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INTRODUCTION

In the front ranges of the southern Rocky Mountains near the communities of Exshaw and Canmore, parautocthonous Famennian and Tournaisian strata are well displayed in the multiple southwestward-dipping thrust sheets dissected by the Bow River and its tributaries (Fig. 1). The principal objective of this field excursion is to provide an overview of the lithostratigraphy and biostratigraphy of this succession by

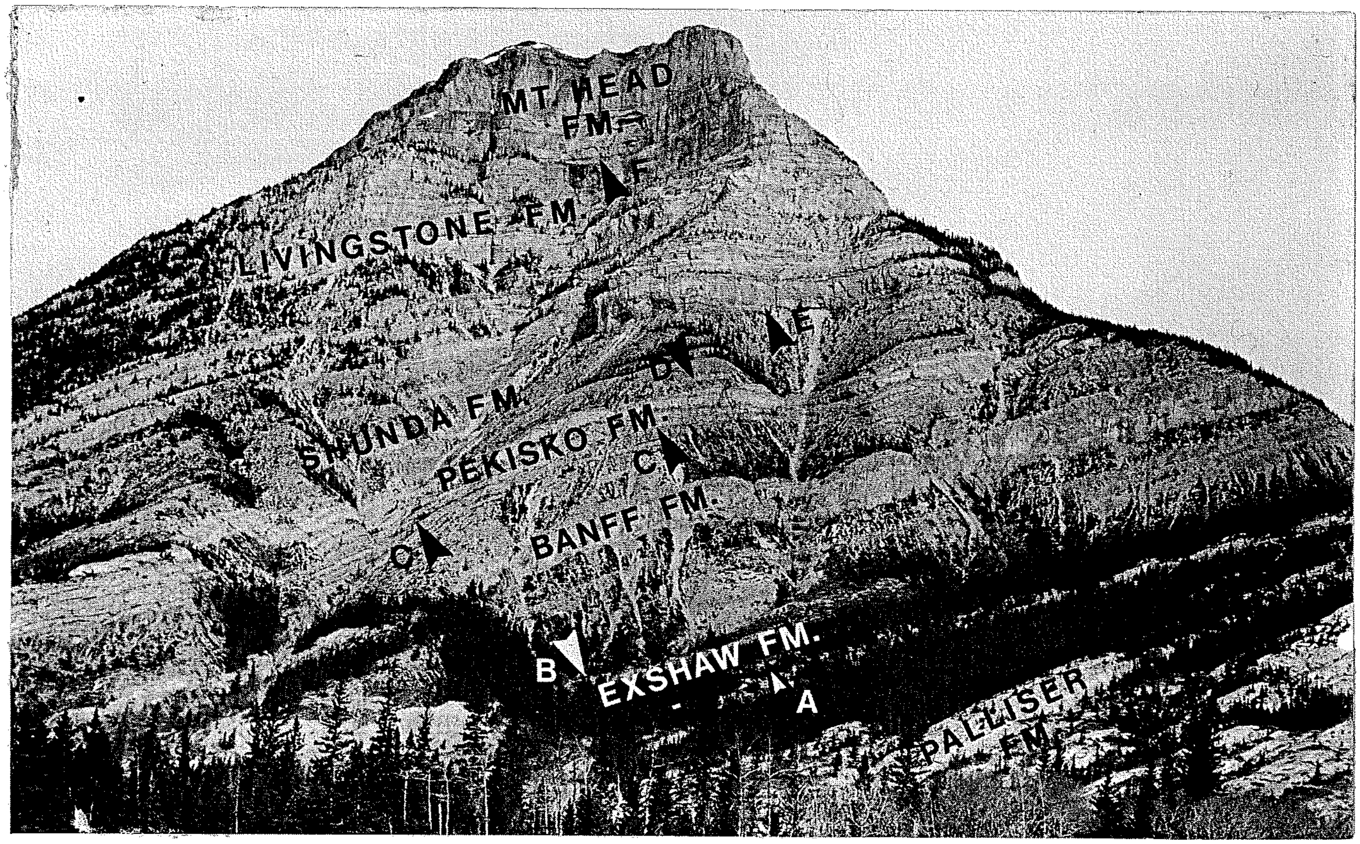


Figure 1. Upper Devonian and Lower Carboniferous succession at Grotto Mountain, Fairholme Range, eastern Rocky Mountains near town of Exshaw, Alberta. A- top of Famennian Palliser Formation and base of Famennian and Tournaisian Exshaw Formation; B- base of lower Tournaisian Banff Formation; C- approximate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

examining exposures along Jura Creek near Exshaw (Fig. 2) and subsequently along the southwestern side of Mount Rundle west of Canmore (Fig. 3). 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. 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. Enroute from Exshaw to Canmore, Tournaisian carbonates will be examined on Highway 1A at the southeastern end of Grotto Mountain (Fig. 1).

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 basal Exshaw Formation (Fig. 4) and were deposited on the western Alberta Shelf (Morrow and Geldsetzer, 1988). Deposition of the Tournaisian strata, preserved in the middle to upper Exshaw and overlying Banff Formation and lower Rundle Group (Fig. 5), took place in eastern Prophet Trough (Richards, 1989). The Famennian and Tournaisian 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 fold and thrust belt of the eastern Cordillera (Fig. 6; Porter et al., 1982; Ricketts, 1989).

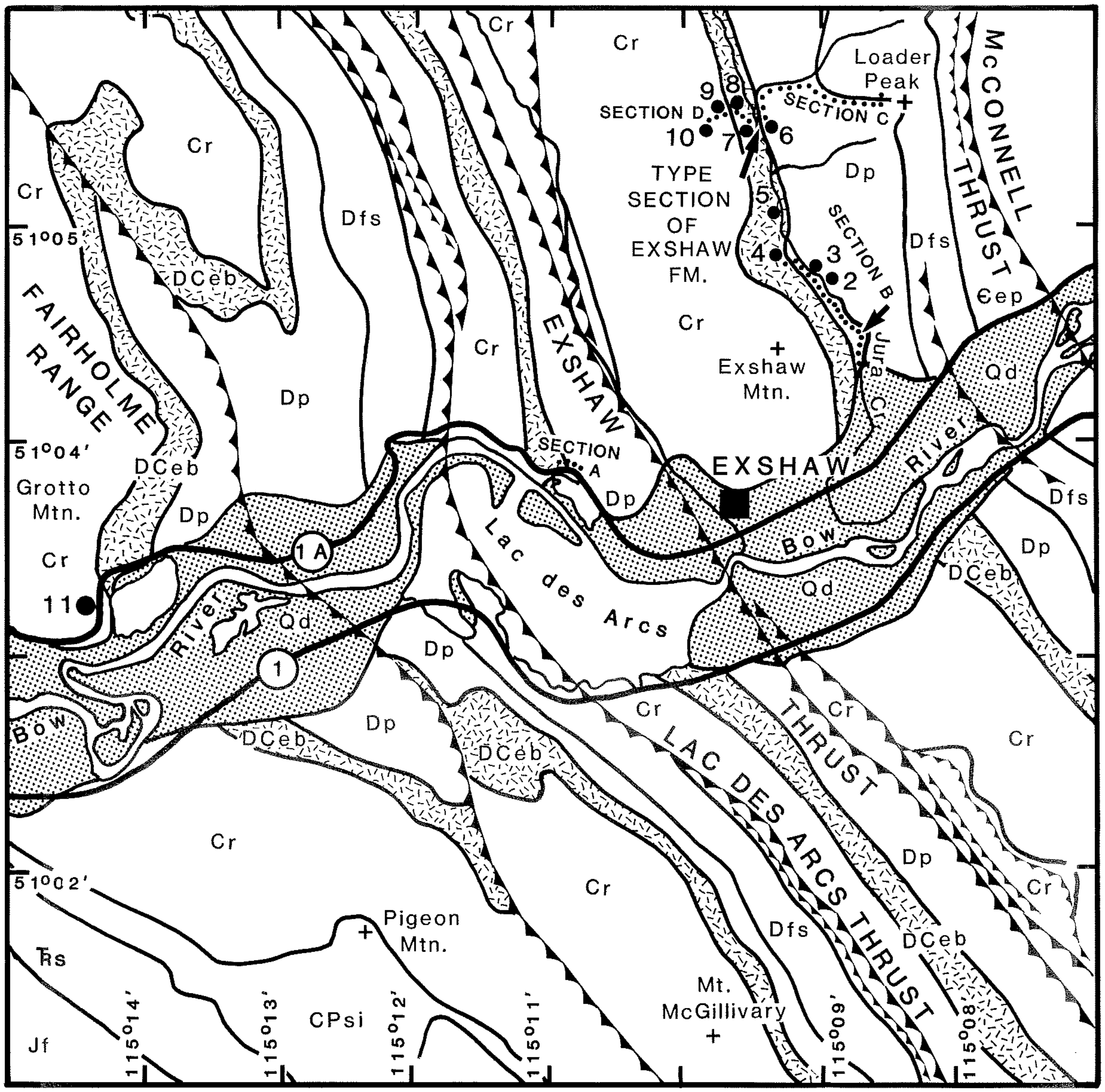
GEOLOGICAL SETTING

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 field trips. 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 on the creek and has provided conodonts and lithostratigraphic data suggesting that deposition was continuous across the systemic boundary.

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 to 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 only recently as a consequence of an integrated approach combining lithostratigraphy, sedimentology and biostratigraphy in the region (Richards and Higgins, 1988; Richards, 1989; Johnston and Chatterton, 1991; Richards et al., 1991; Higgins et al., 1991; Savoy and Harris, 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, Fig. 21) was about 49 kilometres. Because of the substantial lateral displacement, the Lower Carboniferous succession of the McConnell Thrust Sheet differs appreciably from that of the foothills and adjacent Plains.

The Famennian and Tournaisian deposits on the southwestern side of Mount Rundle at stops 12 and 13 (Fig. 3) 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



LEGEND

QUATERNARY

Qd Gravel, silt, and sand

JURASSIC

Jf Fernie Gp.

TRIASSIC

Ћs Spray River Gp.

CARBONIFEROUS AND PERMIAN

CPsi Spray Lakes and Ishbel Gps.

CARBONIFEROUS

Cr Rundle Gp.

DEVONIAN AND CARBONIFEROUS

DCeb Exshaw and Banff Fms.

DEVONIAN

Dp Palliser Fm.

Dfs Fairholme Gp. and Alexo Fm.

CAMBRIAN

Єep Eldon and Pika Fms.

Thrust fault

Line of section

● 2 to ● 11 Field trip stops

Scale

0 metres 2000

Figure 2. Generalized geological map of the Jura Creek region, eastern Rocky Mountain Front Ranges, southwestern Alberta. Map shows section locations discussed in text and locations of stops 1 to 11. Geology modified from Price (1970).

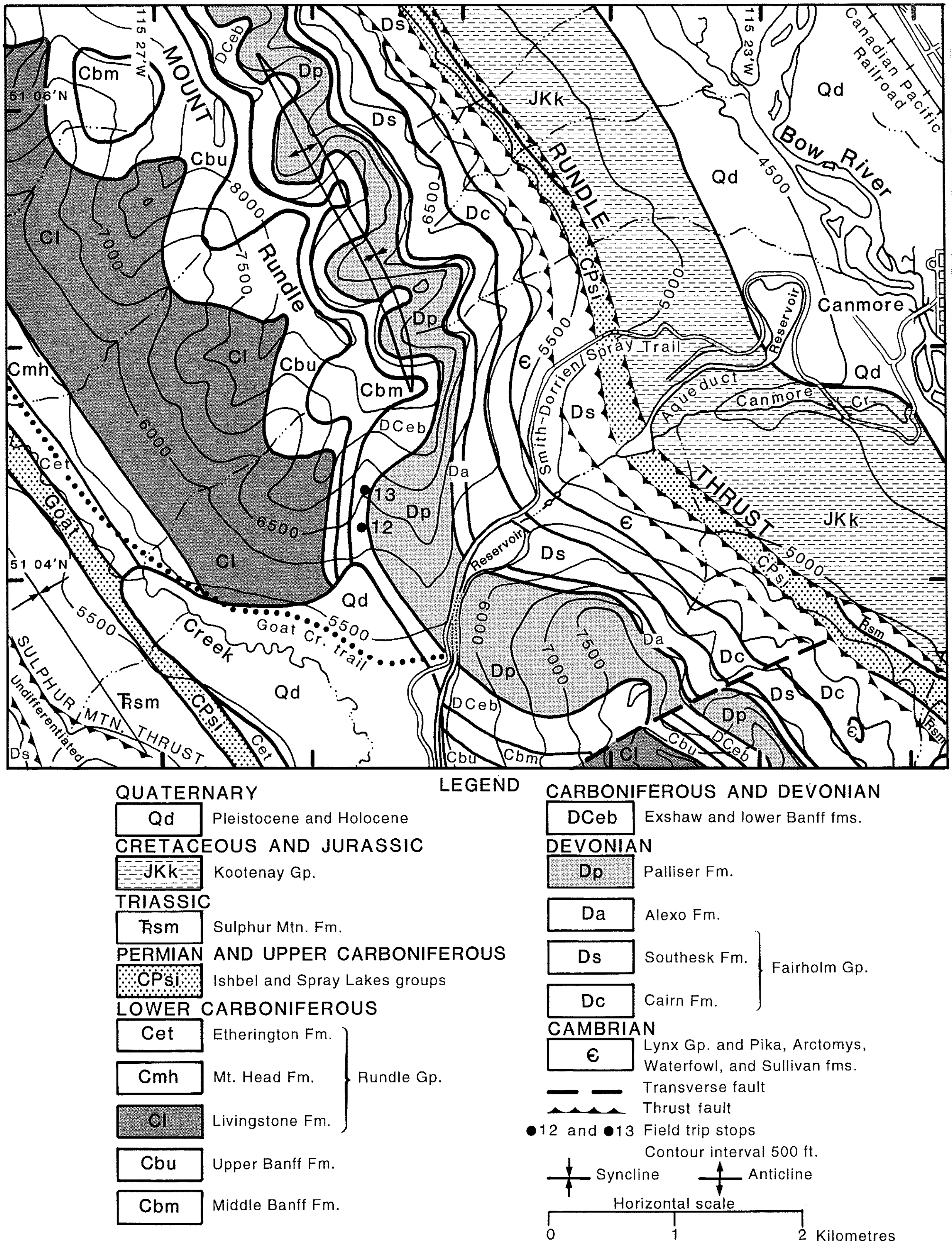


Figure 3. Simplified geological map (modified from Price, 1970) showing geology of region southwest of Canmore, southwestern Alberta and locations of field trip stops 12 and 13 on southwestern side of Mt. Rundle.

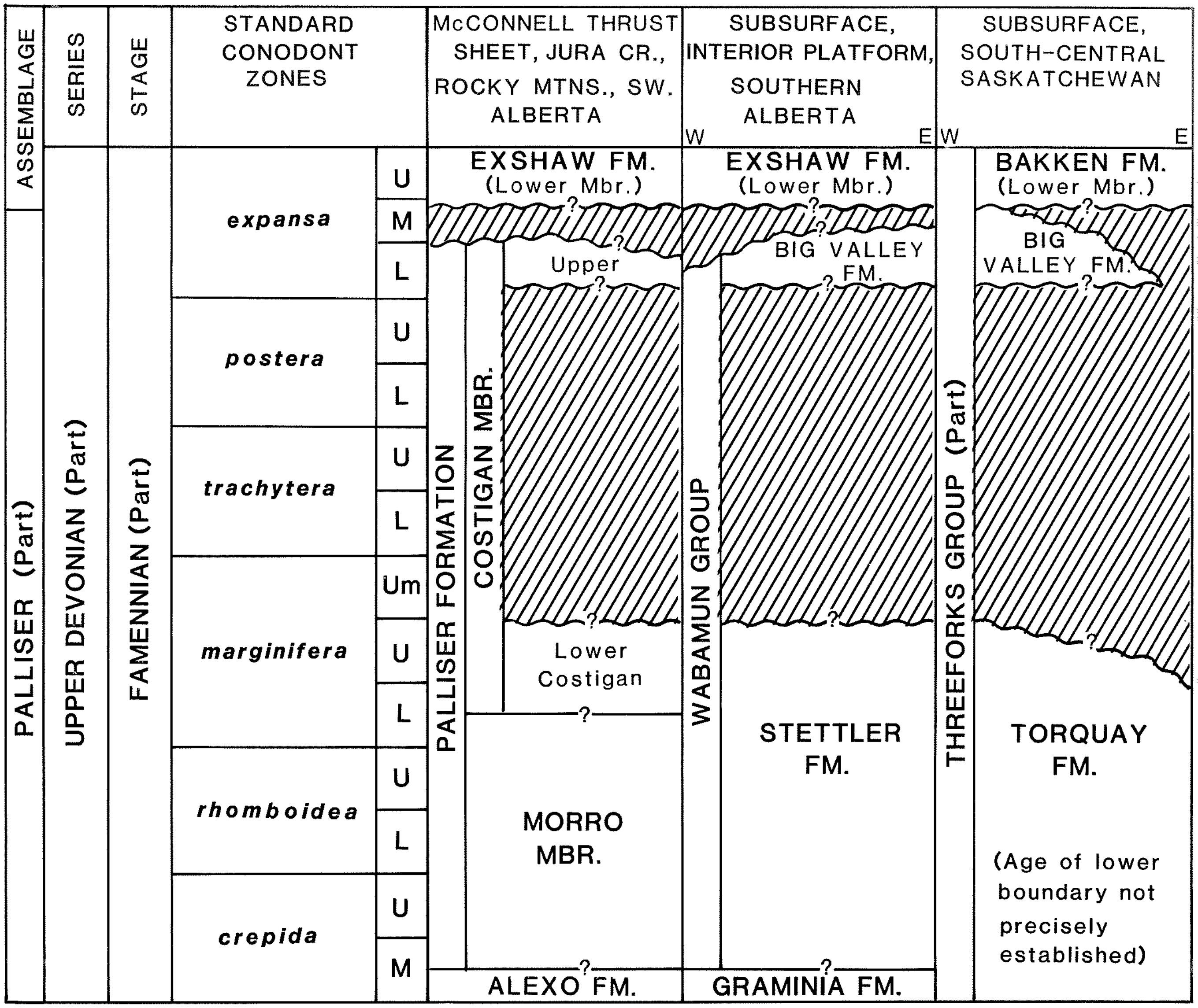


Figure 4. Correlation of Upper Devonian (Famennian) lithostratigraphic units at Jura Creek with: subsurface successions of southern Alberta and southern Saskatchewan, chronostratigraphic units, and standard conodont zones.

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 (Fig. 2). The strata at both 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.

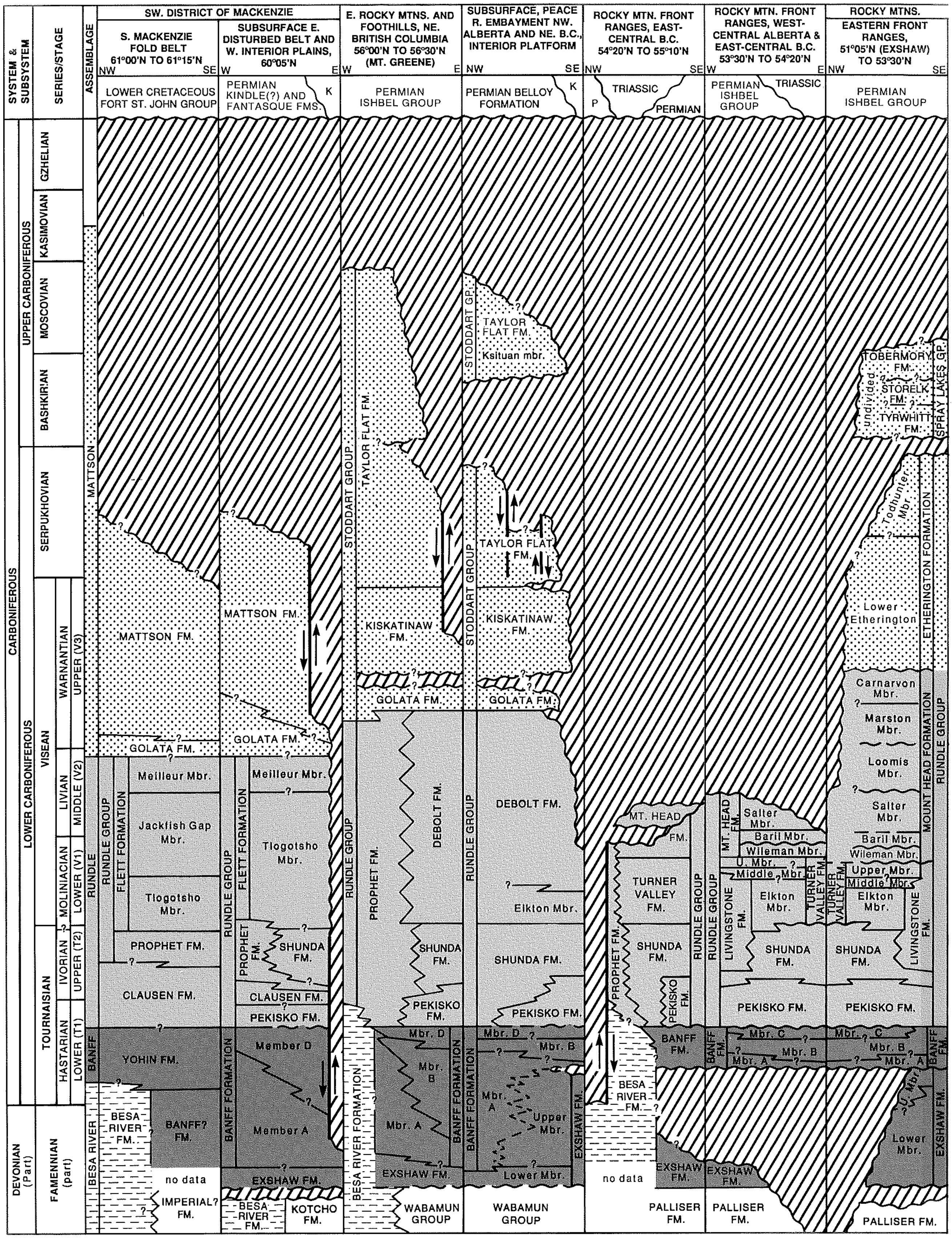
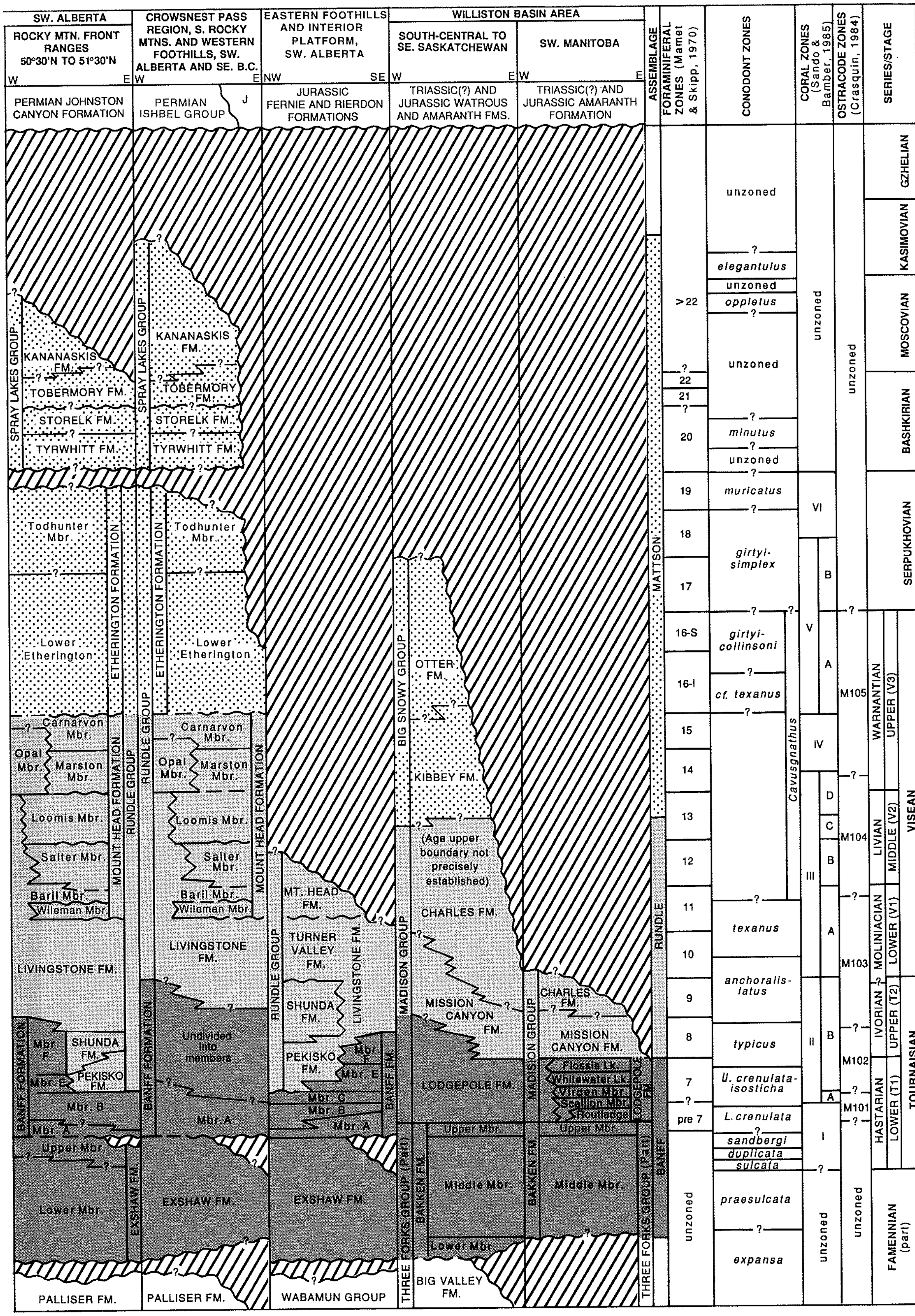


Figure 5. Correlation of Carboniferous lithostratigraphic units, southwestern Manitoba to southwestern District of Mackenzie



with chronostratigraphic units and Carboniferous zonal schemes. Dashed lines indicate nature of contact uncertain; question marks indicate position of lines uncertain (from Richards et al., in press b).

