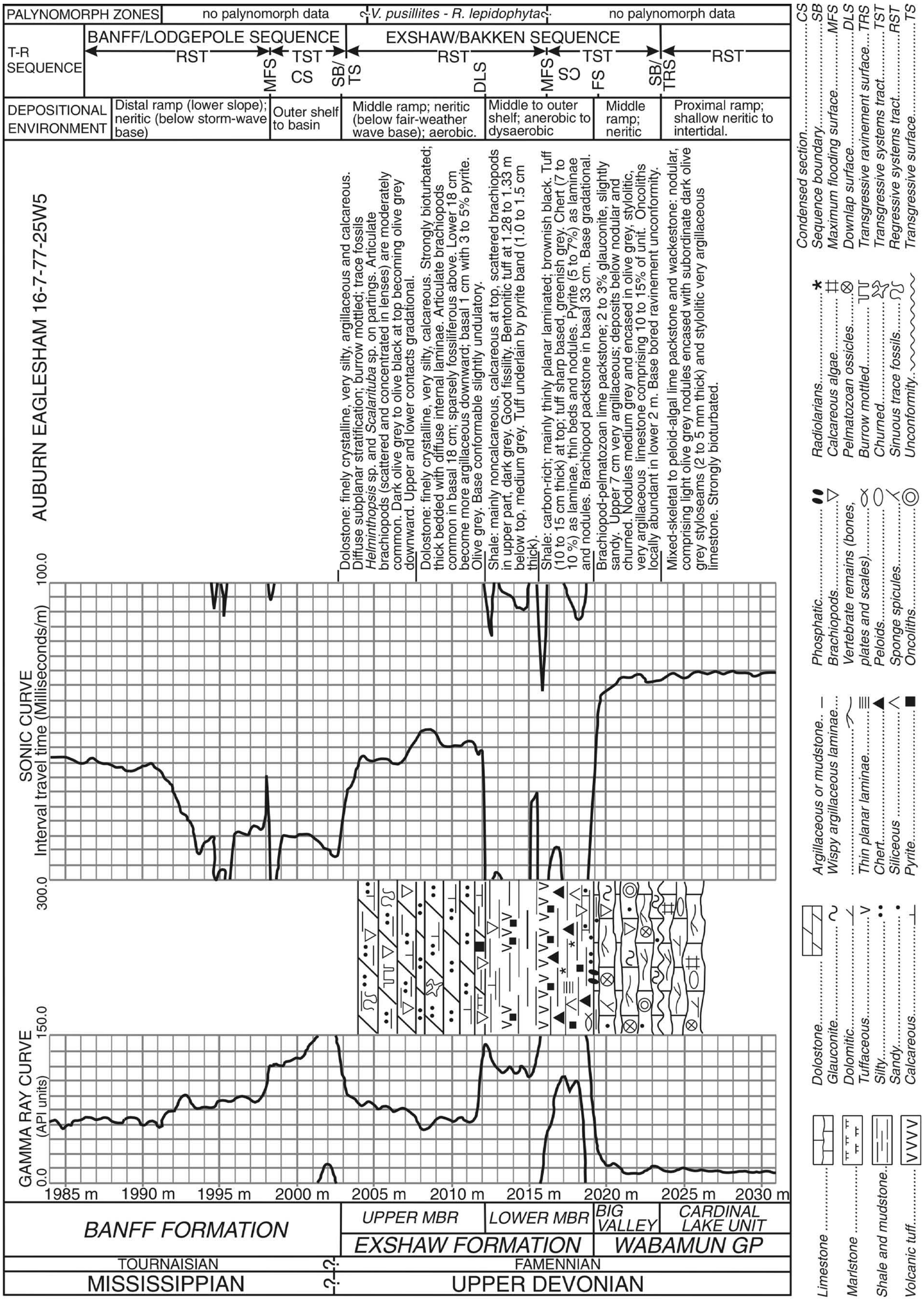

Figure 4.24. Representative borehole section showing relationship between rock types and gamma-ray and sonic-log traces in the Big Valley and Exshaw formations in the Auburn Eaglesham well 16-7-77-25W5 southern Peace River Embayment central Alberta, (from Richards et al., 2002). Lithologic log is based on well core.

The contact between the Exshaw and overlying Banff Formation is sharp and slightly undulatory. Regional lithostratigraphic relationships indicate the base of the Banff is disconformable, cutting down section toward both the northwest and the east. In much of the eastern Rocky Mountains in Jasper National Park and northward, the Banff lies either on the lower Exshaw or on the upper Palliser.

In the Nordegg section, the Exshaw is 6.35 m thick and comprises a lower member dominated by black shale and chert (2.18 m thick) and an upper member dominated by silty dolostone (4.17 m thick). The characteristics and environmental interpretations for the members are shown on Figure 4.23. In the subsurface to the east of the Nordegg region, the lower member is readily identifiable as an anomalously radioactive interval on gamma-ray logs (Fig. 4.24).