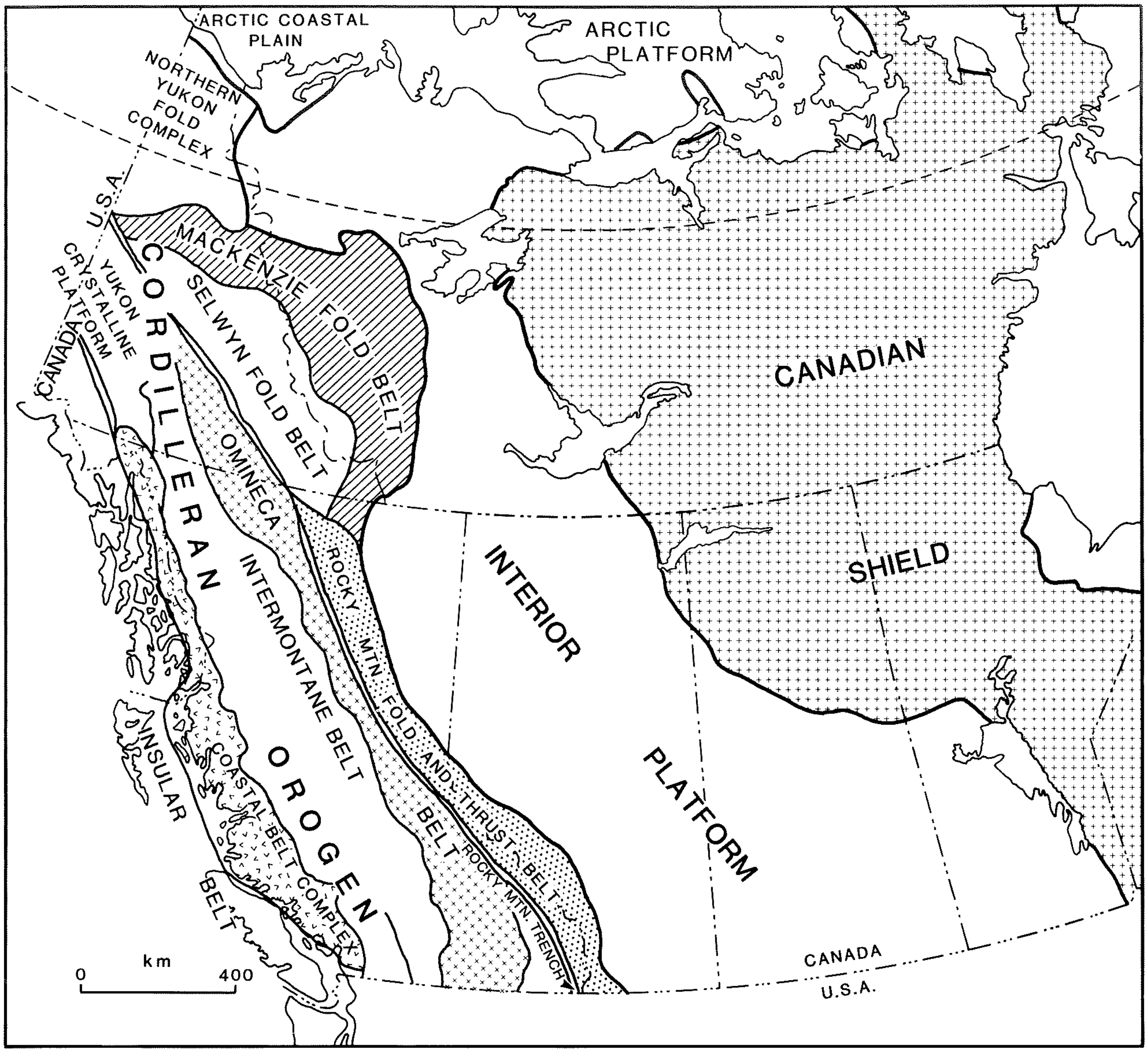


Figure 6. Principal present-day geological elements of western Canada (modified from Douglas et al., 1970).

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 Uplift, and Alberta Trough (Fig. 7). 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 Late Devonian into the Carboniferous, lay along the southwestern side of the basin, which was probably in part a compressional foreland basin during the Famennian and Early Carboniferous (Richards, 1989; Rubin et al., 1991; Smith and Geherels, 1992; Smith et al., 1993; Richards et al., in press).

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 Uplift (Morrow and Geldsetzer, 1988). The latter, extensively exposed during the Frasnian and early Famennian, was largely transgressed by the late Famennian. The Famennian

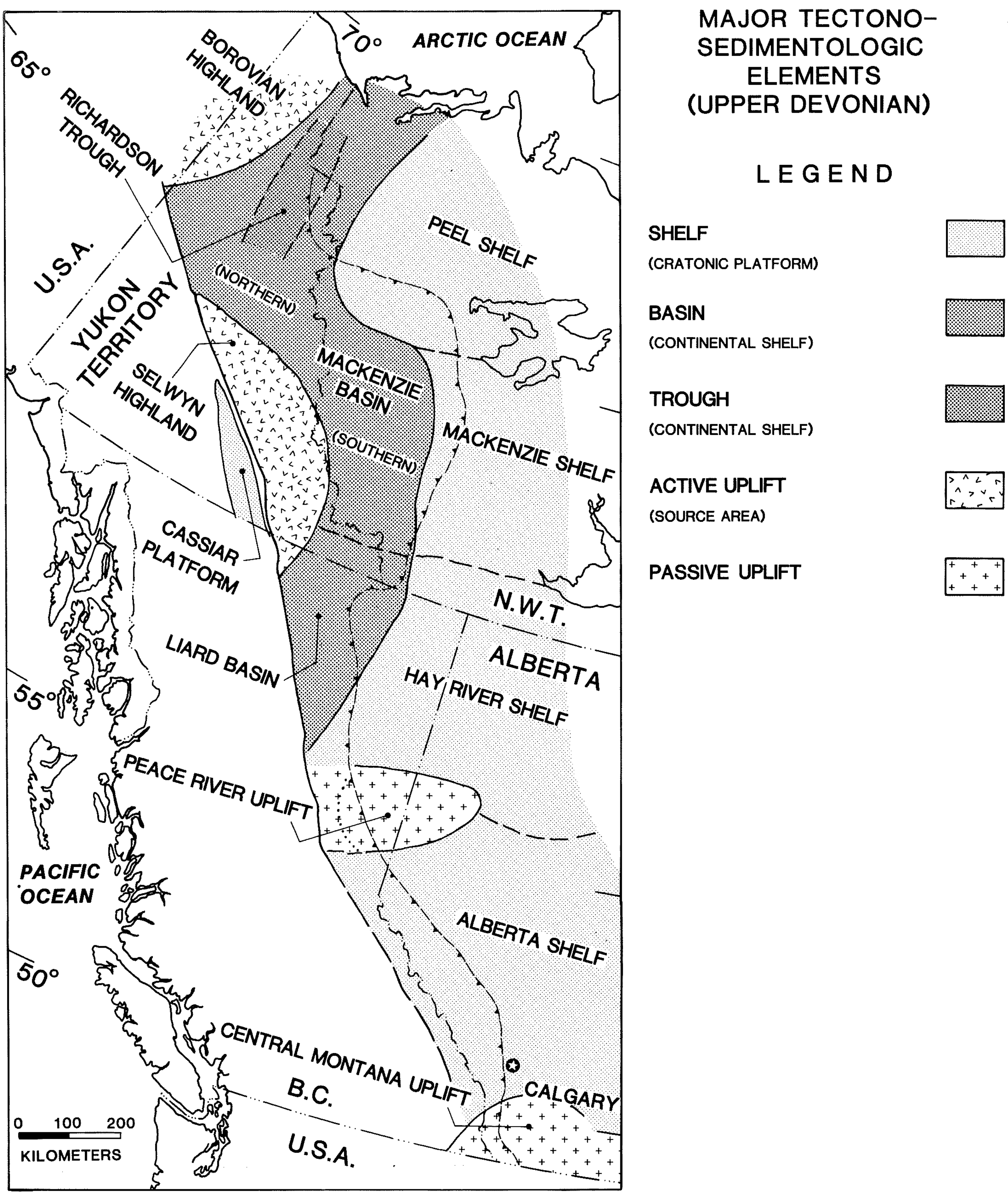


Figure 7. Map showing distribution of Famennian deposits in the Western Canada Sedimentary Basin, and principal Famennian tectonic elements. (modified from Morrow and Geldsetzer, 1988).

Palliser Formation and underlying Alexo Formation at Jura Creek were deposited on the southwestern part of the Alberta Shelf.

In northeastern British Columbia and northward, the broad northwest-trending Liard and Mackenzie troughs of Douglas et al. (1970), dominated by moderately deep-marine environments where basinal shale was deposited, lay on the western side of the cratonic platform. The paleogeography and western extent of the cratonic platform in the southwest is not well known, but the deep Alberta Trough of Douglas et al. (1970) extended along part of the western cratonic platform. The occurrence of the latter 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 (Fig. 8), and the Lussier shale (Savoy, 1992) in the western ranges of the southern Rocky Mountains.

A discontinuous, subaerially exposed positive belt was present along the western side of the Alberta Trough and troughs to the north. The presence of the belt is recorded by westerly-derived Famennian boulders to granules 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 westerly derived clastics were deposited on an easterly thinning clastic wedge preserved as remnants in several units including the Guyet, Sassenach and Besa River formations and Earn Group (Fig. 8). The positive belt, a site of Late Devonian and Early Carboniferous granitic plutonism and volcanism (Evenchick et al., 1984; Mortensen and Jilson, 1985; Okulitch, 1985; Mortensen et al. 1987; Parrish, 1992), coincided in part with the western rim of the latest Devonian and Carboniferous Prophet Trough (Fig. 9).

The western cratonic platform and adjacent troughs underwent episodes of pronounced subsidence. The latter, which started during the Frasnian and continued into the late Early Carboniferous, resulted at least partly from extension (Tempelman-Kluit, 1979; Struik, 1987, 1988; Gordey et al., 1987), but tectonic loading (Richards, 1989; Smith et al., 1993) and intraplate compressive stress (Bond and Kominz, 1991) may have been the major causes.

Carboniferous tectonic elements

During the Carboniferous, the principal tectonic elements in the WCSB were the Prophet Trough, Peace River Embayment, cratonic platform (including the intracratonic Williston Basin), and the Yukon Fold Belt (Figs. 9-11). The characteristics and Carboniferous tectonic histories of these elements and subordinate features within them were outlined by Richards (1989) and by Richards et al. (in press a, b). The Carboniferous in the front ranges of the Exshaw region was deposited in eastern Prophet Trough, whereas that of the adjacent foothills and Interior Platform was deposited on the western cratonic platform.

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 connected to the Antler Foreland Basin of the western United States (Fig. 10), 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 plate convergence and eastward directed subduction. Also, growing evidence (Richards, 1989; Smith et al., 1993; Richards et al., in press b) indicates that southern Prophet Trough (south of Peace River Embayment) was a compressional foreland basin from the late Famennian into the Viséan. 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 (Richards, 1989; Barclay et al., 1990; Richards et al., in press b).

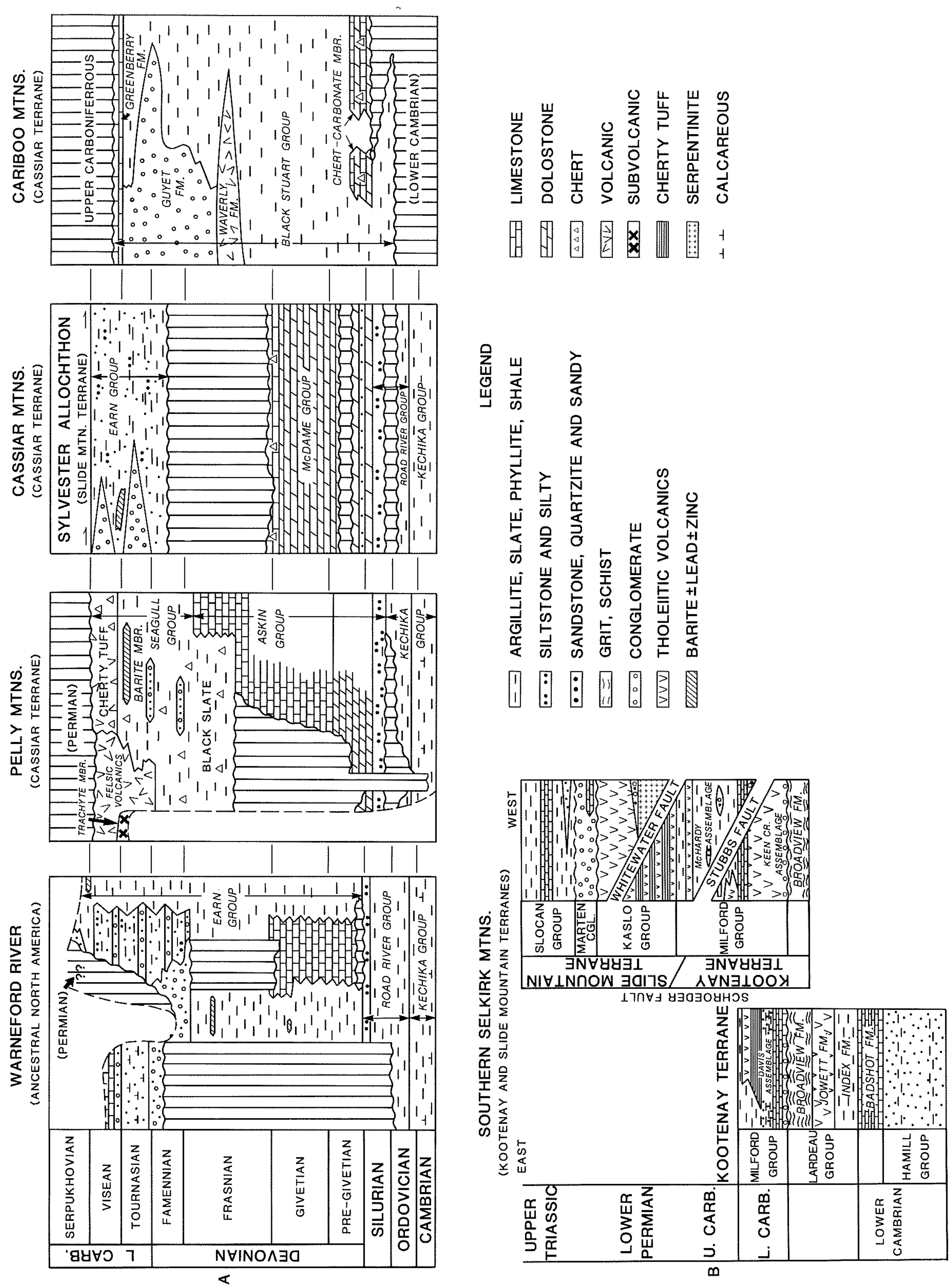


Figure 8. *Stratigraphic relations and correlations of Upper Devonian and Lower Carboniferous lithostratigraphic units in the western assemblage of the WCSB (not to scale). Figure 8A (after Gordey et al., 1987) illustrates deposits of western Prophet Trough; 8B (after Klepacki and Wheeler, 1985) shows the Milford Group of southeastern British Columbia. The Davis and Keen Creek assemblages of the Milford were deposited on the western rim of Prophet Trough, whereas the McHardy assemblage of the Milford and overlying Kaslo Group formed in a marginal basin (Slide Mountain Basin, Fig. 11).*

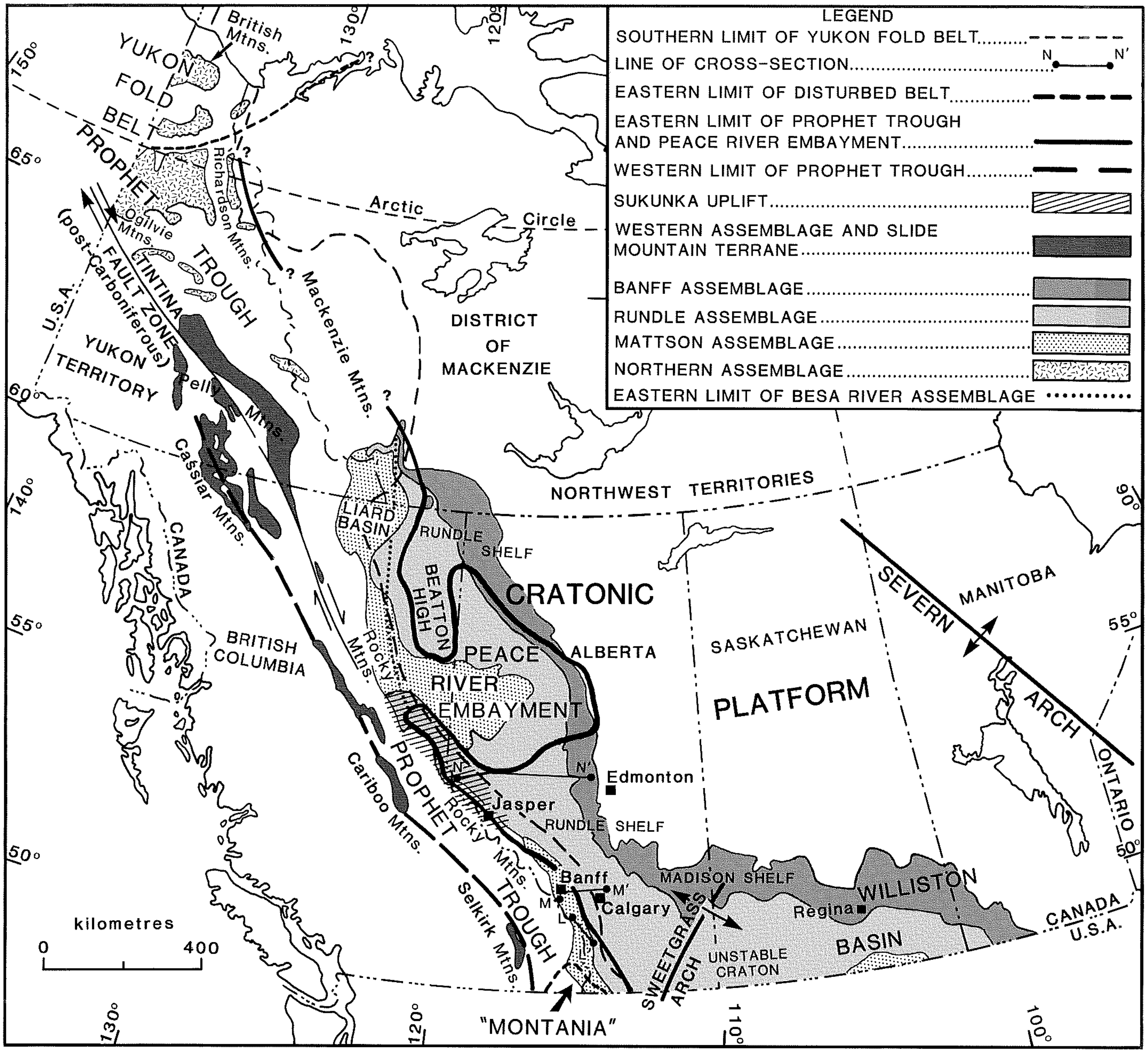


Figure 9. Map showing Carboniferous units subcropping beneath Permian and Mesozoic deposits in the WCSB, tectonic elements, and lines of cross-section. See Figure 5 for formational composition of Banff, Rundle, and Mattson assemblages (from Richards et al., in press b).

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 trough and the cratonic platform to the east. At the latitude of Jura Creek, this hinge, which apparently stepped basinward with time, lay in the western plains to eastern foothills during the early Tournaisian as indicated by marked 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 Rocky Mountain Front Ranges. The latter position is suggested by thickness changes in the Rundle Group and corresponding major lithofacies changes shown on regional cross-sections (Richards et al., in press b).

The western boundary of the Prophet Trough was an elevated rim, extensively exposed from the Late Devonian to the early Viséan, but subsequently largely transgressed. Volcanism and plutonism took place

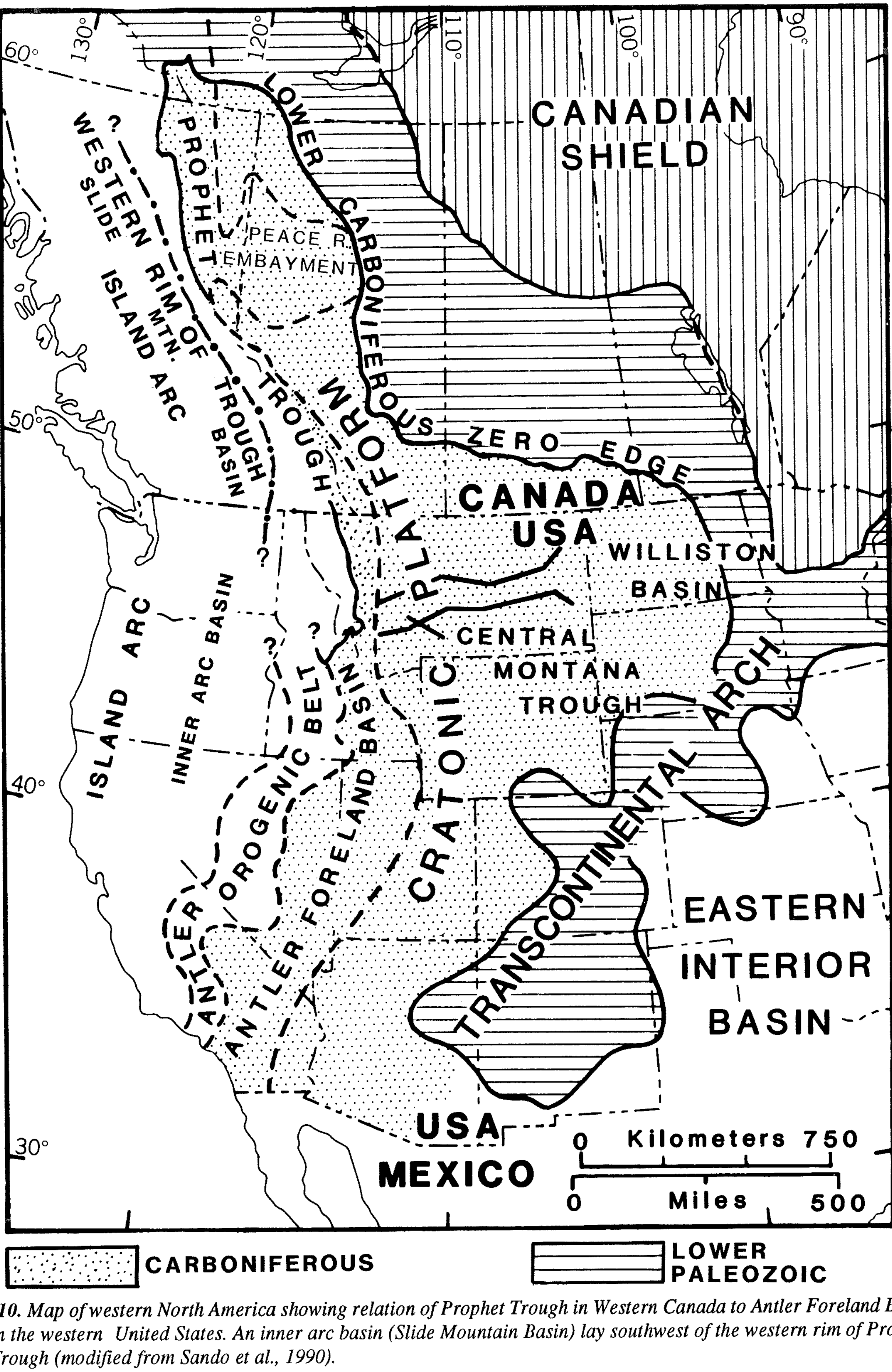


Figure 10. Map of western North America showing relation of Prophet Trough in Western Canada to Antler Foreland Basin in the western United States. An inner arc basin (Slide Mountain Basin) lay southwest of the western rim of Prophet Trough (modified from Sando et al., 1990).

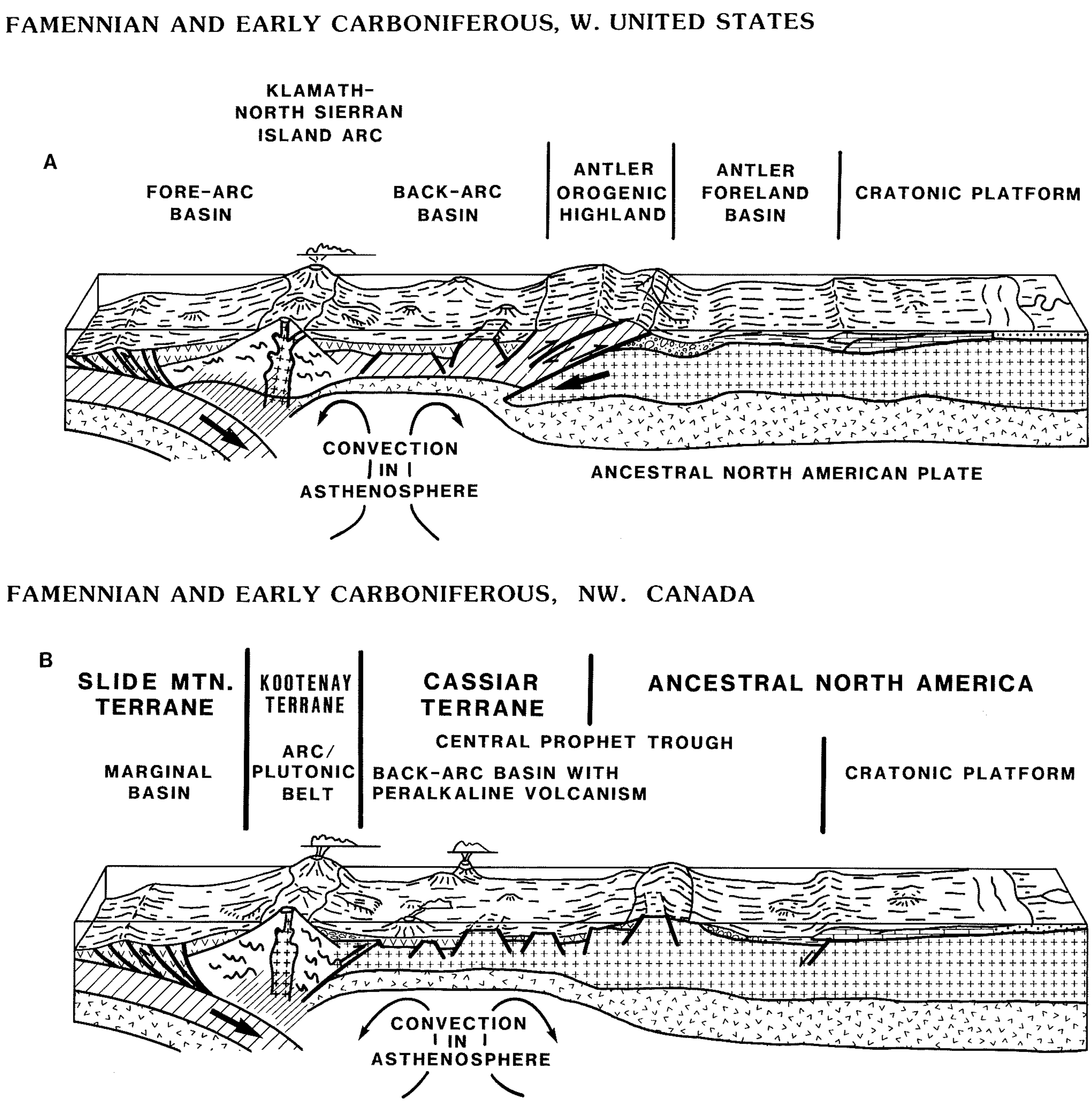
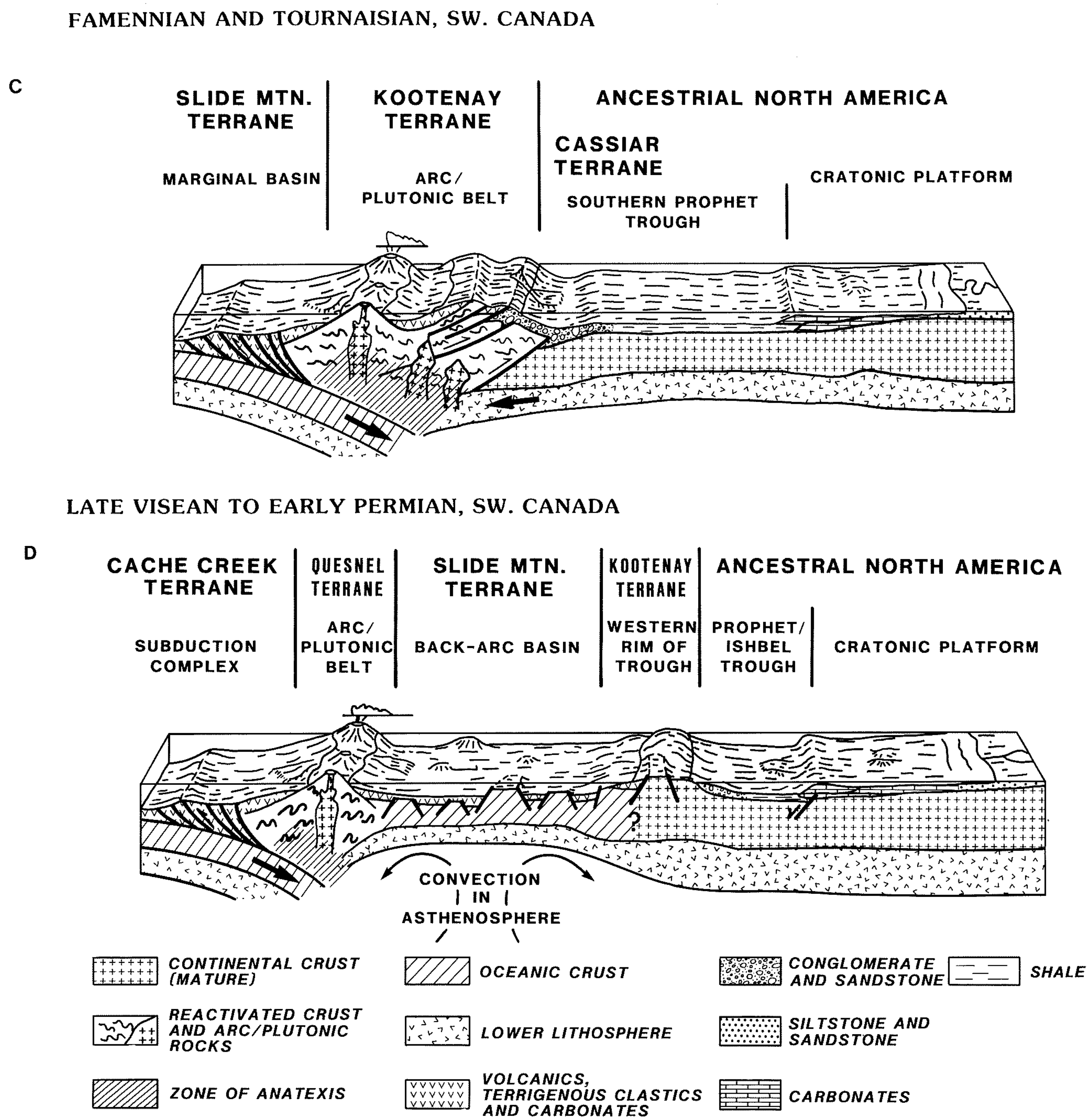


***Figure 11.** Hypothetical generalized models showing relationships between Late Devonian to Early Carboniferous arc/plutonic belts and the western margin of North America. Model A, representing the western United States during the latest Devonian and Early Carboniferous Antler Orogeny, shows a continental margin influenced by compression and episodes of back-arc thrusting (after Poole and Sandberg, 1977). Model B, representing the continental margin of northwestern Canada (central Prophet Trough) during the late Famennian and Early Carboniferous, shows extension-related*



subsidence in the foreland of an arc/plutonic belt. Model C represents southwestern Canada during the Famennian and earliest Carboniferous (Tournaisian). It shows widespread compression-related subsidence in the foreland of an arc/ plutonic belt. Model D, representing southwestern Canada from the late Viséan into the Early Permian, shows extension on a continental margin lying northeast of a back-arc basin and an arc/plutonic belt. Kootenay Terrane preserves remnants of an earlier arc (from Richards, 1989).

within the trough and along its western rim, as recorded by the presence of Late Devonian and Early Carboniferous plutons extending in a narrow belt from southeastern British Columbia into Alaska, by volcanics in northwestern Prophet Trough (Figs. 8, 11B), and by westerly derived marine 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, but are locally preserved in the Cassiar Terrane and on the southwestern part of the ancestral North American plate (Richards, 1989).

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 District of Mackenzie and in the eastern Cordillera (Figs. 4, 12, 13). Part of this succession will be examined along lower Jura Creek, where the Famennian is represented by the middle to upper Palliser Formation and lower Exshaw Formation (Figs. 2, 12). The uppermost Palliser and lower Exshaw will also be examined 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. 4). The lower Exshaw, placed in the Banff assemblage by Richards (1989), 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 assemblge comprises a thick lower transgressive/regressive (TR) sequence overlain by the initial transgressive deposits of a TR sequence that contains the Devonian/Carboniferous boundary and includes the Exshaw Formation (Richards et al., 1991). Deposition of the assemblage probably commenced during the time of the *Palmatolepis triangularis* 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 Uplift. Subsequent carbonate and evaporite (anhydrite and halite) deposition formed a vast carbonate ramp that prograded westward and extended from Manitoba to District of Mackenzie (Fig. 14).

Deposition on a ramp rather than a platform is indicated by the lack of either a reef or grainstone belt 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, Fig. 13); a broad central belt of carbonates and subordinate evaporites extended northwestward to the continental shelf of the Liard Basin (Palliser, Wabamun, and Stettler formations); and 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 much of the WCSB, ramp development terminated during a middle Famennian (*Palmatolepis marginifera marginifera* Zone) regional regression that was accompanied by widespread erosion. The latter is indicated by the unconformity below shale and argillaceous limestone of the transgressive upper Famennian Big Valley Formation (Figs. 4, 13) and locally below the Exshaw Formation. The amount of erosion, which generally diminished basinward, was greatest in the Interior Plains, foothills, and eastern

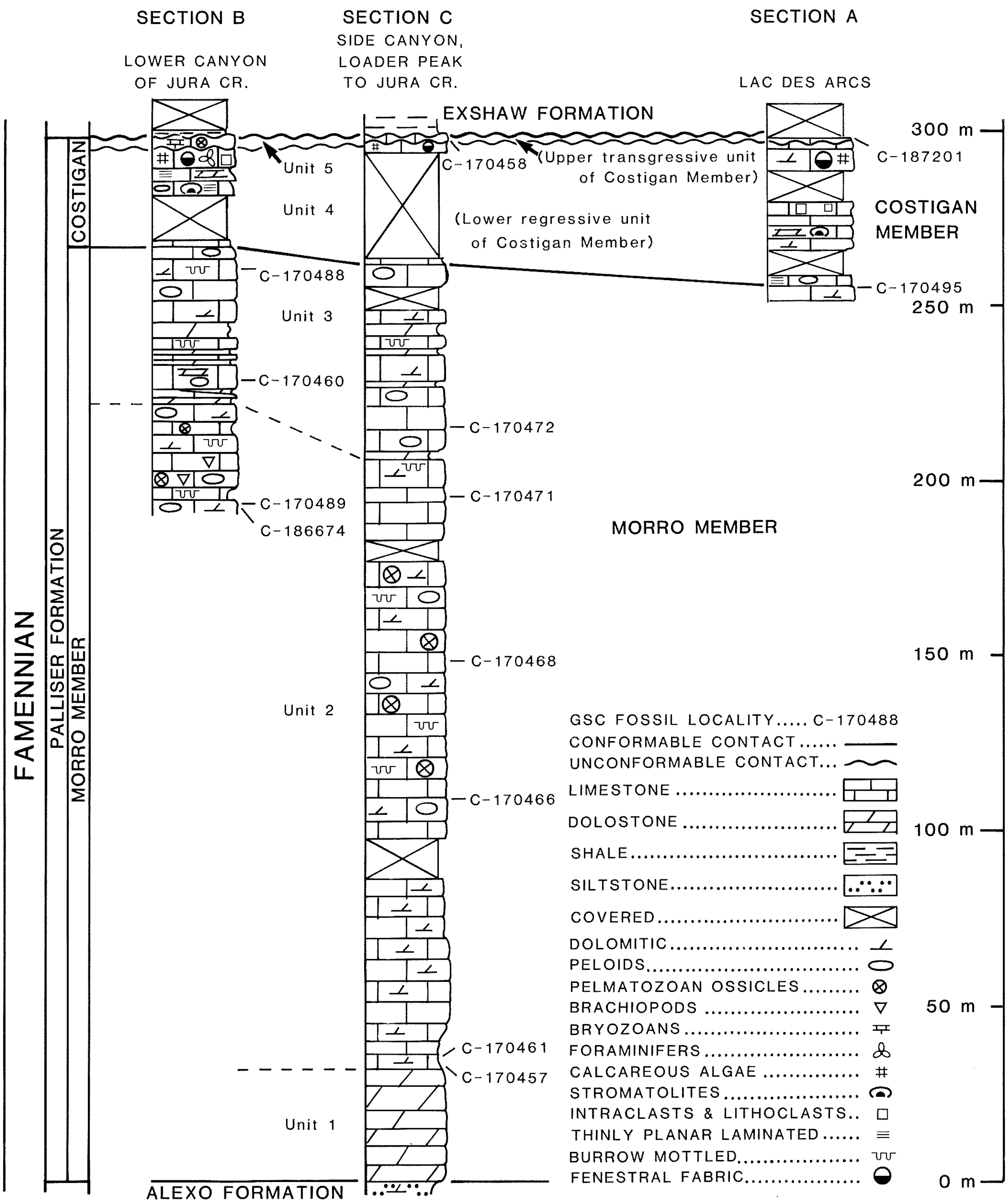


Figure 12. *Generalized cross-section showing location of selected GSC fossil localities and the lithology and lithostratigraphic relationships of Famennian units in the Exshaw region, eastern Rocky Mountains, southwestern Alberta.*

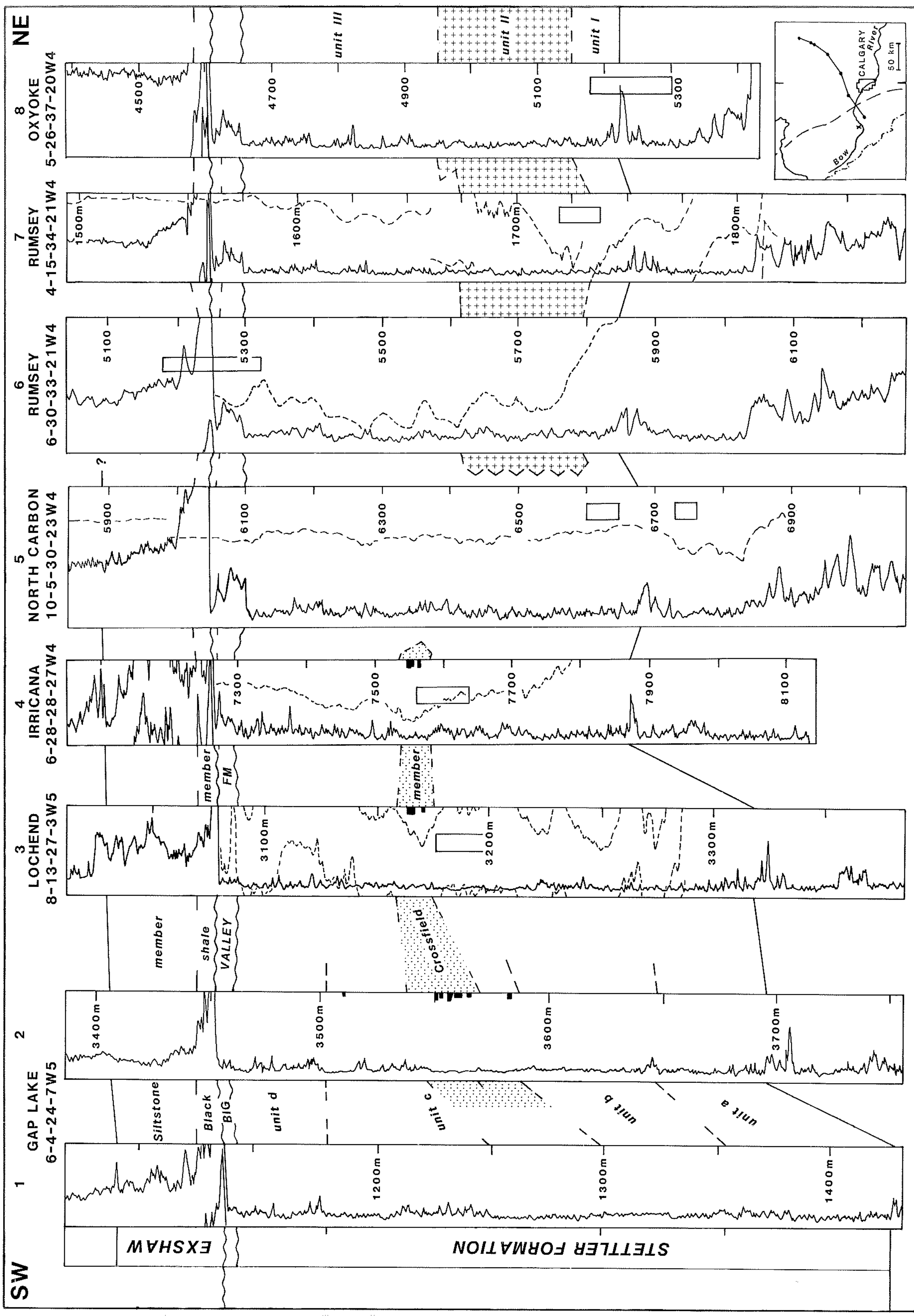


Figure 13. Stratigraphic cross-section showing Upper Devonian strata in southwestern Alberta, using gamma-ray and spontaneous potential curves of selected boreholes. Sections 1 and 2 of the Gap Lake well (6-4-24-7W5) are in different thrust sheets at that locality. Index map shows locations of the boreholes and the type section of the Exshaw Formation (marked by x). The crossed pattern indicates halite, stippled pattern is porous dolostone; rectangular boxes represent cored intervals. Depths in feet unless otherwise indicated.

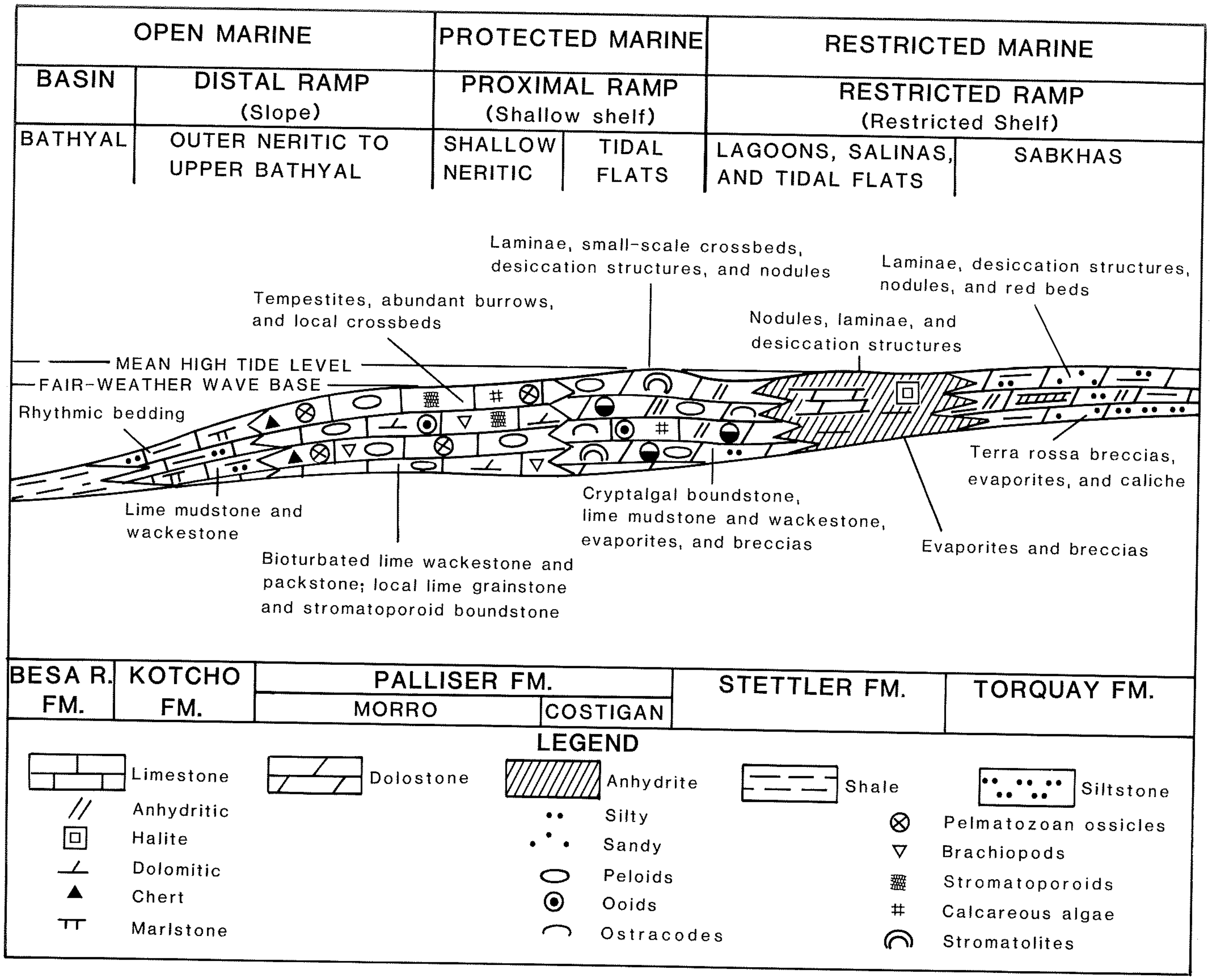


Figure 14. *Generalized depositional model of a Famennian carbonate ramp (from Richards et al., 1991).*

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 eastern front ranges of the Jasper area. Ramp development resumed during deposition of the upper Famennian Big Valley, but stopped prior to deposition of the Exshaw Formation.

Palliser Formation

Lithostratigraphy and sedimentology

Cliff-forming carbonate ramp lithofacies of the Famennian Palliser Formation (Beach, 1943) are widely distributed in the southern and central Rocky Mountains of western Canada and are locally exposed in the western Rocky Mountain foothills of western Alberta (Geldsetzer, 1982; Morrow and Geldsetzer, 1988). East of the Rockies and southwestern Foothills, subsurface correlatives of the Palliser are included in the Wabamun Group. In the Bow Valley region, the thickness of the Palliser ranges from 300 m at Jura Creek to nearly 400 m at Mount Rundle near Banff (Figs. 4, 12, 13).

At Jura Creek and elsewhere in the eastern Rocky Mountains of southwestern Alberta, the Palliser generally conformably overlies the recessive siltstone and silty dolostone of the lower Famennian Alexo Formation. The Palliser/Alexo boundary, which is commonly sharp and may be locally erosional, is placed at a stratigraphic level above which the predominant lithology is dolostone that lacks abundant siliciclastic silt (Fig. 12, unit 1).

The Palliser Formation of southwestern Alberta grades northeastward into the Stettler Formation. To the northwest, in central Alberta and east-central British Columbia, the Palliser passes northeastward into the Wabamun Formation. In east-central and northeastern British Columbia, carbonates of the Palliser and Wabamun grade basinward into basinal shale of the Besa River Formation. A basinward facies change to shale took place in the southwest as well. There, the shale facies is locally represented by the Lussier shale of the western Rocky Mountains (Savoy, 1992).

The Palliser is abruptly and generally unconformably overlain by the Exshaw Formation in most of the southern Rocky Mountains. But in west-central Alberta and east-central British Columbia, where the Exshaw occurs as erosional remnants (Fig. 5), Lower Carboniferous deposits of the Banff Formation overlie the Palliser in most areas (Morrow and Geldsetzer, 1988; Richards and Higgins, 1988; Richards, 1989).

The Palliser was divided by de Wit and McLaren (1950) into two members, the Morro and overlying Costigan (Figs. 4, 12). The Morro and most of the Costigan are coeval correlatives of the subsurface Stettler Formation. The upper two to four metres of the Costigan along Jura Creek is an unconformity-based, skeletal limestone unit that is correlative and coeval with the subsurface Big Valley Formation.

The cliff-forming Morrow Member is 260 m thick at section C, along a side canyon extending from Loader Peak to Jura Creek, and its upper beds are well exposed along the lower canyon of Jura Creek (Fig. 12). At the southwest end of Mount Rundle (Fig. 3), the Morrow is extensively exposed along the road and reservoir, but its thickness can not be determined because the upper part of the member is deeply covered.

The moderately recessive Costigan is 42.2 m thick at section A (road cut at Lac des Arcs). At section B (canyon of lower Jura Creek), where the upper part of the member is well exposed but its basal deposits are deeply covered, the Member is about 40 m thick. In a well exposed section slightly northwest of the head of Jura Creek, the Costigan comprises 31.4 m of strata. At stop 13 on the southwest side of Mount Rundle, the upper 14 m of the member are exposed. The Costigan/Morro contact is poorly exposed at sections A and B but appears to be conformable.

The lower 30 to 40 m of the Morro Member in the Jura Creek area is finely crystalline dolostone locally showing sedimentary breccias and planar laminae (Fig. 12, unit 1). Most of the well-bedded member is, however, dominated by medium- to thick-bedded, burrow-mottled, intraclast-peloid lime wackestone and packstone locally containing abundant brachiopods and pelmatozoan ossicles. Thin- to thick-bedded, recessive units of highly fractured, finely crystalline dolostone are intercalated with the burrow-mottled limestone in the cyclic upper 55 to 60 m of the member. The dolostone beds, locally showing abundant white carbonate nodules that are probably pseudomorphic after anhydrite, have sharp to gradational lower contacts and sharp upper boundaries.