Arkosic sandstone overlain by bentonitic volcanic tuff of variable thickness (about 12 cm thick) is preserved in the upper part of the lower member. Richards *et al.* (2002) extracted zircons and monazite crystals from the ash-fall tuff beds in the Exshaw Formation at several locations in the WCSB for U-Pb dating. The tuff and related clays were selected for the analyses as they show less evidence for marine reworking and potential contamination by detrital grains than the arkosic sandstone to conglomerate. The monazite analyses from the Nordegg tuff gave the best age constraints with an excellent $^{207}Pb/^{235}U$ age of 363.34 ± 0.39 Ma. This result is in close agreement with the zircon data from the same tuff which give a $^{206}Pb/^{207}Pb$ age of 363.4 ± 3.1 Ma and illustrates the contrast in the error and precision of monazite versus zircon analyses.

The pyroclastics in the lower member of the Exshaw Formation resulted from latest Devonian to Tournaisian volcanism and plutonism in western Prophet Trough and along a volcanic/plutonic belt to the west (Richards et al., 2002).

Conodont data (Savoy *et al.* 1999) from Nordegg suggest the tuff bed sampled for geochronology lies within the Middle *expansa* to Lower *praesulcata* zones. The uppermost bed of the Palliser Formation yielded conodonts representative of the Upper *Palmatolepis rugosa trachytera* to Lower *praesulcata* zones. Conodonts have not been obtained from the lower member of the Exshaw at Nordegg. The basal beds of the upper member of the Exshaw contain abraded conodont elements indicative of a late Famennian age (Middle *expansa* to Lower *praesulcata* zones). On the basis of the two faunas, Savoy *et al.* (1999) interpreted the lower member to be within the Middle *expansa* to Lower *praesulcata* zones (Fig. 3). The base of the upper member is only 10 cm above conglomeratic sandstone that has an erosional base. Therefore, the abraded conodont elements may have been reworked from the lower member. A Famennian age for the upper member at Nordegg is considered suspect, because the contact between Famennian and Tournaisian strata normally lies in the upper part of the lower Exshaw in southwest Alberta. Savoy *et al.* (1999) suggested the Devonian-Mississippian boundary may lie within or near the top of the upper member at this section. Overlying strata in the lower Banff Formation contain faunas representing the *sandbergi* to *Siphonodella isosticha* - Upper *Siphonodella crenulata* zones (Fig. 4.23).

The black siliceous shale and associated chert in the lower member of the Exshaw record deposition in relatively deep water basin and drowned-shelf settings (Richards and Higgins 1988, Savoy 1992). Deposition of the lower member took place in the anaerobic to dysaerobic zones and generally below storm wave base, but probably at water depths of less than 300 m (Richards *et al*., 1994; Caplan and Bustin, 1998). Hemipelagic processes produced most of these mud rocks, but sediment gravity flows deposited at least some of the intercalated sandstone and sandy limestone beds present at some localities. The widespread establishment of oxygen-deficient (anoxic) bottom conditions during deposition of the siliceous shale and chert unit is recorded by the high percentages of sulphides and absence of trace fossils and benthonic macrofaunas in most of that unit.

The preservation potential for ash-fall tuff in the hemipelagic mud rocks of the Exshaw's lower member is high because of the low-energy regime that existed during its deposition. Moreover, conditions were generally unfavourable for bioturbation because of the anoxic bottom conditions.

The upper Exshaw records shallowing, regression, and deposition in aerobic to dysaerobic environments at moderate- to shallow-water depths (Richards and Higgins, 1988; Savoy, 1992; Caplan and Bustin, 1998; Richards *et al.* 2002). In the southern Rockies, including the Nordegg and Jura Creek areas, most of this member was probably deposited below storm wave base in middle-shelf settings. Such deposition is suggested by the fine-grained, dark-coloured deposits, the presence of a trace fossil assemblage dominated by grazing traces (pascichnia), and the apparent absence of wave- and current-formed structures. Components of the upper member in the subsurface to the east were deposited in shallow-marine environments (above fair-weather wave base to intertidal) as indicated by the local presence of ooid and skeletal lime grainstone, horizontally stratified sandstone, and small- to medium-scale cross laminae of wave- and storm origin.).

Final Stop (560 km); University of Calgary.

References

Ahr, W.M., 1973. The carbonate ramp: an alternative to the shelf model. Transactions Gulf Coast Association of Geological Societies, 23rd Annual Meeting, Houston, p. 221-225.

Ball, M.M. 1967. Carbonate sand bodies of Florida and the Bahamas. Journal of Sedimentary Petrology, v. 37, p. 556-591.

Bamber, E.W. and Mamet, B.L., 1978. Carboniferous biostratigraphy and correlation, northeastern British Columbia and southwestern District of Mackenzie. Geological Survey of Canada, Bulletin 266, 65 p.

Bamber, E.W. and Waterhouse, J.B., 1971. Carboniferous and Permian stratigraphy and paleontology, northern Yukon, Canada. Bulletin of Canadian Petroleum Geology, v. 19, p. 29-250.

Barclay, J.E., Krause, F.F., Campbell, R.I. and Utting, J., 1990. Dynamic casting and growth faulting: Dawson Creek Graben Complex, Carboniferous-Permian Peace River Embayment, western Canada. Bulletin of Canadian Petroleum Geology, v. 38A, p. 155-145.

Baxter, S. and von Bitter, P.H., 1984. Conodont succession in the Mississippian of southern Canada. In: Part 2: biostratigraphy. P.K. Sutherland and W.L. Manger (eds.). Neuvième Congrès International de Stratigraphie et de Géologie du Carbonifère, Compte Rendu, v. 2, p. 253-264.