Deposition of the Morrow Member occurred mainly in low-energy neritic environments below fair weather wave base. Such a setting is indicated by the predominance of fine grained, strongly bioturbated deposits lacking wave and current formed structures. The upper Morro was deposited in shallow-neritic to intertidal settings as indicated by the presence of dolostone beds containing evaporite pseudomorphs and the restricted-marine character of the overlying lower Costigan Member (Richards and Higgins, 1988). In the lower Morro, the presence of breccias (some resulting from the dissolution of evaporites and related collapse of intercalated carbonates) and planar-laminated dolostone records deposition on the restricted ramp. The presence of the Morro above the silty, restricted-marine carbonates of the Alexo Formation records the culmination of a regional transgression that commenced with the onlap of local subaerial unconformities by the latter formation.

The Costigan Member (Figs. 12, 31) is generally thinner bedded and less resistant than the underlying Morro Member and commonly comprises several thin TR sequences. Lower parts of the sequences in the ranges east of Mount Rundle generally overlie undulatory erosion surfaces and commonly comprise fossiliferous, intraclast-peloid lime wackestone to grainstone. Upper parts of most sequences in the east include fenestral cryptalgal boundstone, stromatolitic cryptalgal boundstone, algal wackestone, carbonate breccias (resulting in part from the dissolution of evaporites), and planar-laminated dolostone. Some of the eastern sequences are incomplete and commence with lithofacies of the upper division. Between Grotto Mountain and Mount Rundle, a major basinward facies change is present in the Costigan. At Mount Rundle, the Costigan sequences comprise argillaceous lime wackestone and packstone containing abundant brachiopods, byrozoans and pelmatozoan ossicles; restricted-ramp deposits are absent.

The basal deposits in the sharp-based sequences of the eastern Costigan record minor transgressions and deposition in shallow-neritic to intertidal environments (Richards and Higgins, 1988). Overlying lithofacies in the sequences record minor regressions and deposition in lagoons and intertidal to supratidal restricted-ramp environments.

Along Jura Creek and at Lac des Arcs, the uppermost Costigan Member, which comprises dolomitic, cherty, skeletal lime wackestone and packstone with subordinate lime grainstone and dolostone, overlies an undulatory unconformity (Fig. 37; Richards and Higgins, 1988; Richards et al., 1991) showing 10 to 20 cm of erosional relief. At stop 13 on Mount Rundle, the base of the uppermost Costigan may be unconformable as well. Below the type section of the Exshaw Formation at stop 6 on Jura Creek, the unconformity truncates stromatoporoid coenostia in the underlying Costigan, but in most of the area it overlies algal lime wackestone, and fenestral cryptalgal lime boundstone. Marine erosion, probably preceded by regional subaerial erosion, produced the unconformity.

The upper unit of the Costigan Member is 3.8 m thick near the head of the lower canyon of Jura Creek (stop 3) and 2.0 m thick below the Exshaw type section. At stop 13 on Mount Rundle, it appears to be 2.1 m thick, but the location of the unit's base at this locality is uncertain. The upper Costigan commonly fines upward and shows evidence of bioturbation and common development of bored hard grounds. The main allochems are pelmatozoan ossicles, bryozoans and intraclasts, but scattered brachiopods and large nautiloids are moderatly common. Some beds contain abundant ooids, and sponge spicules are locally numerous in the upper 50 cm below the type Exshaw.

Deposition of the upper Costigan took place above the oxygen-minimum zone and in an open-marine, shallow-neritic setting (Richards and Higgins, 1988). The upper two to five centimetres of the unit contains abundant pyrite (Table 1, GSC loc. C-195037), but these strata were deposited in the aerobic zone as they are partly bioturbated and abundantly fossiliferous. The presence of the upper Costigan above restricted-marine deposits of the underlying Costigan records a regional transgression, also indicated by the upper Big Valley Formation.

The uppermost Costigan probably records the early phase of a major regional transgression and period of deepening that culminated with deposition of the black shale in the overlying Exshaw Formation (Richards and Higgins, 1988). This transgression, which started near the time of the Lower *Palmatolepis gracilis expansa* conodont Zone in the Jura Creek area and possibly earlier basinward, coincided with a major late Famennian eustatic rise in sea level (Sandberg et al, 1988).

Some erosion apparently followed deposition of the uppermost Costigan. The erosion is indicated by: eastward truncation of the Big Valley Formation below the Bakken Formation in southeastern Saskatchewan, sub-Exshaw and sub-Bakken westward bevelling of the Big Valley from western Saskatchewan (Christopher, 1961) to western Alberta (Fig. 22), and the widespread presence of phosphatic lag deposts in the basal Exshaw and Bakken formations.

Unit and GSC Localities	Metres above base of section	Expandable + / or ML Clays	Mica	Kaolinite + / or Chlorite	Quartz	Feldspars		Calcite	Dolomite + / or Ankerite	Pyrite	Others
						Plagioclase	Orthoclase				
Costigan Mbr. Palliser Fm. C195036	3.85 - 3.95	tr			30	1		64	5		
C195037	3.95 - 4.00	tr			32			41	21	21	
Lower Mbr. Exshaw Fm. C136748B, C195038	4.00 - 4.06	tr tr			31 38		7 25	4 8	9 6	18 7	Sphalerite - 22, 9 Fluorapitite/ hydroxylapatite - 7, 6 Vaesite - 2, 1
C165145	4.06 - 4.10	2			47	2	4		39	6	
C195044	4.5 - 4.6	5			81		7			7	
C195049	5.0 - 5.1	3			88		4			5	Anatase - tr
C195054	5.54 - 5.59	31			17		16	13		11	Gypsum - 12
C195055	5.5 - 5.6	2			82		3		7	6	
C195060	6.0 - 6.1	3			89		5			3	Gypsum - tr
C195065	6.5 - 6.6	4			87		6			3	
C195070	7.0 - 7.1	4			84		6		2	4	Gypsum - tr
C195075	7.5 - 7.6	3			81		7	2	3	4	Gypsum - tr
C195080	8.0 - 8.1	4			81		8	3		3	Gypsum - 1
C195085	8.5 - 8.6	2	5		68		8	5	6	6	
C195090	9.0 - 9.1	5			70		8	6	5	6	
C195095	9.5 - 9.6	2	6		74		8		4	6	
C195100	10.0 - 10.1	4			77		8		5	6	
C195105	10.5 - 10.6	7			60		10	4	11	8	
C195110	11.0 - 11.1	3	3		38		7	38	5	5	
C195115	11.5 - 11.6	6			51		6	27		10	
C195120	12.0 - 12.1	3	3		40		6	36	5	6	
C195125	12.5 - 12.6	4	5		39		7	36	5	4	
C195130	13.0 - 13.1	5	7		44		7	32		5	
Upper Mbr. Exshaw Fm. C195135	13.5 - 13.6	2			29	2	2	57	6	2	
C195140	14.0 - 14.1	3	1		35	tr	2	53	4	2	
C195144	14.4 - 14.5	tr	2	tr	31	2	2	53	8	2	
C136759	15.8	tr	2	tr	28	2	2	54	12		
C136760	17.1	tr	2	tr	30	3	2	54	9		
C136761	17.7	tr	2	tr	31	3	2	46	16		
C136762	20.1	tr	3	1	45	5	4	30	12		
C136763	24.8	tr	2	1	46	3	4	20	24		
C136764	26.1	-	2	1	55	6	6	8	22		
C136765	27.5	-	2	1	53	4	5	9	26	tr	
C136766	29.3	tr	3	1	47	5	5	17	22		
C136767	30.5	-	2	1	48	5	5	20	19		
C136768	34.6	tr	2	2	44	5	4	23	20		
C136769	35.3	-	3	1	39	6	4	34	13		
C136770	37.7	-	2	1	38	4	5	20	30		
C136771	40.3	-	2	tr	35	4	3	25	31	tr	
C136772	43.2	tr	2	1	37	4	4	27	25	tr	
C136773	44.4	tr	2	1	45	4	4	18	24	tr	
C136774	45.6	tr	2	1	50	5	5	11	26	tr	
C136775	48.4	-	2	1	52	6	5	5	29	tr	
C136776	50.6	-	4	1	52	5	5	3	30		
C195144	144.4-14.5	tr	2	tr	31	2	2	53	8	tr	

Table 1. *X-ray diffraction analyses of rock samples collected from the upper Costigan Member and overlying Exshaw Formation at stop 6 (Fig. 2) on Jura Creek. Analyses performed by J.N.Y. Wong and A.G. Heinrich at the Institute of Sedimentary and Petroleum Geology.*

Conodont biostratigraphy

The standard Upper Devonian conodont zonation used here (Figs. 4, 15) was proposed by Ziegler (1962) and underwent major revision by Ziegler (1971) and Ziegler and Sandberg (1984). This zonation has been applied internationally.

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). On the whole, conodont yields from this member were low and preservation poor at Jura Creek but improved southwestward. Figure 15 illustrates the established ranges of the principal Famennian conodonts discussed in this guidebook.

Several faunas were extracted from the Morro Member at section C, a deep side canyon to Jura Creek (Figs. 2, 12). *Palmatolepis quadrantinodosalobata* Sannemann (Plate 1, Fig. 4) was collected 33 m above

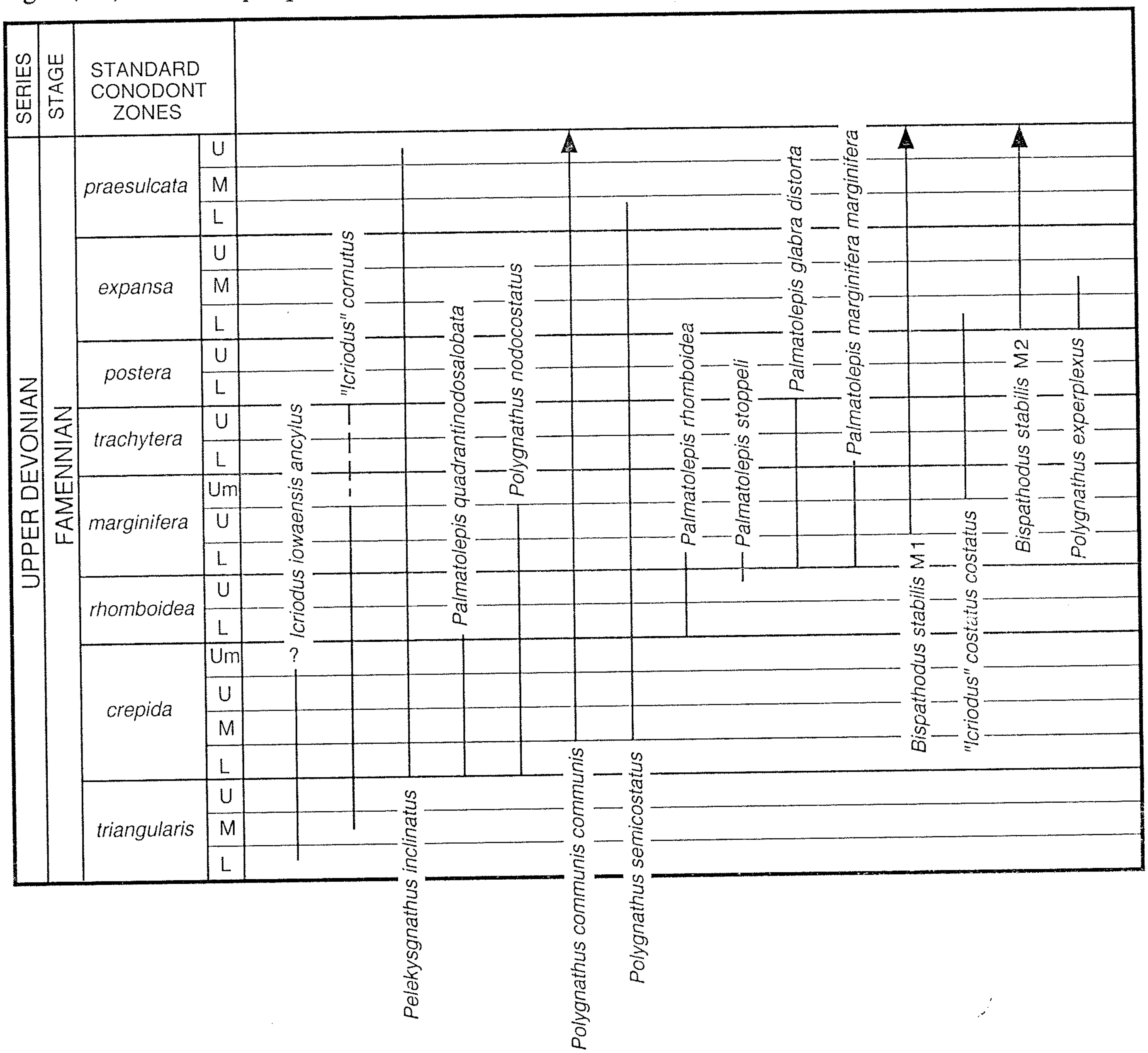


Figure 15. *Range chart showing established ranges of selected conodont species from the Famennian of the Exshaw region, southwestern Alberta.*

the base of the Morrow (GSC loc. C-170457). *"Icriodus" cornutus* Sannemann (Plate 1, Figs. 9, 10) and *Polygnathus semicostatus* Branson and Mehl (Plate 1, Fig. 5) were collected 109 m above the base of the member (GSC loc. C-170466). *Icriodus iowaensis ancylus* Sandberg and Dreesen (Plate 1, Fig. 1) was obtained 150 m above the base of the Morro (GSC loc. C-170468). *Palmatolepis rhomboidea* Sannemann (Plate 1, Fig. 8) was collected 197 m above the base of the Morro (GSC loc. C-170471). These faunas indicate strata as old as the Lower *Palmatolepis crepida* Zone at the base of the section to at least as young as the Upper *Palmatolepis rhomboidea* Zone at the top of the section.

Conodont data from correlative strata in middle section B, 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 marginifera* Zone. Faunas from the section included *Palmatolepis stoppeli* Sandberg and Ziegler (Plate 1, Fig. 7), 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.

The overlying Costigan Member is of middle and late Famennian age in the Exshaw/Jura Creek region. This member has been sampled for conodonts at stops 12 and 13 on Mount Rundle, but the samples have not been completly processed. 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, Fig. 1). 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). Several specimens of *Palmatolepis marginifera marginifera* Helms were collected near the top of the lower Costigan at section A (GSC loc. C-209870, 39.5 to 39.7 m above base of Costigan). Slightly higher in the same section (from GSC C-209871, 39.75 m above base of Costigan), a fauna including *"Icriodus"* cf. *"I." costatus costatus* Thomas and *Palmatolepis glabra distorta* Branson and Mehl, but lacking *P. marginifera marginifera*, was collected. The latter fauna came from a thin, unconformity-bounded TR sequence lying below the upper transgressive unit of the Costigan. *P. marginifera marginifera* first appears at the base of the *marginifera* Zone and ranges upward into the lowermost *trachytera* Zone. *P. glabra distorta* first appears at the base of the *marginifera* Zone and ranges upward to the top of the *trachytera* Zone, and *"Icriodus" costatus costatus* first appears at the base of the Uppermost *marginifera* Zone and ranges into the Lower *expansa* Zone (Ziegler and Sandberg, 1984). On the basis of the faunas collected at C-204870 and C-209871, the top of the lower Costigan at section A is no older than the Uppermost *marginifera* Zone and no younger than the Upper *trachytera* Zone.

The upper transgressive unit of the Costigan Member, lying within the Lower to Middle *Palmatolepis gracilis expansa* zones (Richards and Higgins, 1988; Richards et al., 1991; Savoy and Harris, 1993), yielded (GSC loc. C-136780, 1.9 m below top of Costigan) *Polygnathus experplexus* Sandberg and Ziegler. *P. experplexus* first appears at the base of the Lower *expansa* Zone and ranges upward into the Middle *expansa* Zone (Ziegler and Sandberg, 1984). Associated taxa (from GSC locs. C-136780, C-136781, C-136782, C-170458, C-195029, C-195031 and C-195146) are *Apatognathus* sp., *Bispathodus stabilis* (Branson and Mehl) (Plate 1, Fig. 6), *Pelekysgnathus inclinatus* Thomas (Plate 1, Fig. 3), *Polygnathus communis communis* Branson and Mehl, *P. nodocostatus*, *P. semicostatus*, and *Pelekysgnathus inclinatus* Thomas (Richards and Higgins, 1988).

The *Palmatolepis rugosa trachytera* and *Palmatolepis perlobata postera* zones, which normally lie between the *marginifera* and *expansa* zones in other basins, are not present at Jura Creek and many other areas in the eastern Front Ranges and in the Interior Plains (Richards et al., 1991; Savoy and Harris, 1993; Johnston and Meijer Drees, 1993). The *trachytera* Zone, however, is recognized at section A by Lac des Arcs. The absence of these zones at Jura Creek and elsewhere demonstrates that the magnitude of the unconformity below the upper transgressive unit of the Costigan and correlative upper Big Valley Formation is commonly substantial (Fig. 4).

Stromatoporoids

Below the type section of the Exshaw Formation on Jura Creek (stop 6, Fig. 2) stromatoporoids are common in the upper Costigan Member between 2.4 and 2.0 m below its top. Two specimens collected at 2.05 m below the top of the Costigan (from GSC loc. C-195032) were identified as *Labechia palliseri* Stern by A. Pedder (pers. com.). These stromatoporoids, which have a tabular to highly undulatory growth habit (Plate 3, Fig. 1), are known from five other middle Famennian occurrences in the Costigan Member of Alberta and from one occurrence in the Famennian Trident Member of the Three Forks Formation of Jefferson County, Montana. The species has not been found in older or younger strata in western Canada (A. Pedder, pers. com; Stern, 1961).

Calcareous algae and foraminifers

Abundant calcareous algae and scattered foraminifers are present in the Costigan Member at Jura Creek (Richards et al., 1991). The principal algae and foraminifers recognized in samples (GSC locs. C-136741, C-136742, C-195014 to C-195017) collected from the lagoonal and tidal-flat deposits of the Costigan at stops 3 and 6 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 3 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..

UPPERMOST DEVONIAN AND CARBONIFEROUS STRATIGRAPHY AND DEPOSITIONAL ENVIRONMENTS

Regional stratigraphic framework

The uppermost Devonian and Carboniferous of the WCSB (Figs. 5, 9, 16, 17) is a thick succession of lithofacies mainly 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 Famennian 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.

The uppermost Devonian and Lower Carboniferous succession from southwestern Manitoba to southwestern District of Mackenzie was divided by Richards (1989) into five mapable lithofacies assemblages on the basis of depositional setting, lithology, and depositional history (Figs. 5, 9).

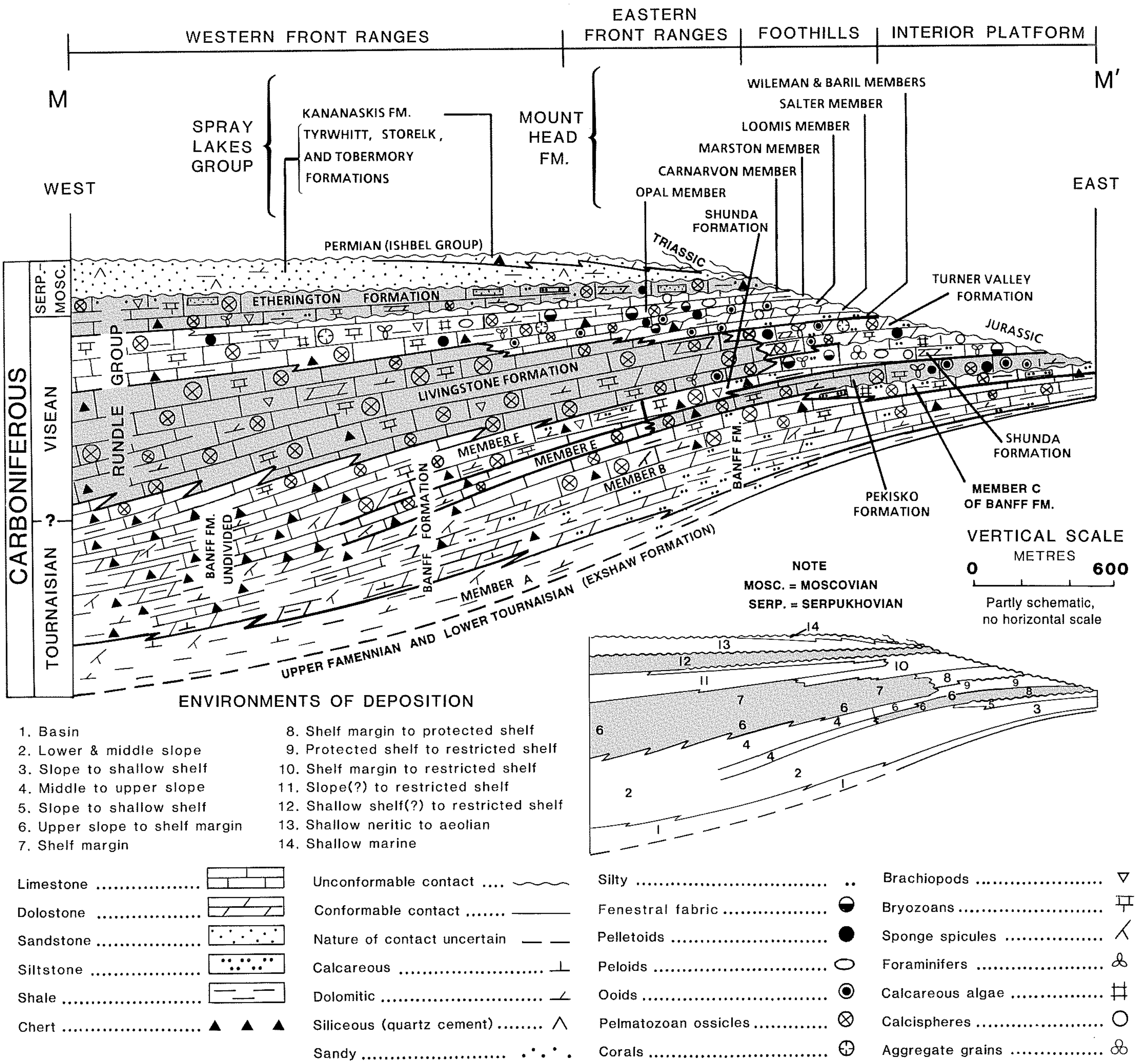


Figure 16. Partly schematic, non-palinspastic cross-section M-M' showing Carboniferous of southwestern Alberta. See Figure 9 for line of section. Modified from Richards (1989).

Lithofacies deposited in western Prophet Trough and on its western rim are called the western assemblage (Figs. 8, 9). This assemblage, largely removed by deep post-Carboniferous erosion, includes carbonates, volcanics and remnants of an easterly thinning clastic wedge (Gordey et al., 1987; Richards, 1989).

The succession to the east, which includes platform to ramp carbonates (Figs. 18, 19) and deltaic terrigenous clastics, comprises the Banff, Rundle, and Mattson lithofacies assemblages. Tournaisian formations constituting parts of the Banff and Rundle assemblages will be examined on this field excursion

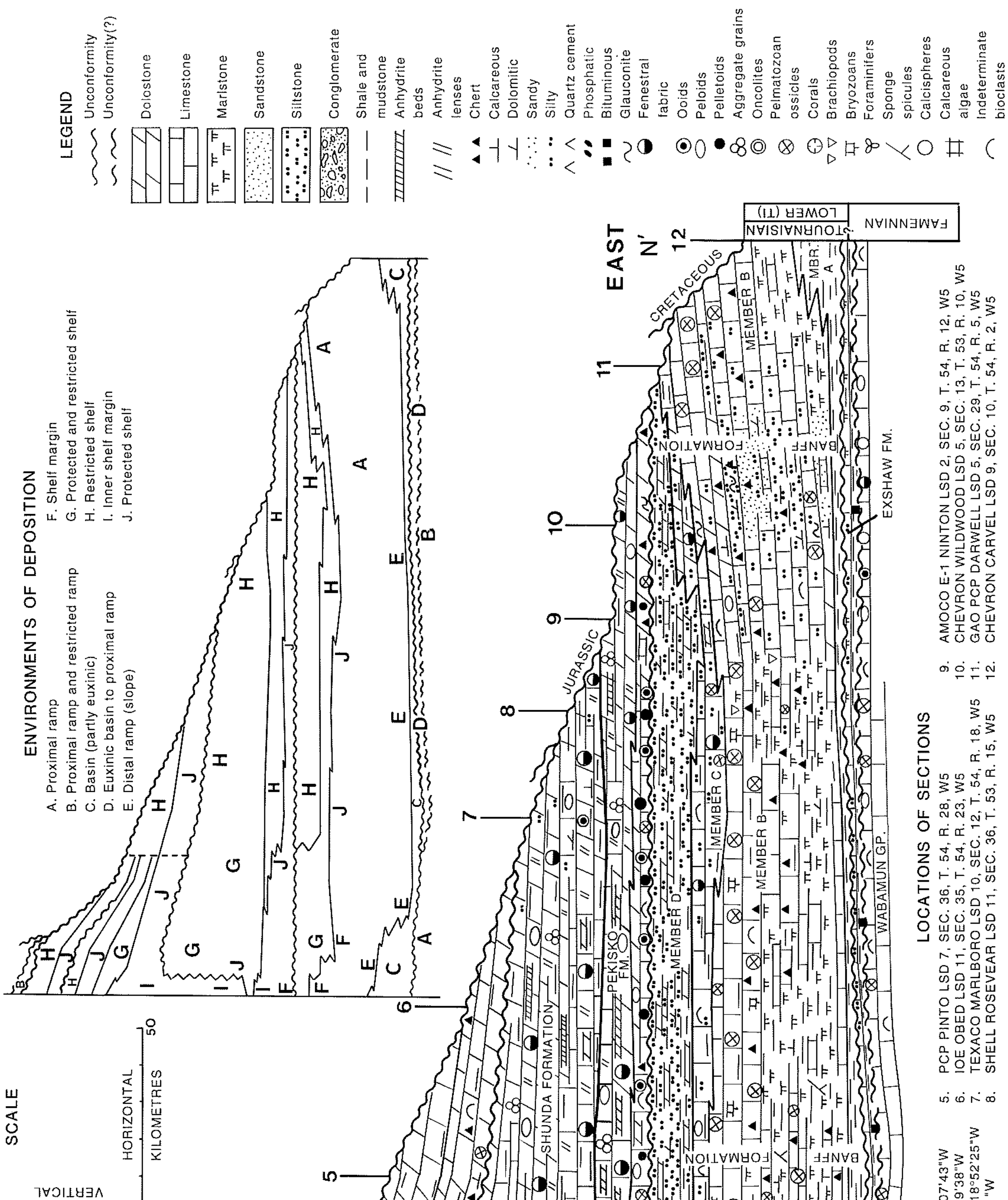


Figure 17. Partly schematic, non palinspastic cross-section N-N' showing uppermost Devonian and Lower Carboniferous of west-central Alberta. See Figure 9 for line of section. Modified from Richards, 1989).

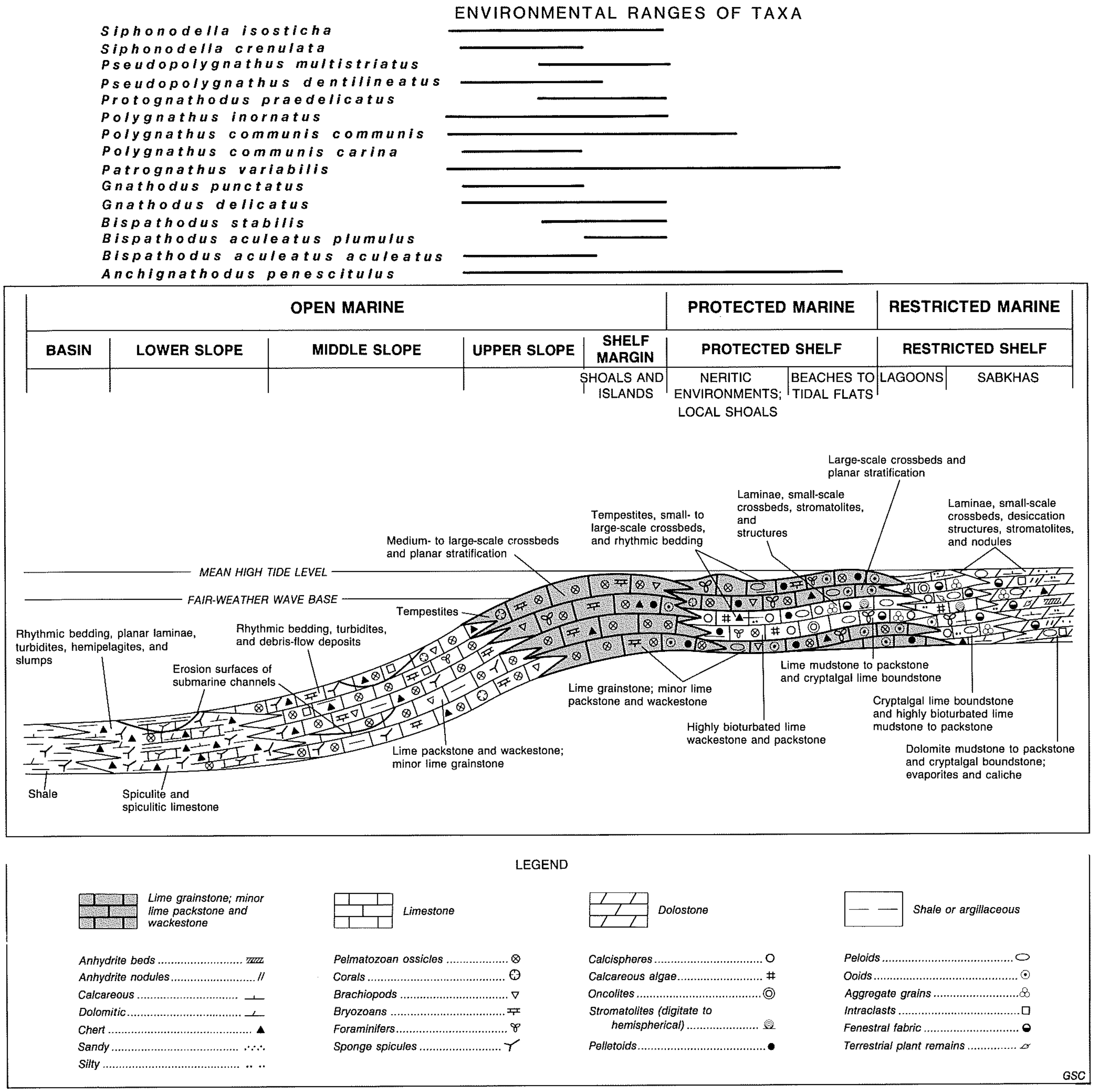


***Figure 18.** Generalized depositional model of a Carboniferous carbonate platform showing established environmental ranges of conodont species characteristic of the Upper* crenulata-isosticha *Zone in the Rundle assemblage of the WCSB (from Higgins et al., 1991).*

along Jura Creek, Grotto Mountain, and Mount Rundle (Figs. 1-3). Younger lithofacies of the Rundle assemblage and those of the Mattson assemblage are widely exposed in the Exshaw and Canmore regions, but will only be seen from a distance on this excursion. The Banff, Rundle and Mattson assemblages resemble the lower, middle, and upper depositional units, respectively, of Macauley et al. (1964) and Richards et al. (in press b). The Mattson assemblage of Richards (1989) was expanded by Richards et al. (1991) and Higgins et al. (1991) to include the sandstone-dominated Upper Carboniferous succession (Fig. 20).

Fine-grained siliciclastics and cherty to argillaceous carbonates of the Banff assemblage are widely overlain by the carbonate-dominated Rundle assemblage, which is in turn partly overlain by the sandstone-

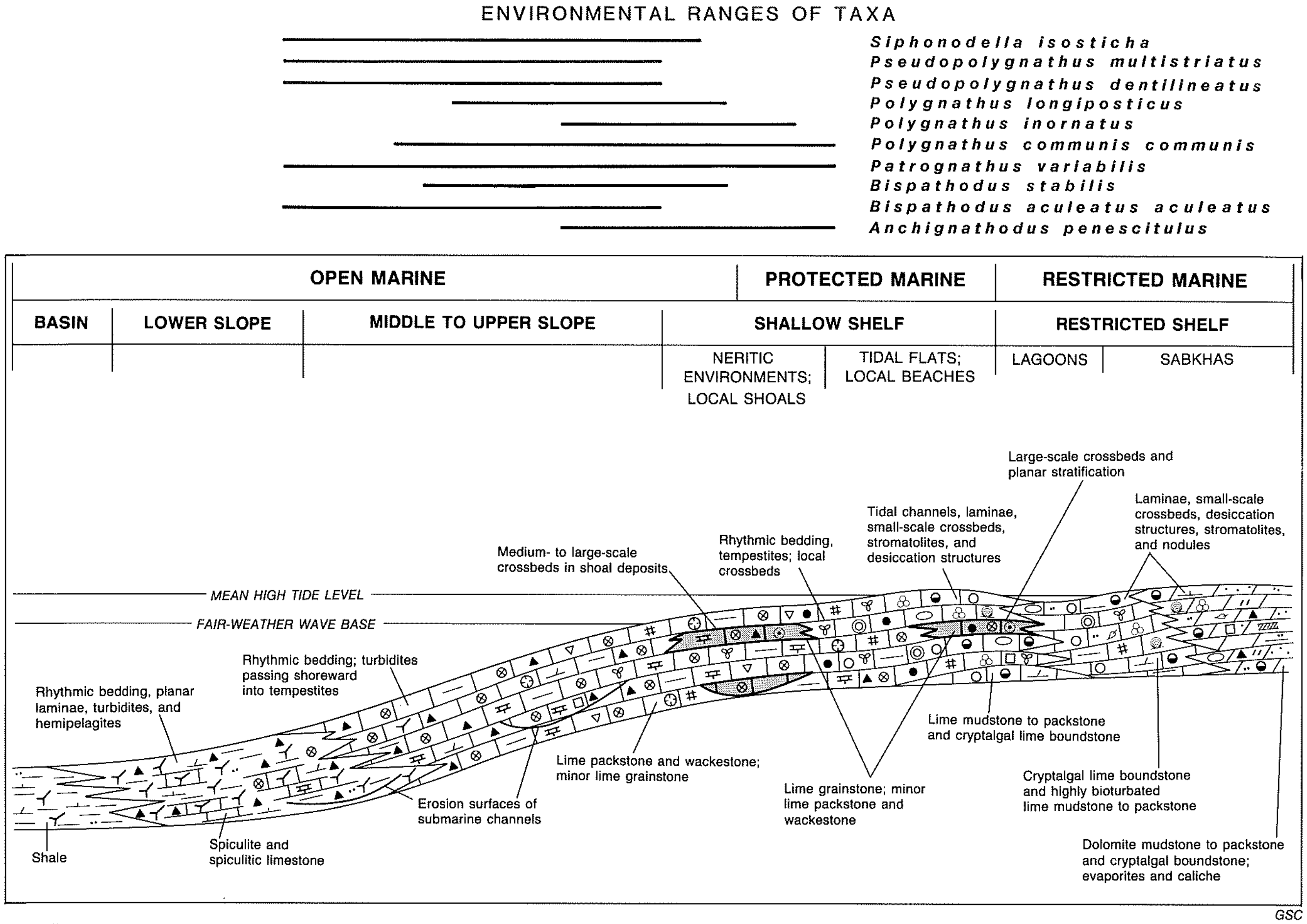


***Figure 19.** Generalized depositional model of a Carboniferous carbonate ramp showing established environmental ranges of conodont species characteristic of the Upper* crenulata-isosticha *Zone in the Banff assemblage of the WCSB (from Higgins et al., 1991). See Figure 18 for legend.*

dominated Mattson assemblage. From east-central British Columbia to southwestern District of Mackenzie, the Banff, Rundle, and Mattson assemblages overlie and pass basinward into a fifth assemblage consisting of the shale-dominated Besa River Formation.

Two regional cross-sections that incorporate borehole logs (Figs. 21, 22; in pocket) illustrate the stratigraphic relationships between the uppermost Devonian and Carboniferous succession exposed at Jura Creek and that of the subsurface in the foothills and Interior Platform. Figure 23, representing a subsurface section near Moose Mountain, 38 km southeastward of Jura Creek, illustrates the relationship between rock types and the gamma-ray log traces used in Figures 21 and 22. The schematic cross-sections, Figures 16, 17, and 20, illustrate the stratigraphy of the Carboniferous of western Alberta and provide environmental interpretations.

Distribution and regional stratigraphy of Banff assemblage

The Banff assemblage (Figs. 5, 9) 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. At Jura Creek, Grotto Mountain and Mount Rundle, the Banff assemblage is represented by carbonates and fine-grained siliciclastics of the Exshaw and overlying Banff Formation.

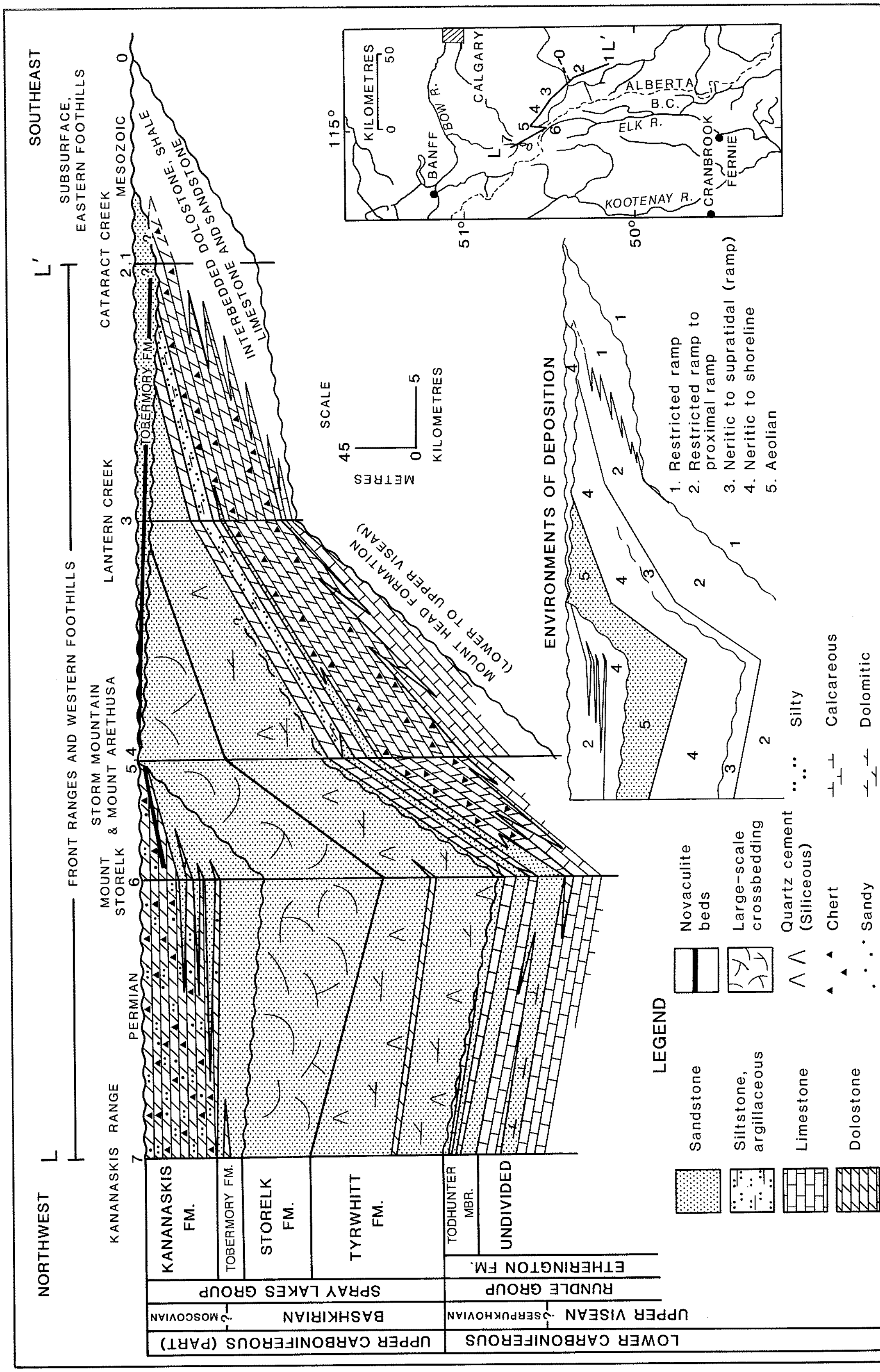


Figure 20. Partly schematic, non palinspastic cross-section L-L' showing Mattson assemblage (uppermost Rundle Group and Spray Lakes Group) of southwestern Alberta (after Scott, 1964). See Figure 9 for line of section.

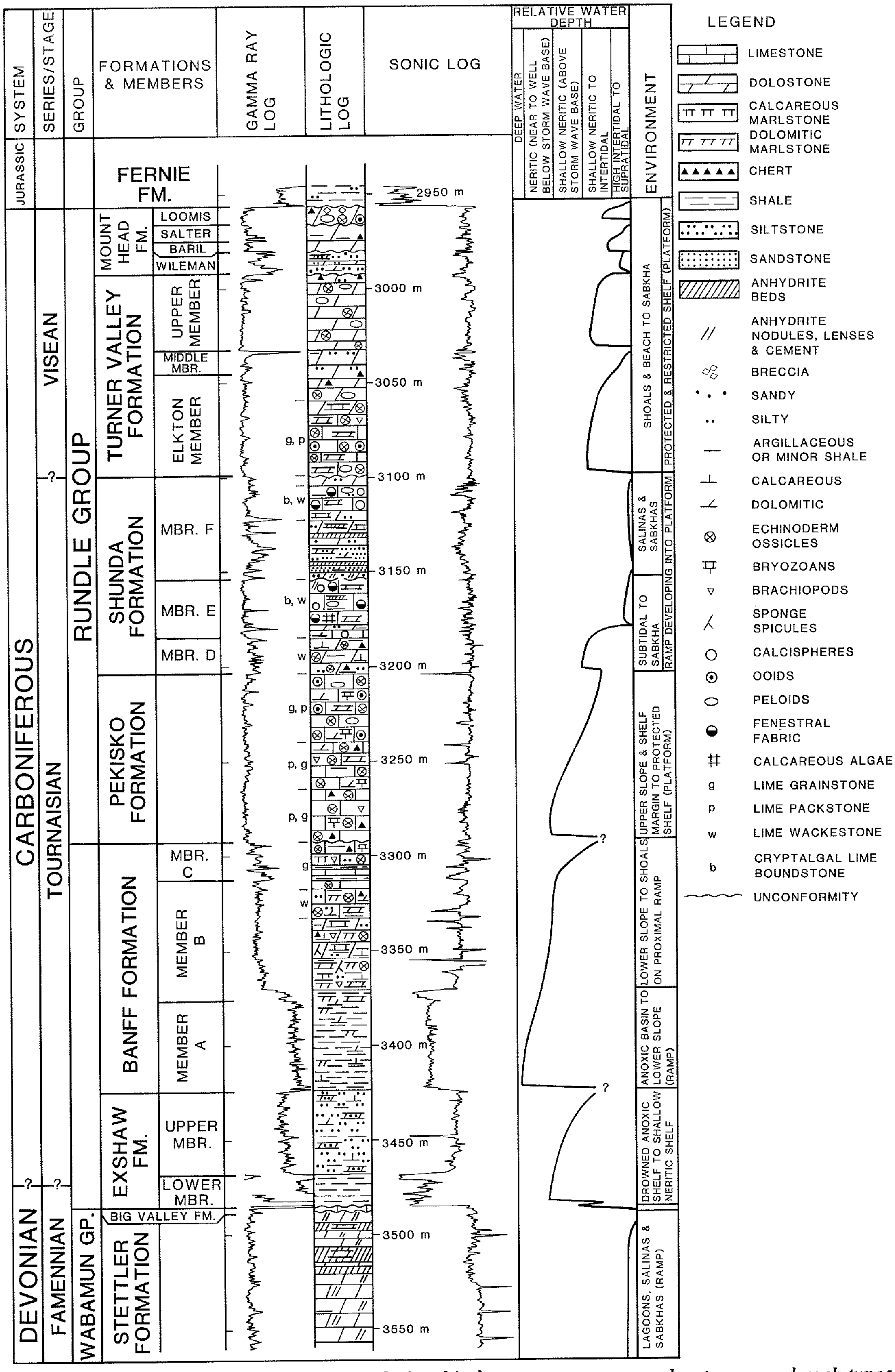


***Figure 23.** Representative borehole section showing relationship between gamma-ray log traces and rock types at Moose Mountain (at 6-25-22-6W5), a locality represented on cross-section H-H' (Pocket Fig. 21).*

In most areas, the Banff assemblage disconformably overlies the upper Famennian Palliser assemblage of Morrow and Geldsetzer (1988). 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 (Figs. 5, 16). Elsewhere, the boundary between these two packages is generally abrupt and commonly a minor disconformity. Deposition of the Banff assemblage began during the the time of the Middle to Upper *Palmatolepis gracilis expansa* 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 (Figs. 18, 19). 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 eastern occurrences of the upper Banff and Exshaw formations (Fig. 24) and in the middle Bakken Formation. The shallow-marine shelf carbonates 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.

Exshaw Formation

Lithostratigraphy and sedimentology

The upper Famennian to lower Tournaisian Exshaw Formation (Warren, 1937), which will be examined at Jura Creek and on Mount Rundle, is widely distributed in the eastern Rocky Mountain Fold and Thrust Belt and occurs on most of the western Interior Platform from southern Alberta to southwestern District of Mackenzie. In the eastern Rockies it is generally present from 49°00'N to 52°30'N, but from 52°30'N into east-central British Columbia it occurs only locally because of uplift and subaerial erosion prior to deposition of the overlying Banff Formation (Figs. 5, 17). The Exshaw, 47 m thick at its type section on Jura Creek (Figs. 25, 38), is generally from 7 to 50 m thick.

In most areas the sharp, subplanar contact between the Exshaw Formation and underlying Upper Devonian strata is generally a minor disconformity, but the contact is at least locally conformable in the Peace River Embayment region (Macqueen and Sandberg, 1970; Richards and Higgins, 1988; Johnston and Meijer Drees, 1993; Richards et al., in press b). The presence of a disconformity is indicated by the presence of basal conglomerates and deposits of different ages immediately below the Exshaw.

At its type section on Jura Creek (Fig. 2, stop 6), the Exshaw abruptly and probably disconformably overlies shallow-marine carbonates of the Costigan Member of the Palliser (Figs. 4, 25). However, the disconformity at this locality is a relatively minor one, interpreted to be the result of submarine erosion (Richards and Higgins, 1988). Both the upper Palliser and the basal Exshaw are within the *expansa* conodont Zone, and no unequivocal sedimentological evidence for either subaerial exposure or substantial erosion occurs at the contact. The Exshaw also unconformably overlies the Palliser Formation on Mount Rundle and throughout the region.

The nature of the contact between the Exshaw and overlying Banff Formation is highly variable in western Alberta (Richards et al., in press b). In the southern Rocky Mountains, it is abrupt and erosional at many eastern localities but commonly gradational in the west. In the foothills and Interior Plains of southern Alberta, it is commonly gradational and difficult to pick (Figs. 22, 23). The Exshaw is disconformably overlain by the Banff Formation in southern Peace River Embayment and in most of west-central Alberta (Figs. 5, 17). In the eastern Rocky Mountain Front Ranges of west-central Alberta and east-central British Columbia, where the Exshaw is truncated northwestward below the Banff, thin transgressive sandstone deposits of the basal Banff Formation disconformably overlie the Exshaw and Palliser formations (Harker and McLaren, 1958; Macqueen and Sandberg, 1970; Richards, 1989).

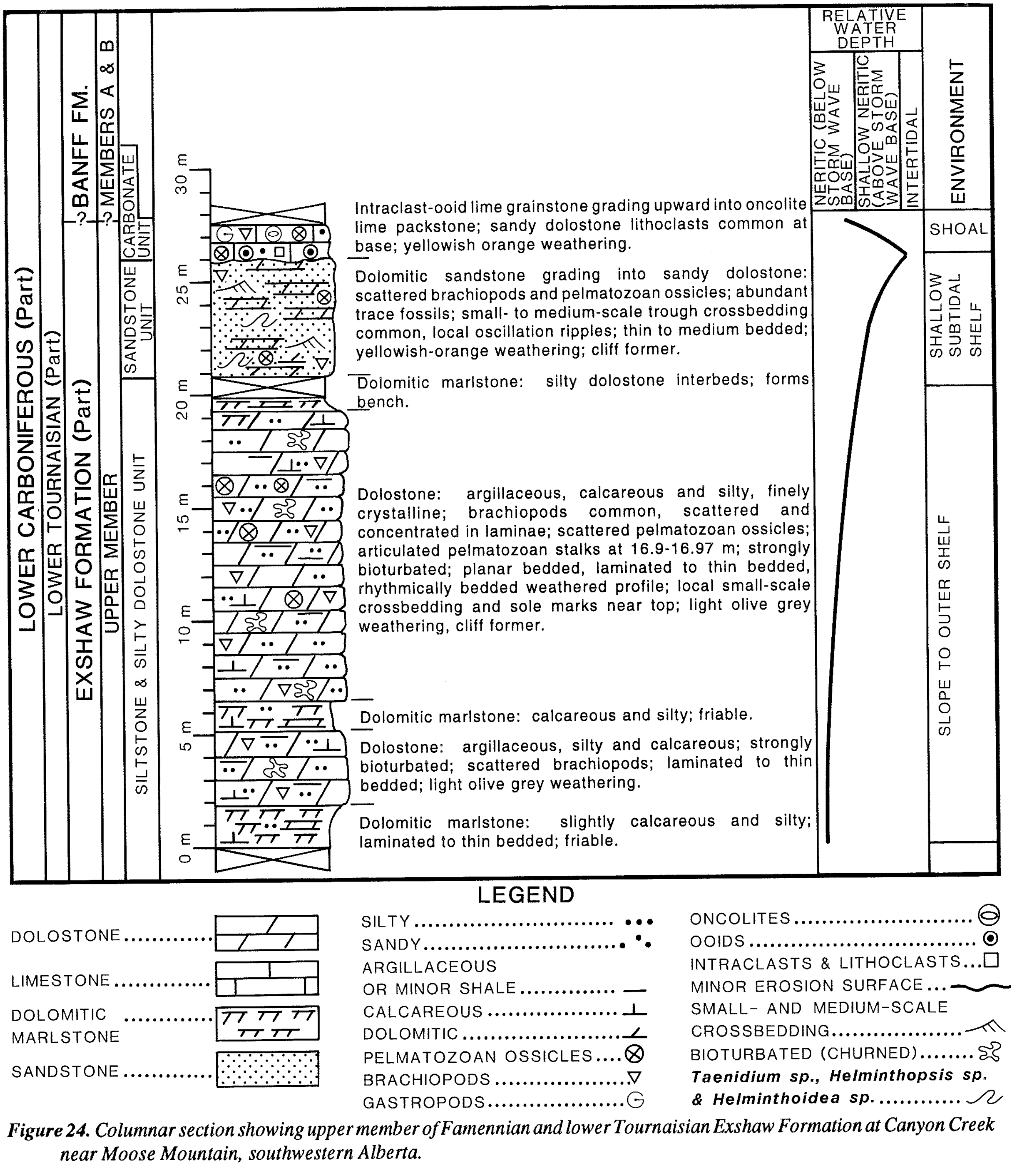


Figure 24. Columnar section showing upper member of Famennian and lower Tournaisian Exshaw Formation at Canyon Creek near Moose Mountain, southwestern Alberta.