Beales, F.W., 1950. The late Paleozoic formations of southwestern Alberta (preliminary account). Geological Survey of Canada, Paper 50-27, 72 p.

Beaumont, C., 1981. Foreland basins. Geophysical Journal of the Royal Astronomical Society, v. 65, p. 291-329.

Bond, G.C. and Kominz, M.A., 1991. Disentangling middle Paleozoic sea level and tectonic events in cratonic margins and cratonic basins of North America. Journal of Geophysical Research - Solid Earth and Planets. v. 96 section B4, p. 6619-6639.

Caplan, M.L. and Bustin, R.M. 1998. Sedimentology and sequence stratigraphy of Devonian-Carboniferous strata, southern Alberta. Bulletin of Canadian Petroleum Geology, v. 46, p. 487-512.

Chatellier, J-Y., 1988. Carboniferous carbonate ramp, the Banff Formation, Alberta Canada. Bulletin des Centres de Recherches Exploration-Production Elf-Aquitaine, v. 12, p. 569-599.

Christopher, J.E., 1961. Transitional Devonian-Mississippian formations of southern Saskatchewan. Saskatchewan Mineral Resources, Report 66, 103 p.

Dixon, J., Dietrich, J.R. and McNeil, D.H., 1992. Upper Cretaceous to Holocene sequence stratigraphy of the Beaufort-Mackenzie and Banks Island areas, northwest Canada. Geological Survey of Canada, Bulletin 407, 90 p.

Douglas, R.J.W., 1953. Carboniferous stratigraphy in the southern foothills of Alberta. Alberta Society of Petroleum Geologists, 3rd Annual Field Conference Guidebook, p. 66-88.

Douglas, R.J.W., 1958. Mount Head map-area, Alberta. Geological Survey of Canada, Memoir 291, 241 p.

Douglas, R.J.W., Gabrielse, H., Wheeler, J.O., Stott, D.F. and Belyea, H.R., 1970. Geology of western Canada. In: Geology and Economic Minerals of Canada. R.J.W. Douglas (ed.). Geological Survey of Canada, Economic Geology Report no. 1, p. 366-488.

Embry, A.F., 1993. Transgressive-regressive (T-R) sequence analysis of the Jurassic succession of the Sverdrup Basin, Canadian Arctic Archipelago. Canadian Journal of Earth Sciences, v. 30, p. 301-320.

Embry, A.F. and Johannessen E.P., 1992. T-R sequence stratigraphy, facies analysis and reservoir distribution in the uppermost Triassic-Lower Jurassic succession, western Sverdrup Basin, Arctic Canada. In: Arctic Geology and Petroleum. T.O. Vorren, E. Bergsager, O.A. Dahl-Stamnes, E. Holter, B. Johansen, E. Lie and T.B. Lund (eds.). Norwegian Petroleum Society (NPF), Special Publication no. 2, p. 121-146.

Evenchick, C.A., Parrish, R.R. and Gabrielse, H., 1984. Precambrian gneiss and late Proterozoic sedimentation in north-central British Columbia. Geology, v. 12, p. 233-237.

Flemings, P.B. and Jordan, T.E., 1989. A synthetic stratigraphic model of foreland basin development. Journal of Geophysical Research, v. 94, p. 3851-3866.

Flajs, G. and Feist, R., 1988. Index conodonts, trilobites and environment of the Devonian-Carboniferous boundary beds at La Serre (Montagne Noir, France). Courier Forschungsinstitut Senckenberg, v. 100, p. 53-107.

Ford, C.M., 2009. Geologic Record of Arid Cyclothems in the Upper Pennsylvanian and Lower Permian Tobermory and Kananaskis formations of Fortress Mountain Ridge Section, Kananaskis Country, southern Alberta, Canada. Unpublished B.Sc. thesis at the University of Calgary (supervised by C.M. Henderson), 93 pp.

Galloway, W.E., 1989. Genetic stratigraphic sequences in basin analysis II: application to northwest Gulf of Mexico Cenozoic basin. American Association of Petroleum Geologists Bulletin, v. 73, no. 2, p. 143-154.

Geldsetzer, H.H.J., 1987. Upper Devonian reef and basinal sedimentation, western Alberta. Second International Symposium on the Devonian System. Excursion B4, Guidebook, Canadian Society of Petroleum Geologists, Calgary, 50 p.

Geldsetzer, H.H.J. and Mallamo, M.P., 1991. The Devonian of the southern Rocky Mountains: The Canmore area. In, Smith, P.L. (ed.), A Field Guide to the Paleontology of Southwestern Canada, Guidebook, The First Canadian Paleontology Conference, Vancouver, pp. 83-102.

Goebel, K.A., 1991. Paleogeographic setting of Late Devonian to Early Mississippian transition from passive to collisional margin, Antler Foreland, eastern Nevada and western Utah. In: Paleozoic Paleogeography of the Western United States - II. J.D. Cooper and C.H. Stevens (eds.). Pacific Section Society Economic Paleontologists and Mineralogists, v. 1, p. 401-418.

Gordey, S.P., 1988. Devono-Mississippian clastic sedimentation and tectonism in the Canadian Cordilleran Miogeocline. In: Devonian of the World. N.J. McMillan, A.F. Embry and D.J. Glass (eds.). Canadian Society of Petroleum Geologists. Memoir 14, v. 2, p. 1-14.