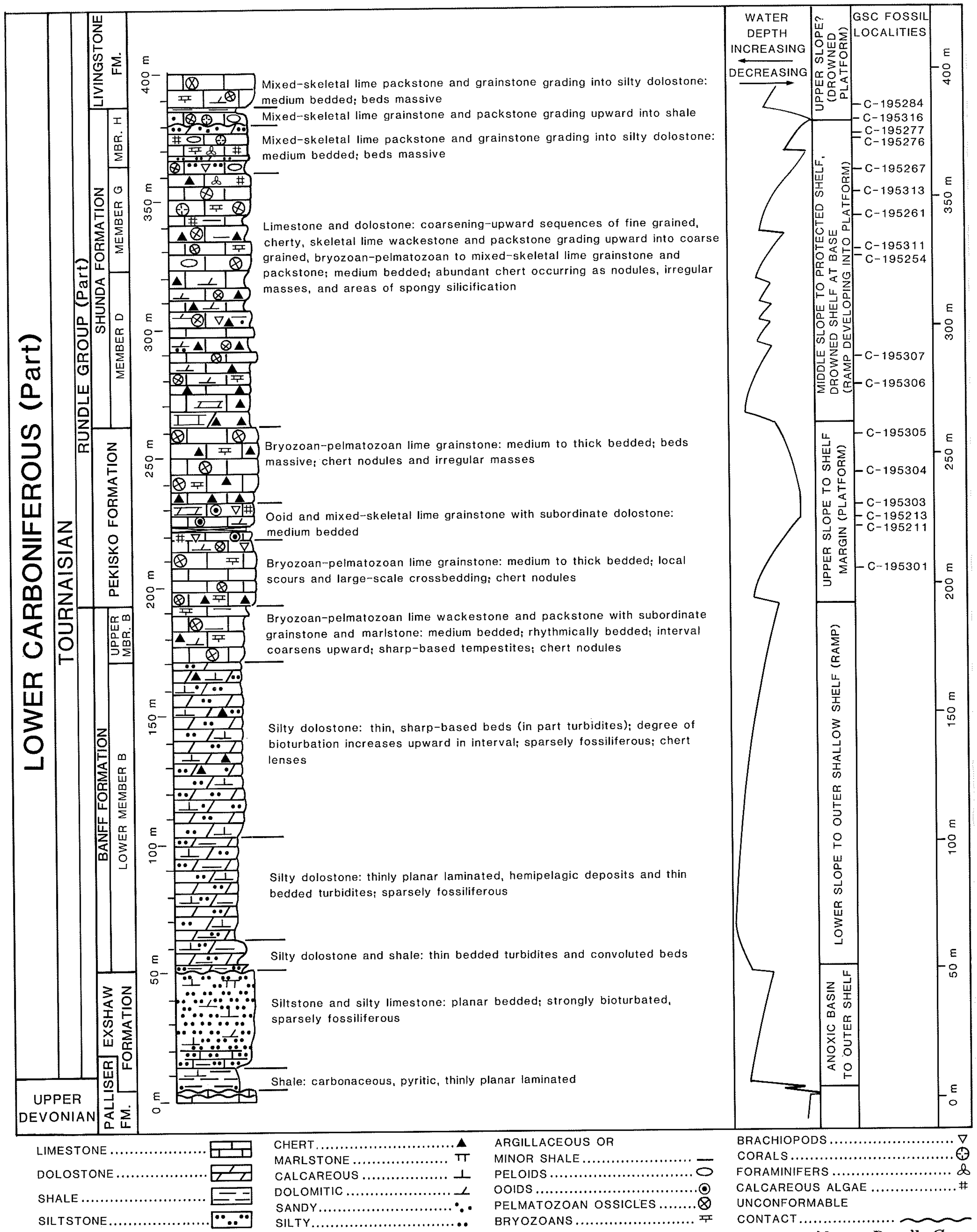


Figure 25. Columnar section of uppermost Palliser Formation, Exshaw Formation, Banff Formation and lower Rundle Group (Pekisko Formation, Shunda Formation, and basal Livingstone Formation) at stops 6 to 10, middle canyon of Jura Creek. Composite section comprising sections 86RAH5, 90RAH7 and 90RAH8.

At the Exshaw type section, the Exshaw/Banff contact is placed at the base of a thin (16 to 19 cm thick) bed of greyish-black, calcareous shale that overlies a thick siltstone unit and is the first shale bed above the Exshaw black shale. Deposits on either side of the contact, which Macqueen and Sandberg (1970) suggested may be a disconformity, have not been precisely dated. The contact, slightly undulatory at this locality and other exposures along Jura Creek, locally shows minor erosional relief, but sedimentological evidence for substantial erosion is absent. Toward the southwest, the Exshaw/Banff contact becomes conformable; at the southeastern end of Mount Rundle and at section A, by Lac des Arcs, it is gradational.

From the Peace River Embayment southward, the Exshaw comprises a lower, shale-dominated member overlain by an upper member consisting of siltstone or sandstone and silty to sandy carbonates (Figs. 24, 25, 36). At the Exshaw type section, the lower member is 9.3 m thick and the upper 37.5 m thick. There, the contact between the members is placed at a break in slope, where the recessive black shale unit grades upward into silty, argillaceous limestone. At the southwestern end of Mount Rundle, the black shale member of the Exshaw is 10.6 m thick and the overlying siltstone member 9.8 m thick.

Three lithologic units constitute the lower member of the type Exshaw: a 1 to 6 cm thick, basal, conglomeratic sandstone bed; a 6.9 m thick middle interval of noncalcareous to slightly calcareous, brownish black shale; and an upper 2.4 m thick unit of calcareous brownish black shale. The basal sandstone bed is absent at Mount Rundle, but the two black shale units are well developed.

The basal bed of the Exshaw stratotype consists of well cemented sandstone (subarkose to arkose) grading into conglomerate. Most granule size and larger clasts in the conglomerate are phosphate nodules and abraded bone fragments; teeth and fish scales are also common. The basal bed contains anomalous concentrations of nickel (in the nickel sulphide vaesite), zinc (in sphalerite), and iron (in pyrite; Tables 1, 2 at GSC locs. C-136748B and C-195038).

Shale of the middle unit of the lower type Exshaw gradationally overlies the slightly wavy top of the sandstone bed. The metal-rich shale (Tables 1, 2) is moderately fissile to blocky, pyritic, noncalcareous to slightly calcareous, siliceous, and has a moderately high organic carbon content (4.2 to 5.5%). Except for its basal 5 to 10 cm, where sponge spicules are common, the shale lacks fossils of macroscopic benthic organisms. Calcareous to cherty concretions containing conodont faunas, which are generally low in diversity and number, are moderately common.

Calcareous shale of the upper unit of the lower type Exshaw abruptly overlies the middle shale unit. The shale of the upper unit is less resistant and siliceous than that of the middle unit. Scattered goniatites, nautiloids, conodonts, and inarticulate brachiopods are present. The percentage of pyrite resembles that of the lower shale unit, whereas the organic carbon content is lower (3.6 to 1.3%) and decreases upward.

Beds and laminae of yellowish-grey marine tuff, up to 1.5 m thick, occur in the black shale at many localities from southwestern Alberta into east-central British Columbia (Richards, 1989; Richards and Higgins, 1988). A thin (up to 5.5 cm thick), deeply-weathered bed of tuff containing expandable mixed-layer clays, orthoclase, and quartz (Table 1, GSC loc. C-195054) lies between 1.540 and 1.595 m above the base of the lower member of the type Exshaw (Fig. 39). A similar bed is present in the lower Exshaw at stop 12 on Mount Rundle. These pyroclastics resulted from latest Devonian volcanism and plutonism in western Prophet Trough and to the west (Gabrielse et al., 1982; Evenchick et al., 1984; Mortensen and Jilson, 1985; Okulitch, 1985; Mortensen et al., 1987; Richards and Higgins, 1988).

Calcareous and dolomitic siltstone with subordinate silty and argillaceous limestone constitute the upper Exshaw in most of the southern Rocky Mountains, including the Jura Creek and Mount Rundle areas. In the type section of the Exshaw Formation, most silt- and sand-size clasts in the upper member are quartz, but X-ray diffraction analyses (Table 1) indicate that feldspar constitutes 4 to 11 per cent of the minerals

C #	DEPTH	Mo	Nb	Zr	Y	Sr	U	Rb	Th	Pb	Zn	Cu	Ni	Mn	Cr	Ba
C195036	3.85-3.95	-4	-2	9	-3	250	-6		-9	-12	11	45	59	510	6	74
C195037	3.95-4.00	-5	-3	21	16	183	16	27	-9	-12	19	81	179	358	12	161
C195038	4.00-4.05	560	11	94	128	253	47	46	12	-13	21941	240	4825	301	20	882
C195039	4.05-4.10	100	-2	45	17	84	14	68	-7	12	103	29	625	337	16	275
C195040	4.10-4.20	202	5	56	-3	39	-6		-8	-11	59	156	766	190	18	281
C195041	4.20-4.30	126	-2	45	18	23	19	87	7	-9	15	50	465	94	19	236
C195042	4.30-.4.40	128	2	47	3	19	8		-6	-9	10	206	453	104	23	251
C195043	4.40-4.50	90	-2	37	14	16	19	85	6	10	3	85	275	89	21	239
C195044	4.50-4.60	71	3	45	16	18	22	101	7	-8	11	9	175	91	23	234
C195045	4.60-4.70	116	-2	48	17	23	23	98	7	-9	52	34	292	97	24	246
C195046	4.70-4.80	120	-2	57	23	24	28	115	7	16	70	32	327	96	26	253
C195047	4.80-4.90	105	-2	48	21	22	23	100	7	10	10	27	337	89	23	222
C195048	4.90-5.00	80	-2	46	16	21	18	99	-6	10	1	0	202	94	23	249
C195049	5.00-5.10	75	-2	38	14	19	14	78	-6	-8	13	26	239	78	22	181
C195050	5.10-5.20	78	-2	30	13	29	13	46	-6	-8	219	55	283	85	32	142
C195051	5.20-5.30	116	-2	41	21	24	19	61	7	-8	424	28	275	73	37	194
C195052	5.30-5.40	126	-2	36	16	26	19	60	6	-8	598	33	302	75	37	154
C195053	5.40-5.54	111	-2	33	17	35	15	56	-6	-8	146	32	306	87	36	144
C195054	5.54	8	-2	151	25	25	19	190	44	25	276	83	220	139	8	354
C195055	5.50-5.60	225	6	93	23	28	27	119	11	10	25	52	355	111	50	293
C195056	5.60-5.70	183	3	56	17	19	14	105	-6	-8	33	72	358	86	52	225
C195057	5.70-5.80	139	3	52	16	14	16	104	-6	-8	63	57	288	62	55	213
C195058	5.80-5.90	104	-2	32	16	24	9	66	-6	-8	28	431	271	78	41	167
C195059	5.90-6.00	93	-2	36	24	35	13	58	-6	-9	119	72	230	118	35	154
C195060	6.00-6.10	81	-2	32	10	14	10	63	-6	-8	46	307	220	56	37	157
C195061	6.10-6.20	104	-2	39	12	12	12	77	-6	-8	142	78	215	45	44	205
C195062	6.20-6.30	132	-2	46	13	12	12	96	-6	-8	175	292	242	54	55	228
C195063	6.30-6.40	131	-2	34	11	10	11	69	-6	-8	122	47	228	37	46	173
C195064	6.40-6.50	75	-2	35	7	11	8	71	-5	-7	1	169	131	30	44	187
C195065	6.50-6.60	94	-2	37	9	10	12	83	6	-8	209	68	189	45	44	226
C195066	6.60-6.70	116	-2	44	13	10	10	86	6	-8	299	520	288	41	50	203
C195067	6.70-6.80	172	2	53	18	12	15	114	10	12	1293	94	343	51	62	256
C195068	6.80-6.90	108	-2	49	11	11	9	99	-6	-8	93	236	188	42	43	256
C195069	6.90-7.00	149	-2	60	19	22	15	111	8	-9	1006	100	398	108	51	272
C195070	7.00-7.10	130	-2	48	15	18	11	98	10	11	344	57	266	77	52	233
C195071	7.10-7.20	206	4	77	21	24	18	144	6	9	1093	34	370	106	65	311
C195072	7.20-7.30	126	-2	49	16	20	13	90	6	-8	1204	186	201	86	50	203
C195073	7.30-7.40	119	-2	39	16	18	12	74	-6	9	978	21	276	69	47	193
C195074	7.40-7.50	113	-2	37	13	18	13	73	7	-8	543	24	212	67	46	212
C195075	7.50-7.60	125	-2	40	14	16	9	80	-6	9	1081	43	255	57	49	160
C195076	7.60-7.70	128	-2	41	15	19	14	82	9	-8	895	39	235	65	51	187
C195077	7.70-7.80	101	-2	32	10	29	5	65	-6	-8	558	16	232	86	41	174
C195078	7.80-7.90	80	-2	31	11	29	8	63	-6	-8	250	32	199	85	37	167
C195079	7.90-8.00	100	-2	39	16	32	10	74	-6	-8	92	27	241	94	43	195
C195080	8.00-8.10	136	-2	53	19	32	10	102	-6	-9	14	47	253	103	50	213
C195081	8.10.8.20	150	3	71	24	50	14	150	-7	13	21	300	322	130	61	284
C195082	8.20.-8.30	142	4	67	22	34	15	173	-6	10	76	52	286	99	61	280
C195083	8.30.-8.40	123	2	56	18	28	15	143	-6	-9	211	54	245	92	56	273
C195084	8.40-8.50	124	-2	59	19	31	14	149	10	9	115	259	238	98	54	295
C195085	8.50-8.60	97	5	57	20	45	11	123	7	10	150	33	263	129	52	272
	" - " followed by number means that value is the detection limit															

Table 2. Concentration (ppm) of selected elements in rock samples from the uppermost Costigan Member and overlying lower member of the Exshaw Formation at stop 6 on Jura Creek. Sample locations are given in metres above base of the measured section (Fig. 36). Base of Exshaw is at 4.0 m above base of section, and base of upper calcareous shale unit

C #	DEPTH	Mo	Nb	Zr	Y	Sr	U	Rb	Th	Pb	Zn	Cu	Ni	Mn	Cr	Ba
C195086	8.60-8.70	98	4	57	17	32	12	142	-6	-9	148	32	280	98	53	288
C195087	8.70-8.80	94	3	55	22	43	10	122	7	15	130	37	250	125	50	279
C195088	8.80-8.90	87	2	50	17	32	14	121	7	13	224	25	254	108	48	275
C195089	8.90-9.00	93	-2	47	16	26	10	111	-6	-8	378	328	266	93	50	276
C195090	9.00-9.10	93	2	56	21	29	10	123	-6	12	482	306	269	99	57	303
C195091	9.10-9.20	101	3	66	24	55	14	169	-7	-9	233	67	266	129	58	291
C195092	9.20-9.30	101	4	65	22	44	13	173	-7	9	155	51	338	119	58	316
C195093	9.30-9.40	96	4	66	22	35	12	171	-6	11	167	211	258	103	55	306
C195094	9.40-9.50	94	4	68	18	25	12	170	8	11	192	46	264	95	54	305
C195095	9.50-9.60	93	2	55	11	20	11	129	9	17	494	33	246	78	49	226
C195096	9.60.9.70	89	4	52	13	24	11	123	-6	9	766	0	220	76	53	278
C195097	9.70-9.80	115	3	67	23	40	14	150	-7	11	723	227	281	111	57	257
C195098	9.80-9.90	81	3	68	13	19	11	139	-6	-8	1029	27	185	69	44	281
C195099	9.90-10.00	92	4	71	18	29	15	145	8	19	1020	144	251	125	47	361
C195100	10.00-10.10	80	-2	53	14	22	9	110	-6	11	1186	38	221	79	45	275
C195101	10.10-10.20	75	-2	46	11	14	8	101	7	11	1075	148	200	65	45	241
C195102	10.20-10.30	85	3	50	11	18	8	108	-6	11	1020	33	216	74	44	259
C195103	10.30-10.40	78	-2	68	15	16	9	174	-6	14	383	200	239	67	52	370
C195104	10.40-10.50	111	6	79	19	27	10	162	8	10	835	41	219	112	57	262
C195105	10.50-10.60	127	5	76	20	30	11	169	-6	14	697	42	306	137	57	392
C195106	10.60-10.70	201	6	84	22	47	15	152	10	35	431	219	200	172	30	384
C195107	10.70-10.80	223	6	77	25	80	14	131	-7	23	1050	67	289	197	43	314
C195108	10.80-10.90	149	3	43	41	310	15	104	-8	19	261	52	219	327	22	360
C195109	10.90-11.00	89	4	44	36	333	7	109	-8	17	434	29	208	328	25	328
C195110	11.00-11.10	47	3	54	35	266	6	121	8	19	274	176	178	242	26	356
C195111	11.10-11.20	24	3	60	28	206	6	147	12	27	21	33	201	199	28	438
C195112	11.20-11.30	23	6	73	25	121	-6	194	10	43	10	28	194	146	31	479
C195113	11.30-11.40	19	6	64	29	192	-6	162	9	36	0	33	161	208	27	369
C195114	11.40-11.50	20	7	75	26	179	-6	191	12	42	4	132	143	179	29	457
C195115	11.50-11.60	-4	8	83	26	155	-6	203	8	51	0	50	131	164	28	446
C195116	11.60-11.70	16	9	79	23	152	8	193	8	46	5	24	148	160	29	418
C195117	11.70-11.80	9	7	77	25	162	-6	188	11	43	0	102	151	166	31	396
C195118	11.80-11.90	11	7	78	25	165	-6	191	13	48	0	21	136	169	29	431
C195119	11.90-12.00	10	8	75	27	251	-6	167	10	37	0	4	122	199	26	410
C195120	12.00-12.10	12	8	76	29	244	-6	164	10	36	0	124	150	199	31	371
C195121	12.10-12.20	12	7	78	31	250	-6	164	-7	35	0	147	124	203	27	424
C195122	12.20-12.30	6	8	78	28	249	-6	164	9	38	0	16	166	203	29	409
C195123	12.30-12.40	5	8	79	27	243	-6	166	11	37	0	90	131	204	27	392
C195124	12.40-12.50	-4	7	68	27	266	-6	154	12	36	3	0	214	224	32	400
C195125	12.50-12.60	-4	7	71	26	239	-6	171	-7	36	0	0	112	199	29	424
C195126	12.60-12.70	-4	9	78	23	148	-6	202	9	49	135	9	121	160	32	366
C195127	12.70-12.80	20	9	78	26	225	-6	189	10	27	52	0	325	197	49	244
C195128	12.80-.12.90	7	10	87	27	219	-6	198	13	58	137	0	124	191	32	354
C195129	12.90-13.00	-4	8	86	25	195	-6	191	10	52	106	0	133	170	34	586
C195130	13.00-13.10	-4	8	89	27	195	-6	189	12	54	29	38	56	171	35	397
C195131	13.10-13.20	-5	8	82	26	325	-7	163	25	164	26	0	266	211	29	655
C195132	13.20-13.30	-4	6	66	28	453	-6	126	-7	26	15	0	123	244	18	360
C195133	13.30-13.40	-4	5	62	25	487	-6	116	-7	22	0	0	72	266	18	14
C195134	13.40	-5	7	63	29	570	-7	112	-9	101	0	46	30	459	22	3284
	"-" followed by number means that value is the detection limit															

is at 11.01 m above base of section. Analyses were done at the Institute of Sedimentary and Petroleum Geology by A.G. Heinrich, who used a Philips PW1400 spectrometer.

present. At Jura Creek and Mount Rundle, primary sedimentary structures other than subplanar bedding are rare in the slightly pyritic, medium to thick bedded upper member, but the trace fossils *Taenidium* sp. (Fig. 40) and *Helminthopsis* sp. are conspicuous. Compressed goniatites are common in the lower two metres of the upper member at the type section.

The basal sandstone and conglomerate bed of the lower type Exshaw resembles a resedimented submarine lag deposit and has been interpreted to be a tempestite deposited near storm wave base (Richards and Higgins, 1988). Its presence above the Costigan records a decrease in water depth.

The lower member in the Jura Creek to Mount Rundle region was deposited in the anaerobic to dysaerobic zones and in moderately deep water (below storm wave base, but 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, Fig. 12) 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. Research by Pedersen and Calvert (1990) suggests that high primary productivity and not water-column anoxia provide the first-order control on the accumulation of carbon-rich deposits and establishment of oxygen-deficient bottom environments in modern oceans.

The upper Exshaw records shallowing, regression, and deposition in aerobic to dysaerobic environments at moderate to shallow water depths. In the southern Rockies, including the Jura Creek 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 eastward was deposited in shallow-marine environments (above fair weather wave base) as it locally contains ooid and skeletal lime grainstone and small- to medium-scale crossbedding (Fig. 24).

In the Calgary region and westward, the Exshaw Formation constitutes most of a third-order TR sequence (Exshaw/Bakken sequence of Richards, 1989) that includes the upper transgressive unit of the Costigan Member and its subsurface correlative, the upper Big Valley Formation. The upper Costigan and Big Valley represent the transgressive systems tract of the sequence, and the lower part of the black shale member of the Exshaw contains the maximun flooding surface. Regression culminated with widespread deposition of shallow-marine sandstone and grainstone of the upper Exshaw and local subaerial erosion.

Conodont biostratigraphy

The conodont zonation used for the uppermost Devonian and Lower Carboniferous 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 (Figs. 5, 26) was outlined for the uppermost Devonian to Upper Carboniferous of the WCSB by Higgins et al. (1991).

The Carboniferous/Devonian boundary, coinciding with the base of the *Siphonodella sulcata* conodont Zone (Paproth, 1980; Austin et al., 1985), probably is preserved 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; Higgins et al. 1991; 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*

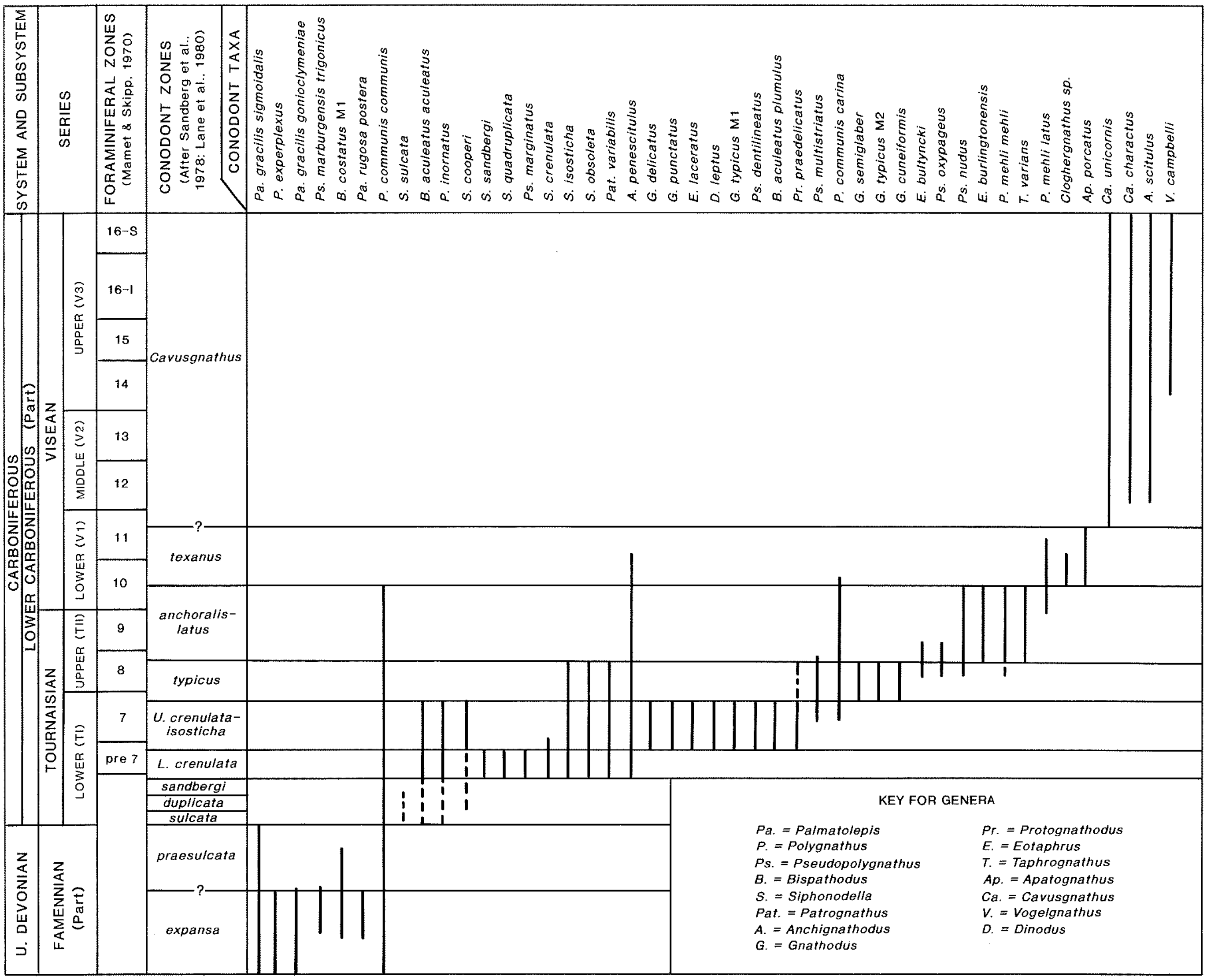


Figure 26. Known stratigraphic ranges of selected conodont species characteristic of the uppermost Devonian and Lower Carboniferous of the WCSB (from Higgins et al., 1991).

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) 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. 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 Carboniferous (early Tournaisian) age. *S. cooperi* has also been reported from the siltstone member of the Exshaw at stop 12 (Fig. 3) 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 (Fig. 36). 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).

Banff Formation

Lithostratigraphy and sedimentology

The Tournaisian Banff Formation (Kindle, 1924; Warren, 1927), consisting of shale, carbonates and sandstone, extends from southeastern British Columbia into southwestern District of Mackenzie. The distribution of the Banff Formation in the Exshaw region, as illustrated on Figure 2, differs greatly from that shown on the geological map of Price (1970), because strata originally mapped as the middle and upper Banff Formation have been assigned to the Pekisko and Shunda formations by Richards (1989) and Richards et al. (1991). A complete Banff section will be examined at Jura Creek, and the lower member (member A) will be studied on Mount Rundle, where it is well exposed. Most of the Banff is exposed at Grotto Mountain (Fig. 1), but will be seen only briefly.

The eastward-thinning Banff (Fig. 22) ranges from less than 150 m on the Interior Platform of Alberta to more than 500 m in southwestern District of Mackenzie (Richards, 1989; Richards et al., in press b). At stops 7 and 8 above the stratotype of the Exshaw Formation, the Banff is 192.4 m thick (Fig. 25).

At Jura Creek and in most of the southwestern part of the WCSB, the Banff Formation overlies the Exshaw Formation. It disconformably overlies the Palliser Formation in the eastern Cordillera from 52°30'N to 54°25'N, where most of the Exshaw was removed prior to Banff deposition. North of 55°00"N, the Banff overlies and passes basinward into the Besa River Formation.

In most of the WCSB, either the Pekisko or the Livingstone Formation overlies the Banff Formation (Figs. 16, 17). At Jura Creek and Grotto Mountain, the Pekisko conformably overlies the Banff, but at Mount Rundle the Livingstone overlies the Banff. The upper contact of the Banff generally coincides with a break in slope as the argillaceous lime wackestone and packstone of the upper Banff are less resistant than lime grainstone of the basal Pekisko and Livingstone.

In the Rocky Mountain Front Ranges of southwestern Alberta, the middle and upper Banff Formation (members E and F; Figs. 4, 16) pass northeastward into the Pekisko Formation and overlying lower to middle Shunda Formation (Richards, 1989; Richards et al., 1991; Richards et al., in press b). The eastern boundary with the Pekisko and Shunda coincides with the basinward limit of the thick lime grainstone units characteristic of the Pekisko.

The Banff consists of several informal members that were described briefly by Richards (1989) and in more detail by Richards et al. (in press a). Only one of these, member B, is well developed at Jura Creek. There, it conformably overlies a thin (16 to 19 cm thick), dark-grey, calcareous bed of silty shale that appears to represent member A of the Banff (Fig. 25). The Banff at Grotto Mountain comprises members A and B. At Mount Rundle, several members (members A, B, E and F) are well developed (Fig. 27), but only member A and basal member B will be examined.

In western Alberta member A, which generally overlies either the upper Exshaw Formation or the Palliser Formation, is dominated by grey to black shale that is commonly phosphatic. Thin siltstone and cabonate beds deposited by sediment gravity flows are commonly present. At stop 12 on the southwestern side of Mount Rundle, member A is 14.7 m thick and contains a thin bed of volcanic tuff. Member A was deposited in deep to moderately deep water as indicated by deep-water conodont assemblages, lithology and regional facies relationships. A regional transgression and episode of marked water deepening is recorded by the presence of these deposits above a subaerial erosion surface developed on the Palliser Formation of west-central Alberta (Fig. 17) and by their widespread occurrence above relatively shallow-water facies in the upper Exshaw Formation (Fig. 24; Richards, 1989; Richards et al., in press b).

Member B, which generally conformably overlies member A and consists of carbonates with subordinate siliciclastics, extends from southern Alberta into northeastern British Columbia. In most areas, it is gradationally overlain by, and grades laterally into, either member C or D (Figs. 17, 22). Where members C and D are absent, as in the Jura Creek to Mount Rundle region, member B is overlain by either member E of the Banff or the Rundle Group (Figs. 16, 25). Member B, mainly 50 to 250 m thick, generally constitutes either the middle Banff or most of the lower and middle Banff of western Alberta.

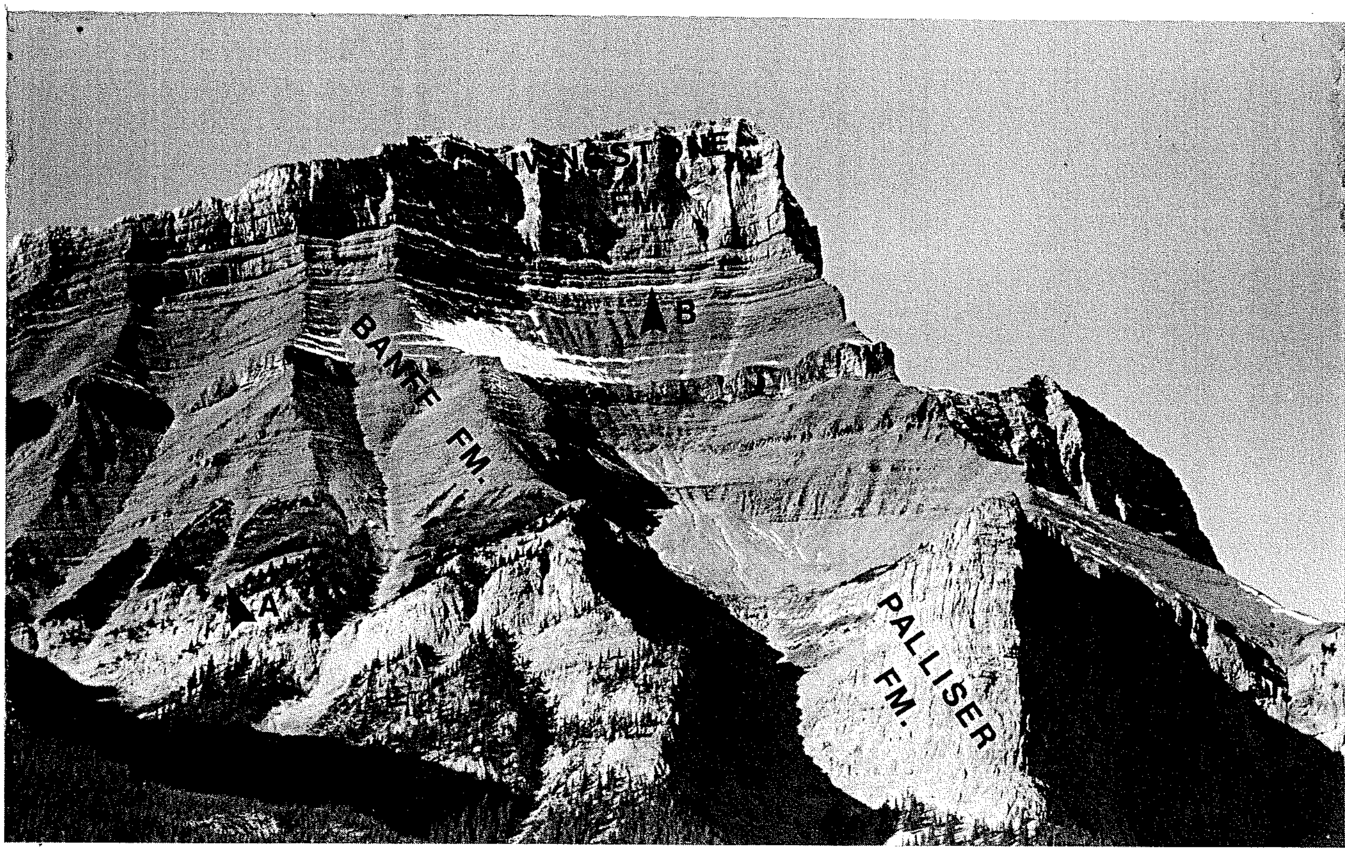


Figure 27. *Looking northwestward to northeastern side of Mount Rundle, from Highway 1 at Canmore, Alberta. Photograph shows Famennian Palliser Formation (arrow A indicates top), Tournaisian Banff Formation (arrow B indicates approximate top), and lower Livingstone Formation. The Exshaw Formation, about 20 m thick, underlies the Banff, but is poorly exposed. Middle resistant rib in Banff correlates with Pekisko Formation to the east.*

Member B consists of cherty to argillaceous spiculite, dolostone, lime mudstone, and wackestone, which commonly grade upward and northeastward into cherty lime packstone and grainstone. Shale is also locally common. Toward the north and northeast on the Interior Platform, siltstone and sandstone become locally abundant. In the southern to central Rocky Mountains and foothills, lower member B is commonly dominated by laminae of silty carbonates and thin turbidite-like carbonate beds rhythmically interbedded with marlstone. Upper member B is commonly dominated by pelmatozoan lime grainstone showing medium- to large-scale crossbedding.

Regionally, member B is a shallowing-upward sequence deposited in environments ranging from basin and lower slope to shelf margin, protected shelf, and proximal ramp (Figs. 17, 18; Richards, 1989; Richards et al., in press a). At Jura Creek, Grotto Mountain and Mount Rundle, member B is dominated by distal ramp lithofacies (lower- to upper-slope deposits). Along Jura Creek, the presence of grainstone and possible tempestites in upper member B suggests that facies deposited on the outer part of the proximal-ramp setting are also present. Regional shallowing upward within the member is recorded by an upward transition from hemipelagites and turbidites, representing basin and slope environments, to tempestites and crossbedded lime grainstone of shelf-margin to protected-shelf and proximal-ramp origin. In the area of the field excursion, deposition on a ramp rather than a platform is indicated by the lack of a grainstone belt characteristic of shelf-margin settings (Fig. 18).

At Jura Creek and in other parts of the WCB where it is overlain by the Pekisko Formation, the Banff Formation constitutes most of the thick, third-order TR sequence called the Banff/Lodgepole sequence by Richards (1989). The transgressive systems tract of the sequence is probably represented by the carbonate unit assigned to the upper Exshaw Formation at Moose Mountain (Fig. 24). Along Jura Creek, the transgressive systems tract appears to be represented by a unit of silty dolostone that shows convoluted beds and thin bedded turbidites and occurs in the basal Banff Formation (Fig. 25). In the Front Ranges of west-central Alberta, a thin (< 2m thick) phosphatic sandstone unit generally constitutes the basal transgressive deposits. At Mount Rundle, as in most of the western part of the WCSB, black shale of member A generally contains the maximum flooding surface of the sequence. Along Jura Creek, however, the maximun flooding surface is apparently in the unit of thinly planar laminated hemipelagic deposits that overlies the basal convoluted facies of member B. Regionally, lithofacies of Banff members B, C, and D generally constitute the regressive systems tract and record progradation and deposition under shallowing-upward conditions in distal-ramp to shallow-neritic shelf settings. In west-central Alberta (Fig. 17), members C and D record the establishment of vast supratidal settings, but these environments were not attained in the areas that will be visited on this field trip.

At Mount Rundle (Fig. 27), the lower Banff Formation represents the Banff/Lodgepole sequence. The middle to upper Banff, correlative with the Pekisko and overlying Shunda Formation at Jura Creek, is within the Pekisko/Shunda TR sequence of Richards (1989).

Conodont biostratigraphy

In the Jura Creek region, the Banff is of early Tournaisian age and lies within the Lower *Siphonodella crenulata* and Upper *Siphonodella crenulata-Siphonodella isosticha* conodont zones (Richards et al., 1991; Savoy and Harris, 1993). Younger strata occur in the middle to upper Banff on Mount Rundle but have not been precisely dated. At Jura Creek, the age of member A and most of member B has not been precisely determined. Most of the deposits are silty dolostone that are not favourable for conodont extraction. From a sample collected 136 m above the base of the Banff above the type Exshaw, Savoy and Harris (1993) extracted a fauna that represents the Lower *crenulata* to Upper *crenulata-isosticha* zones and includes: *Polygnathus communis* Branson and Mehl, *Polygnathus inornatus* Branson, *Bispathodus aculeatus* (Branson and Mehl), *Bispathodus stabilis* (Branson and Mehl), *Hindeodus* cf. *H. penescitulus* (Rexroad and Collinson) and *H. crassidentatus* (Branson and Mehl). Faunas belonging to either the highest Lower *crenulata* Zone or the lower part of the Upper *crenulata-isosticha* Zone have also been extracted from this unit at Princess Margaret Mountain (Richards et al., 1991), which is in the Inglismaldie Thrust Sheet 7 km north of Canmore (Fig. 21, western section). These faunas (GSC locs. C-136428, C-136429; 3.0 m and 0.1 to 0 m below top of Banff, respectively) include *Bispathodus aculeatus aculeatus* (Branson and Mehl), *Polygnathus communis communis* Branson and Mehl, *Siphonodella crenulata* Cooper, and *S.isosticha* (Cooper). *Gnathodus delicatus* (Branson and Mehl), the first appearance of which defines the base of the Upper *crenulata-isosticha* Zone (Sandberg et al. (1978), was not observed.

Faunas of the Lower *crenulata* Zone have been recognized in the lower to middle Banff Formation at many localities in the Rocky Mountains of west-central Alberta and east-central British Columbia. In the latter two areas, the Upper *crenulata-isosticha* Zone was widely recognized in the upper Banff and lower Pekisko formations (Higgins et al., 1991).

Distribution and regional stratigraphy of the Rundle assemblage

The carbonate-dominated Rundle assemblage of the WCSB (Figs. 5, 9) 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 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 Madison Shelf. In the region that we will visit on the field trip, the Rundle assemblage is represented by several formations (Figs. 5, 16, 25), but only the Pekisko, Shunda and basal Livingstone formations will be examined.

The Rundle assemblage generally overlies the Banff assemblage, but in northeastern British Columbia, deposits of the Rundle assemblage overlie and pass basinward into basinal shale of the Besa River assemblage. In most of the WCSB, the Rundle assemblage is unconformably overlain by either Permian or Mesozoic strata. It is, however, overlain by the sandstone-dominated Mattson assemblage on part of the westernmost Interior Platform, and over wide areas in the eastern Cordillera including the Exshaw region. The contact between the Rundle and Mattson assemblages is generally disconformable from southwestern Alberta into the southwestern part of the Peace River Embayment.

Carbonates of the Rundle assemblage were deposited on poorly differentiated carbonate platforms and to a lesser extent on carbonate ramps (Figs. 18, 19). The shelf-margin and proximal-ramp lithofacies of the assemblage generally grade southwestward (basinward) into slope deposits preserved in the upper part of the Banff assemblage of western Alberta and into the Prophet Formation of northeastern British Columbia. On the Interior Platform south of Calgary, they grade southward into slope deposits of the Banff Formation (Fig. 21) that were deposited in the seaway connecting Prophet Trough to the Williston Basin (Fig. 10).

Pekisko Formation

Lithostratigraphy and sedimentology

The Pekisko Formation (Douglas, 1958; Penner, 1958), deposited in the Prophet Trough and the Peace River Embayment and on the western cratonic platform, is widely distributed from southern Alberta to southwestern District of Mackenzie (Figs. 16, 17, 21-23, 25). This formation, consisting of lower and upper Tournaisian limestone and subordinate dolostone, is present on most of the western Interior Platform north of 49°45'N. It is also generally present in the foothills from 49°45'N to 55°00'N and the eastern Rocky Mountains from 50°45'N to 55°00'N. On the field trip, this formation will be examined along Jura Creek (Figs. 42-44) and on Highway 1A at Grotto Mountain.

The Pekisko Formation is thickest (40 to 120 m) in the foothills and eastern front ranges of southwestern Alberta. In the foothills near Moose Mountain (Fig. 23), it is 91 m thick and above the type Exshaw on Jura

Creek, it is 68.74 m thick. Between Jura Creek and Princess Margaret Mountain, it thins gradually basinward, attaining only 29.3 m at the latter section (Fig. 21). From Princess Margaret Mountain to Mount Rundle, it grades basinward into the middle and upper Banff Formation (Fig. 27).

Following Richards et al. (in press b), the Pekisko Formation is restricted to include only the lower clean carbonate unit of the type Pekisko, which occurs between 7,870 and 8,370 ft in a borehole at 2-25-19-3W5 south of Calgary (Douglas, 1958, p. 39). At its type locality, the Pekisko comprises a lower clean carbonate unit, middle argillaceous to silty carbonate unit and an upper clean carbonate unit. The Pekisko is restricted because its definition overlaps that of the Shunda Formation of Stern (1956), which has priority of publication and has been widely applied. The middle and upper units of the type Pekisko are included in the Shunda Formation (members D, E and G on Figures 21-23).

The Pekisko Formation generally overlies and grades basinward (southwestward and southward) into the Banff Formation (Figs. 16, 21). In the Cordillera of southwestern Alberta, the Pekisko generally passes southwestward into the Banff, but on the Interior Platform south of 50°45'N, this transition takes place southward. In most areas, the Banff/Pekisko contact is sharp and erosional. The magnitude of the hiatus is minor, decreases basinward, and probably resulted largely from transgressive ravinement. In the Plains south of Calgary and in the eastern Cordillera south of about 51°15'N, the Banff/Pekisko contact is gradational.

At Jura Creek and Moose Mountain (Figs. 23, 25), as over much of the Interior Platform and in the eastern Cordillera between about 50°30'N and 54°50'N, lithofacies of the Pekisko Formation underlie those of the Shunda Formation. Lithostratigraphic correlations, supported by conodont and foraminiferal data (Richards et al., 1991; Higgins et al., 1991), indicate the Pekisko of southwestern Alberta passes southwestward (basinward) into the lower Shunda Formation and middle Banff Formation rather than into the Livingstone Formation as suggested by Macqueen and Bamber (1967), Macqueen et al. (1972) and Chatellier (1988). Correlations similar to those used here for the Pekisko and Banff formations were proposed by Moore (1958).

Along Jura Creek and on Grotto Mountain, the top of the Pekisko lies at a stratigraphic level where the chert percentage increases abruptly to rapidly upward and coincides with an upward change from medium-grey, bryozoan-pelmatozoan lime grainstone and packstone to dark-grey, argillaceous, dolomitic lime wackestone to packstone and calcareous dolostone of the lower Shunda Formation. Along Jura Creek, the top of the Pekisko is sharp and, therefore, possibly erosional.

Southwestern occurrences of the Pekisko Formation comprise three principal lithofacies: bryozoan-pelmatozoan, ooid-skeletal, and peloid-skeletal. The first two facies are well developed in the Exshaw region, but the peloid-skeletal lithofacies, which constitutes a major part of the Pekisko deposited on the cratonic platform, is generally not present. The Pekisko generally consists of a lithofacies association that becomes finer grained and less resistant upward, but near its basinward depositional limit in southern Alberta, the formation coarsens upward overall.

The bryozoan-pelmatozoan lithofacies is dominated by lime grainstone and constitutes most of the Pekisko near its southwestern and southern depositional limits, including the Exshaw area. It also makes up the lower one-third or more of the formation over wide areas to the north and east of Exshaw. Medium- to large-scale crossbedding, resulting from the development of submarine channel fills (Middleton, 1963; Bamber et al., 1981) and dunes to sand waves, is present in this lithofacies at Jura Creek and most other western localities.

The grainstone-dominant ooid-skeletal lithofacies commonly constitutes most of the lower Pekisko Formation near its erosional zero edge on the Interior Platform and part of the upper Pekisko to the southwest (Figs. 16, 17). At Jura Creek, this is a relatively minor facies occurring in the middle Pekisko.

At Jura Creek and Grotto Mountain, as in most other regions, the Pekisko was deposited on a carbonate platform (Fig. 18). The bryozoan-pelmatozoan lithofacies was mainly deposited on the outer part of the shelf margin and upper slope. In the Jura Creek region, deposition on the upper slope to shelf margin is indicated by the high-energy deposits (grainstone), presence of large-scale crossbedding, predominance of open-marine fossils, and relation to coeval middle-slope and protected-shelf lithofacies. Deposition of the ooid-skeletal lithofacies in the Pekisko Formation took place in two main settings: the inner shelf-margin, and along beaches of the landward part of the protected shelf. The ooid-skeletal lithofacies at Jura Creek was probably deposited in high-energy environments along the landward part of the shelf margin because it overlies and grades basinward into the bryozoan-pelmatozoan lithofacies and passes eastward into protected-shelf deposits.

In southwestern Alberta, the Pekisko Formation and overlying Shunda Formation constitute a third-order TR sequence that comprises three main TR subsequences and was called the Pekisko/Shunda sequence by Richards (1989). Evidence for a transgression at the base of the Pekisko is not obvious at Jura Creek and Grotto Mountain. In west-central Alberta, however, it is clearly recorded by the presence of the skeletal and ooid grainstone of the Pekisko above intertidal to supratidal siliciclastics and carbonates of members C and D in the Banff Formation (Fig. 17). In the foothills and Interior Plains, at the latitude of Calgary and northward, the subsequent regression is recorded by an upward transition from shelf-margin and protected-shelf grainstone in the lower Pekisko to restricted-shelf lithofacies of the Shunda (Figs. 16, 17). At Jura Creek, the culmination of the regression is recorded by the upper Shunda (Fig. 25), whereas the Pekisko records shallowing upward conditions followed by deepening.

Conodont biostratigraphy

Along Jura Creek, most of the Pekisko Formation is in the Upper *crenulata-isosticha* Zone and only the upper 4.3 m of the Pekisko above the Exshaw stratotype (stop 9) can be unequivocally assigned to the *Gnathodus typicus* Zone. The boundary between these two zones lies between 50.0 and 64.5 m above the base of the Pekisko Formation at the latter section. All of the Pekisko Formation is within the Upper *crenulata-isosticha* Zone at Princess Margaret Mountain, which indicates the uppermost Pekisko has graded basinward into the lower Shunda Formation between Jura Creek and the latter section. The Upper *crenulata-isosticha* and *typicus* zones, which indicate a late early to early late Tournaisian age, have been recognized in the lower to middle Pekisko and upper Pekisko, respectively, at numerous localities in east-central British Columbia (Higgins et al., 1991). The *typicus* Zone has also been recognized in the Pekisko at Moose Mountain, 38 km southeast of Jura Creek.

Faunas from the Upper *crenulata-isosticha* Zone between stops 8 and 9 above the type Exshaw (GSC locs. C-195301, C-195303, C-195304) and at Princess Margaret Mountain (GSC locs. C-136427, C-136430) contain: *Anchignathodus penescitulus* (Rexroad and Collinson), *Gnathodus delicatus* Branson and Mehl (Plate 2, Fig. 12), *G. typicus* Cooper Morphotype 1 of Lane, Sandberg and Ziegler, *Polygnathus communis carina* (Plate 2, Figs. 3, 4), *P. communis communis*, *P. inornatus*, *Protognathodus praedelicatus* Lane, Sandberg and Ziegler, *Pseudopolygnathus dentilineatus* E. R. Branson, *Siphonodella crenulata*, *S. isosticha* (Plate 2, Figs. 13, 14), and *S. obsoleta* Hass (Plate 2, Fig. 15).

Samples from the Upper *crenulata-isosticha* Zone at 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 49.74 and 50.04 m above the base of the Pekisko.

The only conodont assemblage assigned to the *typicus* Zone was collected at GSC locality C-195305, between 64.44 and 64.74 m above the base of the Pekisko Formation at stop 9 (Figs. 2, 25). The fauna, derived from a 4.09 kg sample, comprised 190 elements and included: *Bispathodus aculeatus aculeatus* (Plate 2,

Fig. 5), *Bispathodus* sp. *B. spinulicostatus* (E. R. Branson) (Plate 2, Fig. 6), *Gnathodus cuneiformis* Mehl and Thomas (Plate 2, Fig. 7), *G. typicus* Cooper morphotype 2 of Lane, Sandberg and Ziegler (Plate 2, Figs. 8-10), *Hindeodus*? sp. and *Polygnathus communis carina* Hass. The latter was the most abundant species.

Foraminifers and calcareous algae

Foraminifers and calcareous algae are not abundant in most of the Pekisko Formation at Jura Creek, but are moderately common in two samples collected from this formation above the type section of the Exshaw Formation (stops 7 to 8). The lowest sample from that section (GSC loc. C-195211) was collected 28.24 m above the base of the Pekisko and contains: *Asphaltinella* sp., *Columbiapora johnsoni* Mamet, *Pekiskopora*? sp. and *Tuberendothyra tuberculata* (Chernysheva). The second sample (GSC loc. C-195213), collected 31.34 m above the base of the Pekisko, contained: *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 upper Pekisko Formation of west-central Alberta. Where the *Asphaltinella* and *Columbiapora* microfacies have been precisely dated in western North America, they always occur in basal Zone 8 of Mamet and Skipp (1970). The presence of *T. tuberculata* confirms this age at Jura Creek.

Shunda Formation

Lithostratigraphy and sedimentology

The Tournaisian Shunda Formation (Stern, 1961; Figs. 16, 17, 21, 22), deposited on the western cratonic platform and in Prophet Trough and Peace River Embayment, extends from southwestern Alberta into southwestern District of Mackenzie. On the field excursion, the Shunda will be examined between stops 9 and 10 on Jura Creek, where it is extensively exposed. It is also widely exposed on Grotto Mountain, but only its basal beds will be examined at that locality (Fig. 2, stop 11). The Shunda is widely distributed on the Interior Plains north of about 50°20'N and in the eastern Cordillera from 50°20'N to the Sukunka Uplift (Fig. 9). This formation, which generally thins northeastward, is 125.2 m thick at Jura Creek (Fig. 25).