Gordey, S.P., Abott, J.G., Tempelman-Kluit, D. J. and Gabrielse, H., 1987. "Antler" clastics in the Canadian Cordillera. Geology, v. 15, p. 103-107.

Henderson, C.M., 1997. Uppermost Permian conodonts and the Permian-Triassic boundary in the Western Canada Sedimentary Basin. Bulletin of Canadian Petroleum Geology, v. 45, p., 693-707.

Henderson, C.M, McGugan, A., 1986. Permian conodont biostratigraphy of the Ishbel Group, southwestern Alberta and southeastern British Columbia. Contributions to Geology, University of Wyoming 24, 219-235.

Higgins, A.C., Richards, B.C. and Henderson, C.M., 1991. Conodont biostratigraphy and paleoecology of the uppermost Devonian and Carboniferous of the Western Canada Sedimentary Basin. In: Ordovician to Triassic Conodont Paleontology of the Canadian Cordillera. M.J. Orchard and A.D. McCracken (eds.). Geological Survey of Canada, Bulletin 417, p. 215-251.

Johnson, J.G., Klapper, G. and Sandberg, C.A., 1985. Devonian eustatic fluctuations in Euramerica. Geological Society of America Bulletin, v. 96, p. 567-587.

Johnston, D.I. and Chatterton, D.E., 1991. Famennian conodont biostratigraphy of the Palliser Formation, Rocky Mountains, Alberta and British Columbia, Canada. In: Ordovician to Triassic Conodont Paleontology of the Canadian Cordillera. M.J. Orchard and A.D. McCracken (eds.). Geological Survey of Canada Bulletin 417, p. 163-183.

Johnston, D.I. and Chatterton, B.D.E. 2001. Upper Devonian (Famennian) conodonts of the Palliser Formation and Wabamun Group, Alberta and British Columbia, Canada. Palaeontographica Canadiana, No. 19, 154 pp.

Jordan, T.E. and Flemings, P.B., 1991. Large-scale stratigraphic architecture, eustatic variation, and unsteady tectonism: a theoretical evaluation. Journal of Geophysical Research, v. 96, p. 6681-6699.

Kindle, E.M. 1924. Standard Paleozoic section of the Rocky Mountains near Banff, Alberta. Pan-American Geologist, v. 42, p. 113-124.

Klapper, G., 1997. Graphic correlation of Frasnian (Upper Devonian) sequences in Montagne Noire, France, and western Canada. In, Klapper, G., Murphy, M.A. and Talent, J.A. (eds.), Paleozoic Sequence Stratigraphy, Biostratigraphy, and Biogeography: Studies in Honor of J. Granville ("Jess") Johnson. Geological Society of America Special Paper 321, pp. 113-129.

Lane, H.R., Sandberg, C.A. and Ziegler, W., 1980. Taxonomy and phylogeny of some Lower Carboniferous conodonts and preliminary standard post- Siphonodella zonation. Geologica et Palaeontologica, v. 14, p. 117-164.

Logan, A., and McGugan, A., 1968. Biostratigraphy and faunas of the Permian Ishbel Group, Canadian Rocky Mountains. Journal of Paleontology, v. 37, p. 1123-1139.

Macauley, G., Penner, D.G., Procter, R.M. and Tisdall, W.H., 1964. Chapter 7, Carboniferous. In: Geological History of Western Canada. R.G. McCrossan and R.P. Glaister (eds.). Alberta Society of Petroleum Geologists, p. 89-102.

Macqueen, R.W. and Bamber, E.W., 1967. Stratigraphy of Banff Formation and lower Rundle Group (Mississippian), southwestern Alberta. Geological Survey of Canada, Paper 67-47, 37 p.

Macqueen, R.W.and Sandberg, C.A. 1970. Stratigraphy, age, and inter-regional correlations of the Exshaw Formation, Alberta Rocky Mountains. Bulletin of Canadian Petroleum Geology, v. 18, p. 32-66.

Macdonald, D.E., 1987. Geology and resource potential of phosphates in Alberta. Alberta Geological Survey, Alberta Research Council, Earth Science Report87-1, 65 p.

MacRae, J. and McGugan, A., 1977. Permian stratigraphy and sedimentology, southwestern Alberta and southeastern British Columbia. Bulletin of Canadian Petroleum Geology, v. 25, p. 752-766.

Mallamo, M.P. and Geldsetzer, H.H.J., 1991.The western margin of the Upper Devonian Fairholme Reef Complex, Banff-Kananaskis area, southwestern Alberta. In, Current Research, Part B, Geological Survey of Canada, Paper 91-1B, pp. 59-69.

Mamet, B.L., 1967. The Devonian-Carboniferous boundary in Eurasia. In: International Symposium on the Devonian System, Calgary, 1967. D.H. Oswald (ed.). Alberta Society of Petroleum Geologists, v. 2, p. 995-1007.

Mamet, B.L., 1976. An atlas of microfacies in Carboniferous carbonates of the Canadian Cordillera. Geological Survey of Canada, Bulletin 255, 131 p.

Mamet, B.L., 1984. Carboniferous small foraminifers and stratigraphy. In: Biostratigraphy. P.K. Sutherland and W. L. Manger (eds.). Neuvième Congrès International de Stratigraphie et de Géologie du Carbonifère, 1979. Compte Rendu, no. 2, p. 3-18.

Mamet, B.L. and Bamber, E.W., 1979. Stratigraphic correlation chart of the lower part of the Carboniferous, Canadian Cordillera and Arctic Archipelago. In: Paleontological Characteristics of the Main Subdivisions of the Carboniferous. S.V. Meyen, V.V. Menner, E.A. Reitlinger, A.P. Rotai and M.N. Solovieva (eds.). Huitième Congrès International de Stratigraphie et de Géologie Carbonifère, 1975, Compte Rendu, v. 3, p. 37-49.

Mamet, B.L., Bamber, E.W. and Macqueen, R.W., 1986. Microfacies of the Lower Carboniferous Banff Formation and Rundle Group, Monkman Pass map-area, northeastern British Columbia. Geological Survey of Canada, Bulletin 353, 93 p.

Mamet, B.L. and Mason, D., 1968. Foraminiferal zonation of the Lower Carboniferous Connor Lake section, British Columbia. Bulletin of Canadian Petroleum Geology, v. 16, p. 147-166.

Mamet, B.L. and Skipp, B., 1970. Lower Carboniferous calcareous foraminifera: preliminary zonation and stratigraphic implications for the Mississippian of North America. In: Sixième Congrès International, de Stratigraphie et de Géologie du Carbonifère, Sheffield 1967. Compte Rendu, 3, p. 1129-1146.

McGugan, A. and Rapson, J.E., 1963. Permian stratigraphy and nomenclature, western Alberta and

adjacent regions. Edmonton Geological Society Guidebook, 5th Annual Field Conference, p. 52-64.
McGugan, A., Rapson-McGugan, J.F., Mamet, B.L. and Ross, C.A., 1968. Permian and Pennsylvanian biostratigraphy, and Permian depositional environments, petrography and diagenesis, southern Canadian Rocky Mountains. In: Canadian Rockies, Bow River to North Saskatchewan River, Alberta. H. Hornford (ed.). Canadian Society of Petroleum Geologists 16th Annual Field Conference, Guidebook, p. 48-66.
McIlreath, I.A. and James, N.P., 1978. Facies models 13: Carbonate slopes. Geoscience Canada, v. 5, p. 189-199.
McLean, R.A. and Klapper, G., 1998. Biostratigraphy of Frasnian (Upper Devonian) strata in western Canada. Bulletin of Canadian Petroleum Geology, volume 46, pp. 515-563.
Meijer Drees, N.C. and Johnston, D.I., 1994. Type section and conodont biostratigraphy of the Upper Devonian Palliser Formation, southwestern Alberta. Bulletin of Canadian Petroleum Geology, v. 42, p. 56-62.
Meijer Drees, N.C. and Johnston, D.I., 1994. Type section and conodont biostratigraphy of the Upper Devonian Palliser Formation, southwestern Alberta. Bulletin of Canadian Petroleum Geology, volume 42, pp. 55-62.
Meijer Drees, N.C., Johnston, D.I. and Richards, B.C., 1993. The Devonian Palliser Formation and its equivalents, southern Alberta, Canada. Geological Survey of Canada, Open File 2698, p.69
Moore, P.F., 1988. Devonian geohistory of the western interior of Canada. In: Devonian of the World. N.J McMillan, A.F. Embry and D.J. Glass (eds.). Canadian Society of Petroleum Geologists, Memoir 14, v. 1, p. 67-83.
Morrow, D.W. and Geldsetzer, H.H.J., 1988. Devonian of the eastern Canadian Cordillera. In: Devonian of the World. N.J. McMillan, A.F. Embry and D.J. Glass (eds.). Canadian Society of Petroleum Geologists, Memoir 14, v. 1, p. 85-121.
Mortensen, J.K. and Jilson, G.A., 1985. Evolution of the Yukon-Tanana terrane: evidence from southeastern Yukon Territory. Geology, v. 13, p. 806-810.
Mortensen, J.K., Montgomery, J.R. and Fillipone, J., 1987. U-Pb zircon, monazite, and sphene ages for granitic orthogneiss of the Barkerville terrane, east-central British Columbia. Canadian Journal of Earth Sciences, v. 24, p. 1261-1266.
Nemyrovska, T.I., 1999. Bashkirian conodonts of the Donets Basin, Ukraine: Scripta Geologica, 119, 93 pp.
Norris, D.K., 1965. Stratigraphy of the Rocky Mountain Group in the southeastern Cordillera of Canada. Geological Survey of Canada, Bulletin 125, 82 p.
Okulitch, A.V., 1985. Paleozoic plutonism in southeastern British Columbia. Canadian Journal of Earth Sciences, v. 22, p. 1409-1424.
Pamenter, C.B., 1956. Imitoceras from the Exshaw Formation of Alberta. Journal of Paleontology, v. 30, p. 965-966.
Paproth, E. and Streel, M., 1984. Precision and practicability: On the definition of the Devonian-Carboniferous boundary. Courier Forschungsinstitut Senckenberg, v. 67, p. 255-258.
Paproth, E., Feist, R., and Flajs, G., 1991. Decision on the Devonian-Carboniferous boundary stratotype. Episodes, v. 14, p. 331-336.
Parrish, J.T., 1982. Upwelling and petroleum source beds with reference to Paleozoic. American Association of Petroleum Geologists Bulletin, v. 66, p. 750-774.
Parrish, R.R., 1992. Miscellaneous U-Pb zircon dates from southeast British Columbia. In: Radiogenic Age and Isotopic Studies: Report 5. Geological Survey of Canada Paper 91-2, p. 143-153.
Peterhänsel, A. and Pratt, B.R., 2008. The Famennian (Upper Devonian) Palliser platform of western Canada - architecture and depositional dynamics of a post-extinction epeiric giant. In: Dynamics of Epeiric Seas. B.R. Pratt and C. Holmden (eds.). Geological Association of Canada Special Paper 48, p. 247-281.
Poole, F.G. and Sandberg, C.A., 1991. Mississippian paleogeography and conodont biostratigraphy of the western United States. In: Paleozoic Paleogeography of the Western United States - II. J.D. Cooper and C.H. Stevens (eds.). Pacific Section, Society of Economic Paleontologists and Mineralogists, v. 1, p. 107-136.
Porter, J.W., Price, R.A. and McCrossan, R.B., 1982. The Western Canada Sedimentary Basin. Philosophical Transactions of the Royal Society of London, v. A 305, p. 169-192.
Posamentier, H.W., Jervey, M.T. and Vail, P.R., 1988. Eustatic controls on clastic deposition I - conceptual framework. In: Sea-level Changes: an Integrated Approach. C.K. Wilgus, B.S. Hastings, H. Posamentier, J.C. Van Wagoner, C.A. Ross and C.G.St.C. Kendall (eds.). Society of Economic Paleontologists and Mineralogists, Special Publication no. 42, p. 109-124.
Posamentier, H.W. and Vail, P. R., 1988. Eustatic controls on clastic deposition II -sequence and systems tract models. In: Sea-level Changes: an Integrated Approach. C.K. Wilgus, B.S. Hastings, H. Posamentier, J. Van Wagoner, C.A. Ross and C.G.St.C. Kendall (eds.). Society of Economic Paleontologists and Mineralogists, Special Publication no. 42. p. 125-154.
Potma, K., Weissenberger, J.A.W., Wong, P.K. and Gilhooly, M.G., 2001. Toward a sequence stratigraphic framework for the Frasnian of the Western Canada Basin. Bulletin of Canadian Petroleum Geology, volume 49, pp. 37-85.
Price, R.A., 1970. Geology - Canmore (east half), Alberta. Geological Survey of Canada, Map 1265A.
Price, R.A., 1970. Geology - Canmore (west half), Alberta. Geological Survey of Canada, Map 1266A.
Price, R.A., Balkwill, H.R., Charlesworth, H.A.K., Cook, D.G., and Simony, P.S., 1972. The Canadian Rockies and tectonic evolution of the southeastern Cordillera, Excursion AC15, International Geological Congress 24th session, Montreal Canada, 129 pp.
Price, R.A. and Mountjoy, E.W., 1972. Geology - Banff (east half), Alberta - British Columbia. Geological Survey of Canada, Map 1294A.
Quinlan, G. M. and Beaumont, C., 1984. Appalachian thrusting, lithospheric flexure, and the Paleozoic stratigraphy of the eastern interior of North America.

Canadian Journal of Earth Sciences, v. 21, p. 973-996.
Raasch, G. O., 1956. The Permian Rocky Mountain Group in Alberta. Alberta Society of Petroleum Geologists, Sixth Annual Field Conference and Guide Book, p. 114-119.
Raasch, G. O., 1958. Upper Paleozoic section at Highwood Pass, Alberta. In: Jurassic and Carboniferous of Western Canada. A.J. Goodman (ed.). American Association of Petroleum Geologists, John Andrew Allan Memorial Volume, p. 190-215.
Read, J.F., 1982. Carbonate platforms of passive (extensional) continental margins: types, characteristics and evolution. Tectonophysics, v. 81, p. 195-212.
Richards, B.C., 1989. Upper Kaskaskia Sequence: uppermost Devonian and Lower Carboniferous, Chapter 9. In: Western Canada Sedimentary Basin, a Case History. B.D. Ricketts (ed.). Canadian Society of Petroleum Geologists, p. 165-201.
Richards, B.C., Barclay, J.E., Bryan, D., Hartling, A., Henderson, C.M. and Hinds, R.C., 1994a. Chapter 14 - Carboniferous strata of the Western Canada Sedimentary Basin. In: Geological Atlas of the Western Canada Sedimentary Basin. G.D. Mossop and I. Shetson (eds.). Canadian Society of Petroleum Geologists and Alberta Research Council, p. 221-250.
Richards, B.C., Bamber, E.W., Henderson, C.M., Higgins, A.C., Johnston, D.I., Mamet, B.L. and Meijer Drees, N.C., 1994b. Uppermost Devonian (Famennian) and Lower Carboniferous (Tournaisian) at Jura Creek and Mount Rundle, southwestern Alberta. Geological Survey of Canada, Open File 2866, p. 1-79, 81.
Richards, B.C., Bamber, E.W., Higgins, A.C. and Utting, J., 1993. Carboniferous, Subchapter 4E. In: Sedimentary Cover of the Craton in Canada. D.F. Stott and J.D. Aitken (eds.). Geological Survey of Canada, Geology of Canada no. 5, p. 202-271 (also Geological Society of America, The Geology of North America, v. D-1).
Richards, B.C., Henderson, C.M., Higgins, A.C., Johnston, D.I., Mamet, B.L. and Meijer Drees, N.C., 1991. The Upper Devonian (Famennian) and Lower Carboniferous (Tournaisian) at Jura Creek, southwestern Alberta. In: A Field Guide to the Paleontology of Southwestern Canada. P.L. Smith (ed.). Paleontology Division of the Geological Association of Canada, p. 35-81.
Richards, B.C. and Higgins, A.C., 1988. Devonian-Carboniferous boundary beds of the Palliser and Exshaw formations at Jura Creek, Rocky Mountains, southwestern Alberta. In: Devonian of the World. N.J. McMillan, A.F. Embry and D.J. Glass (eds.). Canadian Society of Petroleum Geologists, Memoir 14, v. 2, p. 399-412.
Richards, B.C., Lane, H.R. and Brenckle, P.L., 2002a. The IUGS Mid-Carboniferous (Mississippian-Pennsylvanian) Global Boundary Stratotype Section and Point at Arrow Canyon, Nevada, USA. In: Carboniferous and Permian of the World. L.V. Hills, C.M. Henderson and E.W. Bamber (eds.).Canadian Society of Petroleum Geologists, Memoir 19, p. 802-831.
Richards, B.C., Ross, G.M. and Utting, J., 2002b.U - Pb geochronology, lithostratigraphy and biostratigraphy of tuff in the upper Famennian to Tournaisian Exshaw Formation: evidence for a mid-Paleozoic magmatic arc on the northwestern margin of North America. In: Carboniferous and Permian of the World. L.V. Hills, C.M. Henderson and E.W. Bamber (eds.). Canadian Society of Petroleum Geologists, Memoir 19, p. 158-207.
Richards, B.C., Bamber, E.W., Henderson, C.M., Higgins, A.C., Johnston, D.I., Mamet, B.L. and Meijer Drees, N.C., 1994. Uppermost Devonian (Famennian) and Lower Carboniferous (Tournaisian) at Jura Creek and Mount Rundle, southwestern Alberta. Geological Survey of Canada, Open File 2866, 81 pp.
Ricketts, B.D., 1989. Introduction, chapter 1. In: Western Canada Sedimentary Basin, a case History. B.D. Ricketts (ed.). Canadian Society of Petroleum Geologists, p. 3-8.
Root, K.G., 2001. Devonian Antler fold and thrust belt and foreland basin development in the southern Canadian Cordillera: implications for the Western Canada Sedimentary Basin. Canadian Society of Petroleum Geologists, v. 49, p. 7-36.
Ross, C.A. and Bamber, E.W., 1978. Middle Carboniferous and Early Permian fusulinaceans from the Monkman Pass area, northeastern British Columbia. In: Contributions to Canadian Paleontology. Geological Survey of Canada, Bulletin, 267, p. 25-41.
Rubin, C.M., Miller, M.M. and Smith, G.M., 1990. Tectonic development of Cordilleran mid-Paleozoic volcano-plutonic complexes; evidence for convergent margin tectonism. In: Paleozoic and Early Mesozoic Paleogeographic Relations; Sierra Nevada, Klamath Mountains, and Related Terranes. D.S. Harwood and M.M. Miller (eds.). Geological Society of America, Special Paper 255, p. 1-16.
Sandberg, C.A, Ziegler, W., Leuteritz, K. and Brill, S.M., 1978. Phylogeny, speciation, and zonation of Siphonodella (Conodonta, Upper Devonian and Lower Carboniferous). Newsletters in Stratigraphy, v. 7, p. 102-120.
Sando, W.J. and Bamber, E.W., 1985. Coral zonation of the Mississippian System in the western interior province of North America. United States Geological Survey, Professional Paper 1334, 61 p.
Savoy, L.E., 1992. Environmental record of Devonian-Mississippian carbonate and low-oxygen facies transitions, southernmost Canadian Rocky Mountains and northwest Montana. Geological Society of America Bulletin, v. 104, p. 1412-1432.
Savoy, L.E. and Harris, A.G., 1993. Conodont biofacies in a ramp to basin setting (latest Devonian and earliest Carboniferous) in the Rocky Mountains of southernmost Canada and northern Montana. United States Geological Survey, Open File Report 93-184.
Savoy, L.E., Harris, A.G. and Mountjoy, E.W. 1999. Extension of lithofacies and conodont Biofacies models of Late Devonian to Early Carboniferous carbonate ramp and black shale systems, southern Canadian Rocky Mountains. Canadian Journal of Earth Sciences, v. 36, p. 1281-1298.
Schindewolf, O.H., 1959. Adolescent cephalopods from the Exshaw Formation of Alberta. Journal of Paleontology, v. 33, p. 971-976.

Scott. D.L., 1964a. Stratigraphy of the lower Rocky Mountain Supergroup in the southern Canadian Rocky Mountains. PhD thesis, University of British Columbia, Vancouver, B.C., 133 p.

Scott. D.L., 1964b. Pennsylvanian stratigraphy. Bulletin of Canadian Petroleum Geology, v. 12, Flathead Valley Guidebook Issue, p. 460-493.

Selby, D. and Creaser, R.A., 2005. Direct radiometric dating of the Devonian-Mississippian time-scale boundary using Re-Os black shale geochronometer. Geology, v. 33 (7), p. 545-548.

Sloss, L.L., 1963. Sequences in the cratonic interior of North America. Geological Society of America, Bulletin, v. 74, p. 93-114.

Sloss, L.L., 1964. Tectonic cycles of the North American craton. In: Symposium on Cyclic Sedimentation. D.F. Merriam (ed.). State Geological Survey of Kansas, Bulletin, 169, v. II, p. 449-460.

Smith, M.T., and Gehrels, G.E. 1992. Structural geology of the Lardeau Group near Trout Lake, British Columbia: implications for the structural evolution of the Kootenay Arc. Canadian Journal of Earth Sciences, v. 29, p. 1305-1319.

Smith, M.T., Dickinson, W.R. and Gehrels, G.E., 1993. Contractional nature of Devonian-Mississippian Antler tectonism along the North American continental margin. Geology, v. 21, p. 21-24.

Stewart, W.D. and Walker, R.G., 1980. Eolian coastal dune deposits and surrounding marine sandstones, Rocky Mountain Supergroup (Lower Pennsylvanian), southeastern British Columbia. Canadian Journal of Earth Sciences, v. 17, p. 1125-1140.

Stockmal, G.S., Beaumont, C. and Boutilier, R., 1986. Geodynamic models of convergent margin tectonics: transition from rifted margin to overthrust belt and consequences for foreland-basin development. American Association of Petroleum Geologists Bulletin, v. 70, p. 181-190.

Struik, L.C., 1987. The ancient western North American margin: an alpine rift model for the east-central Canadian Cordillera. Geological Survey of Canada, Paper 87-15, 19 p.

Switzer, S.B., Holland, W.G., Christie, D.S., Graf, G.C., Hedinger, A.S., McAuley, R.J., Weirzbicki, R.A. and Packard, J.J., 1994. Devonian Woodbend - Winterburn strata of the Western Canada Sedimentary Basin. In, Mossop, G.D. and Shetsen, I. (eds.), Geological Atlas of the Western Canada Sedimentary Basin, Canadian Society of Petroleum Geologists and Alberta Research Council, Calgary, pp. 165-201.

Tempelman-Kluit, D.J., 1979. Transported cataclasite, ophiolite and granodiorite in Yukon: evidence of arc-continent collision. Geological Survey of Canada, Paper 79-14, 27 p.

Trapp, E., Kaufmann, B., Mezger, K., Korn, M., and Weyer, D., 2004. Numerical calibration of the Devonian-Mississippian boundary: Two new U-Pb isotope dilution-thermal ionization mass spectrometry single-zircon ages from Hasselbachtal (Sauerland, Germany). Geology, v. 32, p. 857-860.

Uyeno, T.T., 1991. Pre-Fammenian Devonian conodont biostratigraphy of selected intervals in the eastern Canadian Cordillera. In, Orchard, M.J. and McCracken, A.D. (eds.), Ordovician to Triassic Conodont Paleontology of the Canadian Cordillera. Geological Survey of Canada, Bulletin 417, pp. 129-161.

Vail, P.R., Mitchum R.M.Jr. and Thompson, S.III., 1977. Seismic stratigraphy and global changes of sea level, part 4: global cycles of relative changes of sea level. In: Seismic Stratigraphy - Applications to Hydrocarbon Exploration. C.E. Payton (ed.). American Association of Petroleum Geologists, Memoir 26, p. 83-97.

Van Wagoner, J.C., Posamentier, H.W., Mitchum, R.M., Vail, P.R., Sarg, J.F., Loutit, T.S. and Hardenbol, J., 1988. An overview of the fundamentals of sequence stratigraphy and key definitions. In: Sea-level Changes: an Integrated Approach. C.K. Wilgus, B.S. Hastings, H.W. Posamentier, J.C. Van Wagoner, C.A. Ross, and C.G.St.C. Kendall (eds.). Society of Economic Paleontologists and Mineralogists, Special Publication no. 42, p. 39-45.

Warren, P.S., 1927. Banff area, Alberta. Geological Survey of Canada, Memoir 153, 94 p.

Wheeler, J.O., Brookfield, A.J., Gabrielse, H., Monger, J.W.H., Tipper, H.W., and Woodsworth, G.J., 1988. Terrane map of the Canadian Cordillera. Geological Survey of Canada, Open File 1894, Scale 1:2,000,000.

White, W.H., 1959. Cordilleran tectonics in British Columbia. American Association of Petroleum Geologists Bulletin, v. 43, p. 60-100.

Wilson, J.L., 1975. Carbonate facies in geologic history. Springer-Verlag, New York, 471 p.

Ziegler, W., 1962. Taxonomie und Phylogenie Oberdevonischer Conodonten und ihr stratigraphische Bedeutung. Hessisches Landesamt Bodenforschung Abhandlungen, v. 38, 166 p.

Ziegler, W., 1971. Conodont stratigraphy of the European Devonian. In: Symposium on Conodont Biostratigraphy. W.C. Sweet and S.M. Bergstrom (eds.). Geological Society of America, Memoir 127, p. 227-284.

Ziegler, W. and Sandberg, C.A., 1984. Palmatolepis-based revision of upper part of standard Late Devonian conodont zonation. In: Conodont Biofacies and Provincialism. D.L. Clark (ed.). Geological Society of America, Special Paper 196, p. 179-194.

Ziegler, W. and Sandberg, C.A., 1990. The Late Devonian standard conodont zonation. Courier Forschungsinstitut Senckenberg, v. 121, 115 p.