The Shunda Formation, as applied by Richards et al. (in press b) and herein, includes unnamed formation F of Richards (1989) and Higgins et al. (1991). Earlier, most of formation F in the WCSB had either been included in the Shunda Formation (Macauley, 1958; Macauley et al., 1964) or informally called "Shunda" formation (Bamber and Mamet, 1978; Beauchamp et al., 1986). Formation F, dominated by open-marine skeletal limestone, could be readily differentiated from the restricted-marine Shunda of Richards (1989) at outcrops, but not in the subsurface. The Shunda, as used herein, is unified by its lithological heterogeneity and by the predominence of argillaceous carbonates.

In southwestern Alberta, the Shunda Formation generally conformably overlies the Pekisko Formation, but along Jura Creek, the contact is sharp and, therefore, possibly erosional. Toward the southwest, the lower and middle Shunda grade basinward into the Banff Formation, whereas most of the upper Shunda (member F) grades into the Livingstone Formation. On the Interior Platform south of Calgary, the Shunda grades southward into the Livingstone (Fig. 21; Richards et al., in press b).

The Shunda of western Alberta is generally abruptly, and commonly unconformably, overlain by the Turner Valley Formation in the foothills and eastern front ranges and on the western Interior Platform (Figs. 16, 17). Near its basinward depositional limit in the Cordillera southwest of Calgary, the Shunda is widely overlain by the Livingstone Formation (Figs. 16, 21, 22). East of the subcrop edge of the Turner Valley Formation, the Shunda is unconformably overlain by Jurassic and Cretaceous strata.

In southwestern Alberta, the cyclic, carbonate-dominated Shunda Formation is divided into several informal members, labelled D to H (Figs. 21, 22; Richards et al., in press b). At Jura Creek members D, G and H are well exposed (Fig. 25) and will be examined on the field trip. At the latter locality, the moderately recessive member D comprises coarsening-upward sequences that are dominated by argillaceous, cherty dolostone but capped with skeletal lime grainstone. Cliff-forming member G consists of coarsening upward sequences of cherty lime wackestone and packstone overlain by bryozoan-pelmatozoan lime grainstone. Recessive member H is dominated by mixed-skeletal lime packstone and grainstone, but two units of silty to sandy dolostone are present. The latter clastics correlate with sandy siltstone at the base of Shunda member F in the east (Fig. 23) and with a basinward-thickening wedge of dolomitic siltstone in the Banff Formation of the western front ranges.

Authigenic chert constitutes 5 to 35% of the minerals present in most carbonate units in this formation at Jura Creek, occurring as irregular nodules and masses, beds, areas of spongy silicification, and as a selective replacement. Most carbonate beds in the Shunda at this locality are massive and partly bioturbated; some are rhythmically interbedded with marlstone. Crossbedding is locally present in the grainstone but is not conspicuous.

Regionally, most of the Shunda Formation comprises restricted-shelf lithofacies deposited on platforms and, to lesser extents, ramps. However, lithofacies of slope to proximal-ramp aspect (Figs. 19, 25) predominate at Jura Creek and at other southwestern occurrences of the formation (Richards et al., 1991). At Jura Creek, ramp deposits probably constitute the lower part of member D and member H. Ramp deposition is indicated by the apparent absence of a high-energy, shelf-margin grainstone belt (characterisitic of platforms) between restricted-marine facies of the eastern Shunda Formation and the open-marine facies at Jura Creek and southwestward. Member G and the grainstone bearing middle to upper part of member D may represent the upper slope to outer shelf margin of a thin platform successsion.

Most of the Shunda in the Jura Creek region was probably deposited in the outer- to inner-neritic zone on a carbonate ramp. Such deposition is suggested by the predominance of open-marine fossils (pelmatozoans, bryozoans, brachiopods, sponge spicules) in strongly bioturbated, fine-grained deposits, the occurrence of tempestites, and the presence of coarsening- and shallowing- upward sequences capped by bryozoan-pelmatozoan lime grainstone locally showing medium-scale crossbedding. The presence of abundant calcareous algae, including dasycladaceans, near the top of this unit at Jura Creek suggests deposition occurred partly within very shallow water (euphotic zone).

The Shunda Formation of southwestern Alberta is part of a third-order, TR sequence (Pekisko/Shunda sequence of Richards, 1989) that includes the Pekisko Formation and lower Livingstone Formation. At least three significant TR subsequences are present in this sequence in the Jura Creek region (Fig. 25). The first subsequence comprises the lower and middle Pekisko. The second, the upper Pekisko and members D, G, and lower H of the Shunda. The third subsequence disconformably overlies the second and includes the uppermost Shunda and overlying upper Tournaisian deposits of the Livingstone Formation. The major regression recorded by the upper part of the second subsequence is best indicated by restricted-shelf deposits of lower member F to the east and north (Fig. 23).

Conodont biostratigraphy

In the Exshaw to Canmore region, most of the Shunda Formation lies within in the upper Tournaisian *typicus* Zone. Assemblages (GSC locs. C-195306, C-195307, C-195311) from the lower and middle Shunda at stops 9 and 10 above Jura Creek contain only long ranging taxa: ?*Hindeodus* sp., *Polygnathus communis carina* (Plate 2, Fig. 3), and *P. communis communis* (Plate 2, Fig. 2). Richer, more diverse assemblages were collected from the upper Shunda at stops 9 and 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) at stops 9 and 10, yielded: *Eotaphrus* sp. cf. *E. bultyncki* (Grossens) (Plate 2, Fig. 1), *Hindeodus* sp. and *Polygnathus communis communis*. A sample from GSC locality C-195316, between 119.0 to 119.2 m above the Shunda's base (6.36 to 6.16 m below top) at stop 10 contained: *Bispathodus stabilis*?, *Eotaphrus bultyncki*, *Apatognathus* sp., and *Polygnathus mehli mehli* Thompson. Samples from the Shunda at Princess Margaret Mountain (Fig. 21, western section) 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.

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 9 to 10 by Jura Creek 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 formation F). 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.

Foraminifers and calcareous algae

At Jura Creek, the Shunda Formation contains foraminifers assigned to upper Tournaisian zone 8 (Fig. 5) of Mamet and Skipp (1970). These fossils are rare in the lower part of the formation, but become moderately common in middle to upper member G and in member H. 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) included: *Calcisphaera* sp., *Earlandia clavatula* (Howchin), *Protoumbella* sp., and *Spinoendothyra* sp.. Assemblages resembling those from the upper Shunda have been widely recognized in the lower Shunda Formation of western Alberta and east-central British Columbia (Mamet, 1976; Mamet et al., 1986).

Rugose corals

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 stop 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. (Plate 3, Fig. 2) and *Sychnoelasma* sp. (Plate 3, Fig. 3). At GSC locality C-195319, 6.96 to 6.46 m below the base of the Livingstone, several specimens of *Vesiculophyllum* sp. were collected. Colonies of the tabulate coral *Syringopora* sp. are moderately common at both localities.

Vesiculophyllum and *Sychnoelasma* range from the middle of the Banff Formation into the lower Rundle Group. *Stelechophyllum circinatus* occurs in the Mooney Falls Member of the Redwall Limestone in Arizona, in the upper part of coral zone II (Fig. 5) of Sando and Bamber (1985). This species has also been found in east-central British Columbia, near the Sukunka River, in upper Tournaisian strata approximately 30 m above the base of the Rundle Group.

At a section immediately south of the type section of the Exshaw Formation, the colonial rugose coral *Stelechophyllum micrum* (Kelly) (Plate 3, Figs. 5a-c) was collected from the Shunda at 85.4 m below the base of the Livingstone Formation (GSC loc. C-41867). This species occurs within coral zone IIB of Sando and Bamber (1985) at numerous localities in southwestern Alberta, where it ranges from the upper Pekisko Formation into the lower Shunda Formation. *S. circinatus* was also collected from this section, 15.2 m below the top of the Shunda (GSC loc. 62109; Plate 3, Figs. 4a-c).

Livingstone Formation

Lithostratigraphy and sedimentology

The upper Tournaisian to middle Viséan Livingstone Formation (Douglas, 1958) extends from southern Alberta into east-central British Columbia (Figs. 1, 16, 21). Dominated by bryozoan-pelmatozoan lime grainstone, it occurs from 49°00'N to 51°30' in the Rocky Mountains and foothills of southwestern Alberta and southeastern British Cilumbia. It also underlies the western Plains south of 50°00'N. The Livingstone was deposited in the Prophet Trough and in the seaway connecting the trough to the Williston Basin. The thickness of the northeastward-thinning Livingstone is chiefly from 275 to 425 m in the Cordillera and less than 130 m on the Interior Platform. The formation is about 317 m thick at Jura Creek (Bamber et al., 1984, Fig. 3) and 302.2 m thick at Princess Margaret Mountain. The Livingstone is well exposed in the region of the field trip, but will be examined only at stop 10 above Jura Creek.

Boundaries of the Livingstone are diachronous. In most areas, it conformably overlies the Banff Formation, but in the east it conformably overlies the western facies of the Shunda Formation. At Jura Creek, it gradationally overlies the latter. Southwestward in the eastern Cordillera and southward on the southernmost Interior Platform, the basal Livingstone becomes younger as it grades basinward into the upper part of the Banff Formation. The upper Livingstone, where it is overlain by the Mount Head Formation, becomes younger southwestward as the Wileman and Baril members followed, in turn, by the Salter and Loomis members, grade basinward into the Livingstone. In the Exshaw to Canmore region, the Livingstone is abruptly overlain by silty dolostone of the Wileman Member.

A bryozoan-pelmatozoan lithofacies constitutes most of the Livingstone Formation, but an ooid-skeletal and several other facies occur (Richards et al., in press a). Both the bryozoan-pelmatozoan and ooid-skeletal lithofacies are developed in the Jura Creek region, but only the former will be examined.

In the bryozoan-pelmatozoan facies, which comprises bryozoan-pelmatozoan lime grainstone with subordinate lime packstone and dolomitized limestone, chert is locally common and becomes more abundant basinward. Most of the carbonate beds are massive or have diffuse internal stratification, but medium- to very large scale tabular and trough crossbedding is locally common in the eastern front ranges. Both this lithofacies and the ooid-skeletal lithofacies commonly constitute the lower part of thick, fining-and shallowing-upward sequences capped by dolostone.

A shelf-margin origin for most of the bryozoan-pelmatozoan lithofacies in the eastern front ranges is indicated by its lateral relation to slope and protected- to restricted-shelf facies that are coeval with it (Fig. 16). Such an origin is also indicated by the high-energy deposits of the Livingstone, large-scale crossbedding, and the predominance of crinoids and other open-marine fossils.

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.

STOP DESCRIPTIONS

Stop 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. 28, 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. Yamnusca (also called Mt. John Laurie). On Loader Peak, southwest of Mt. Yamnusca, 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 Devonain (Famennian) Palliser Formation are exposed on upper Loader Peak. Jura Creek (Fig. 2) is present in the valley developed along the southwest side of Loader Peak.

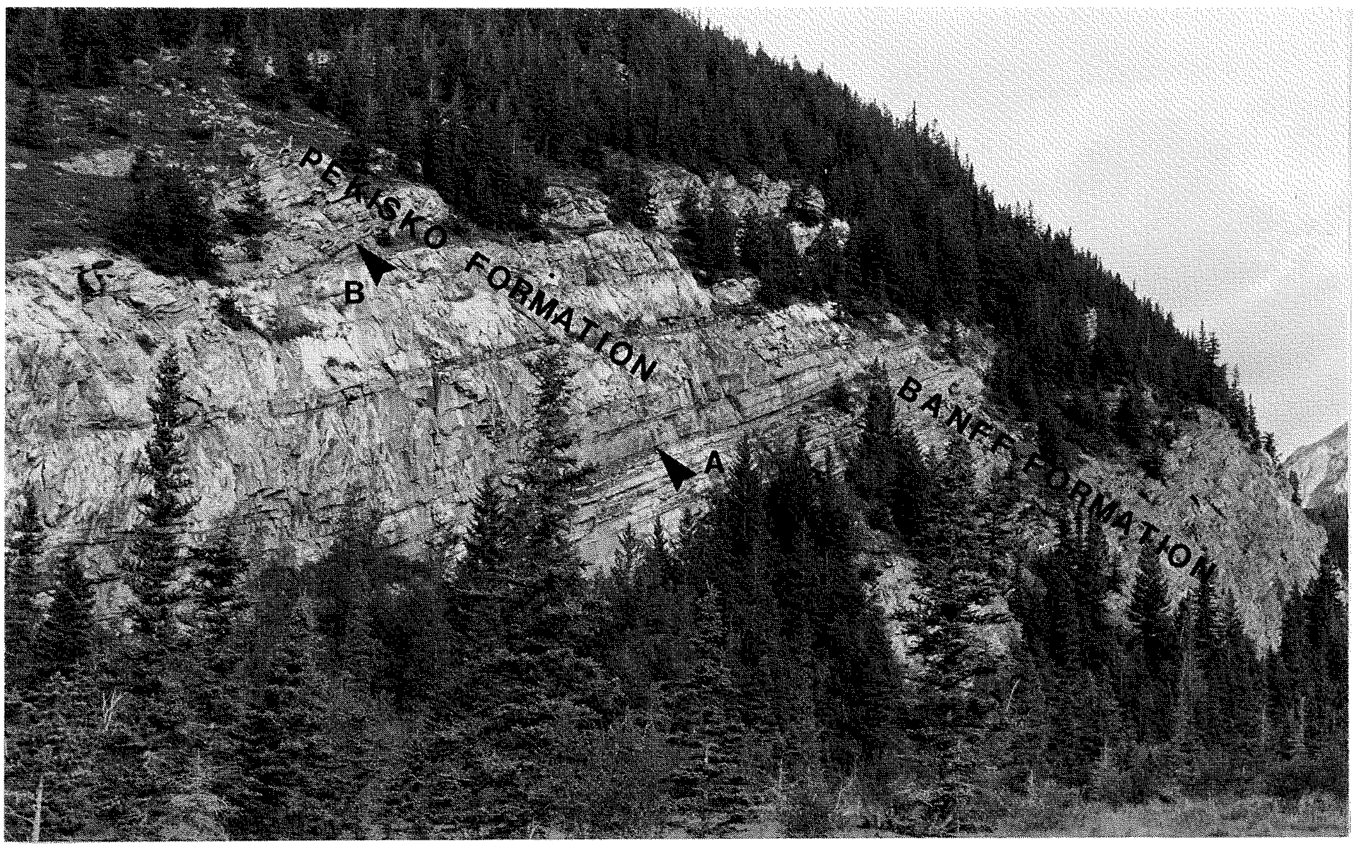


Figure 29. *Lower Tournaisian Banff Formation and overlying lower and middle Tournaisian Pekisko Formation (arrow A indicates base) along western side of alluvial fan developed at mouth of lower canyon of Jura Creek. Banff comprises distal to proximal ramp deposits (silty dolostone grading upward into lime wackestone and grainstone). Pekisko comprises slope to shelf-margin grainstone. Arrow B indicates large-scale cross-stratification (foreset bedding related to filling of submarine paleochannel). View is toward northwest from alluvial fan of lower Jura Creek.*

From stop 1 drive, via highways 1x and 1A, to Jura Creek for stops 2 to 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 Continental Lime Limited. Park on the side of Highway 1A near the point where 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. Slope deposits of the lower Tournaisian Banff Formation (silty dolostone grading upward into lime wackestone, packstone, and grainstone) and overlying upper-slope to shelf-margin lime grainstone of the lower and upper Tournaisian Pekisko Formation are well exposed on the west side of the fan (Fig. 29). Continue north on the fan to the mouth of the canyon. If the creek is dry, continue upstream through the canyon to stop 2. Medium to thick bedded fossiliferous, burrow-mottled, intraclast-peloid lime wackestone and packstone of the Famennian Morro Member of the Palliser (Figs. 4, 12) 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.

Stop 2. Outcrop of upper part of transgressive-regressive lower and middle Famennian Morro Member of Palliser Formation (Figs. 12, 30), 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 medium- to thick-bedded, burrow-mottled, dolomitic lime wackestone and packstone with subordinate finely crystalline, highly jointed dolostone. The lithofacies were deposited mainly in neritic, proximal-ramp environments (Figs. 12, 14); some of the dolostone units may be of intertidal to supratidal origin. Conodonts assignable to the Lower *rhomboidea* to Lower

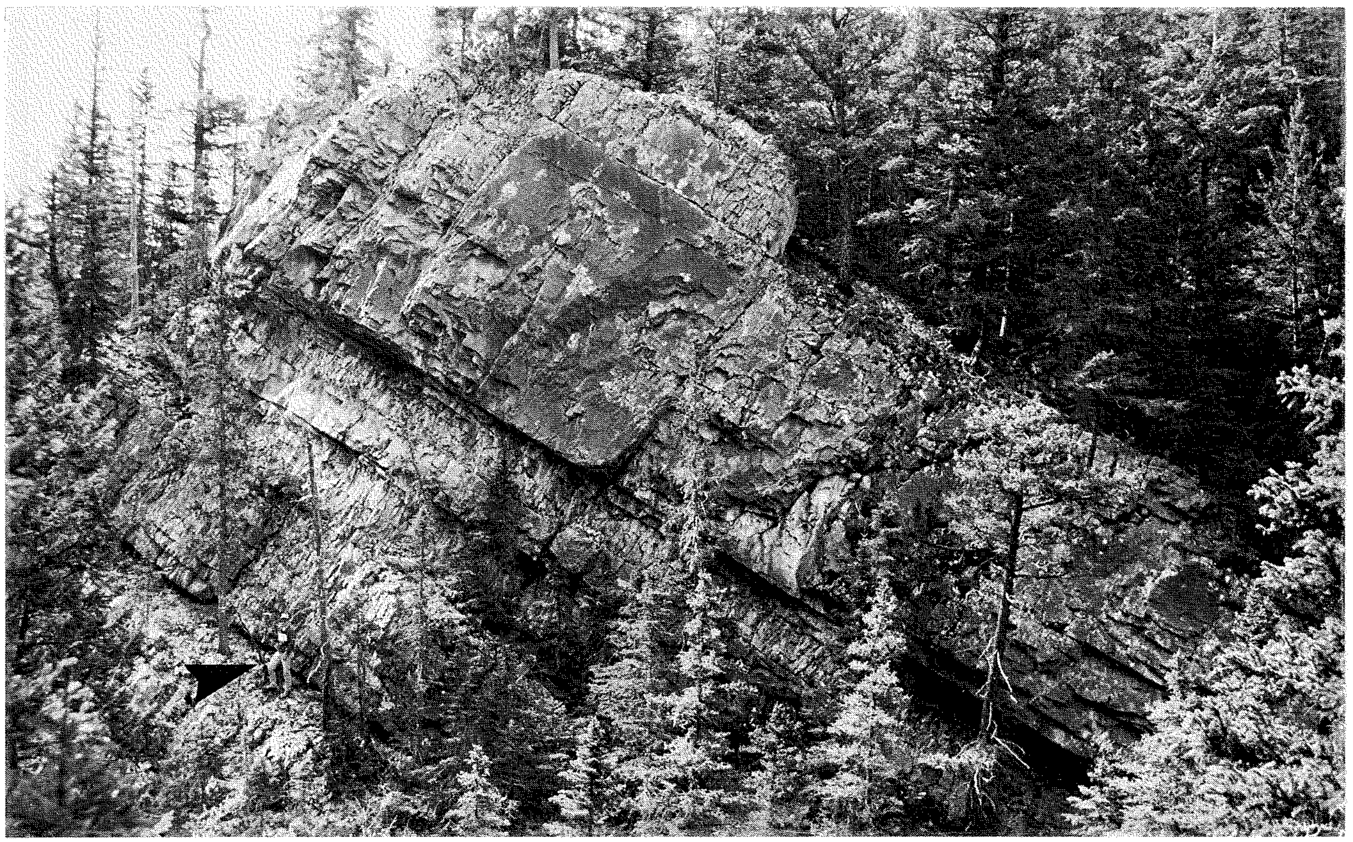


Figure 30. *Outcrop of middle Famennian, proximal-ramp deposits of upper Morro Member of Palliser Formation at stop 2, head lower canyon of Jura Creek, McConnell Thrust Sheet, southwestern Alberta. Recessive units are dolostone, resitant units are burrow-mottled, dolomitic lime wackestone and packstone. Man at lower left indicates scale; view is toward southwest.*

marginifera zones (Figs. 4, 15) of middle Famennian age were collected from the limestone (GSC locs. C-186674, C-170489, C-170460, C-170488).

Stop 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, 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. The Morro Member and Costigan Member below the *Palmatolepis gracilis expansa* conodont Zone jointly constitute a third-order TR sequence. The maximum flooding surface probably lies within the middle part of the Morro Member.

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

Stop 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. 31, 32). 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 (Fig. 33), breccias resulting from penecontemporaneous erosion, breccias caused by dissolution of evaporites, desiccation structures, and thin transgressive-regressive sequences. These strata, deposited mainly in proximal- 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.

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. 2, 12) and from the upper Morro Member along Jura Creek indicate all of 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 6. Only long-ranging conodonts were collected from this unit at stop 4.

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

Convoluted bedding resulting from penecontemporaneous soft-sediment deformation (Fig. 34) is common at the southern end of the outcrop. Sparsely fossiliferous, silty dolostone grading into dolomitic siltstone constitute the convoluted beds, which are overlain by turbidites grading upward into thinly planar-

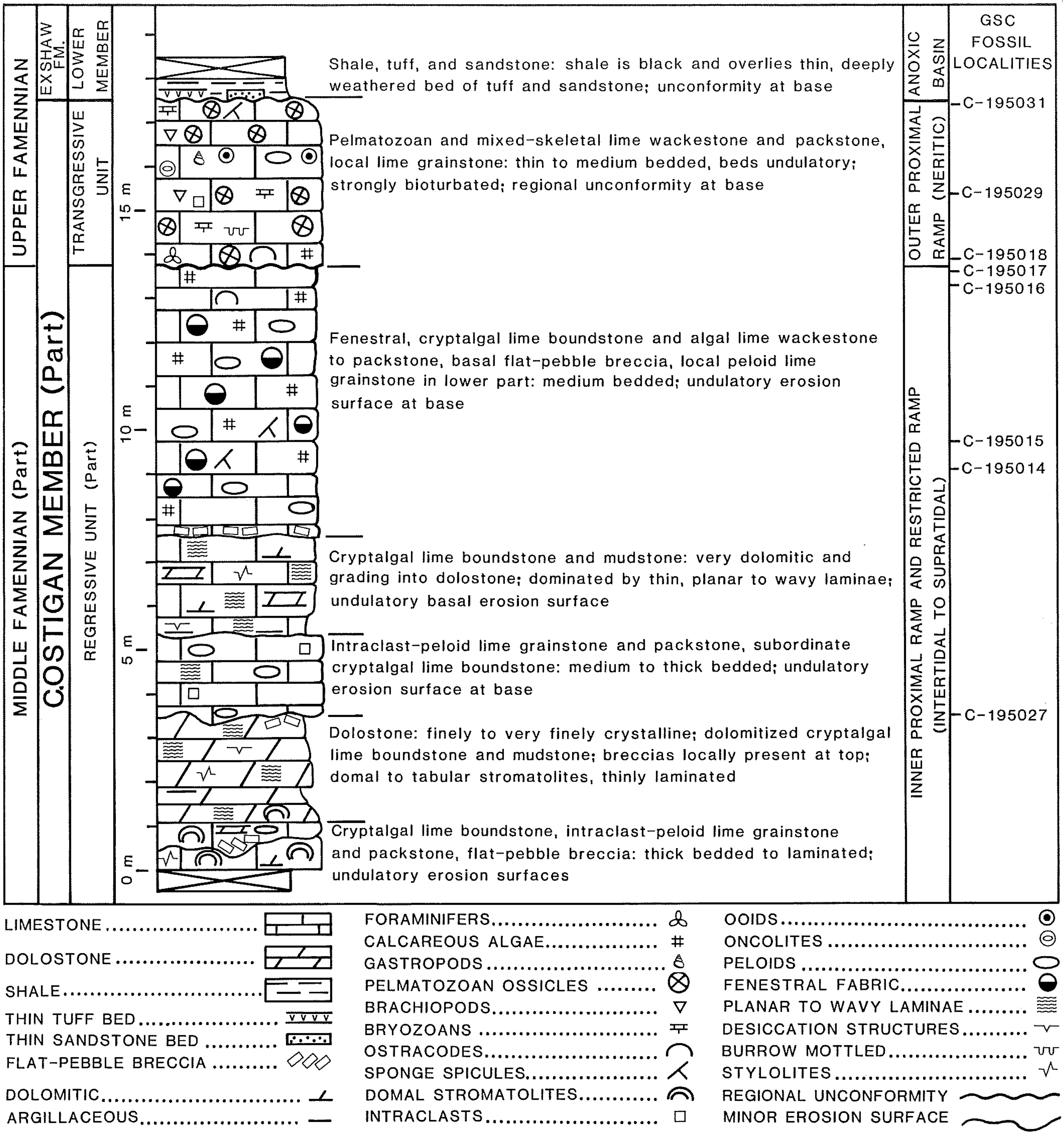


Figure 31. Detailed stratigraphic column showing location of selected GSC fossil localities and the rock types and sedimentary structures in Famennian Costigan Member at stop 4, slightly upstream from lower canyon of Jura Creek.

laminated, hemipelagic, silty dolostone. Slightly upstream and down section, thin-bedded, distal turbidites (CDE and DE sequences) are well exposed (Fig. 35). 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 not evident.

Stop 6. Middle canyon of Jura Creek, 3.1 km upstream from Highway 1A. The lower regressive unit and overlying upper transgressive unit of the Costigan Member of the Famennian Palliser Formation (Figs. 36,

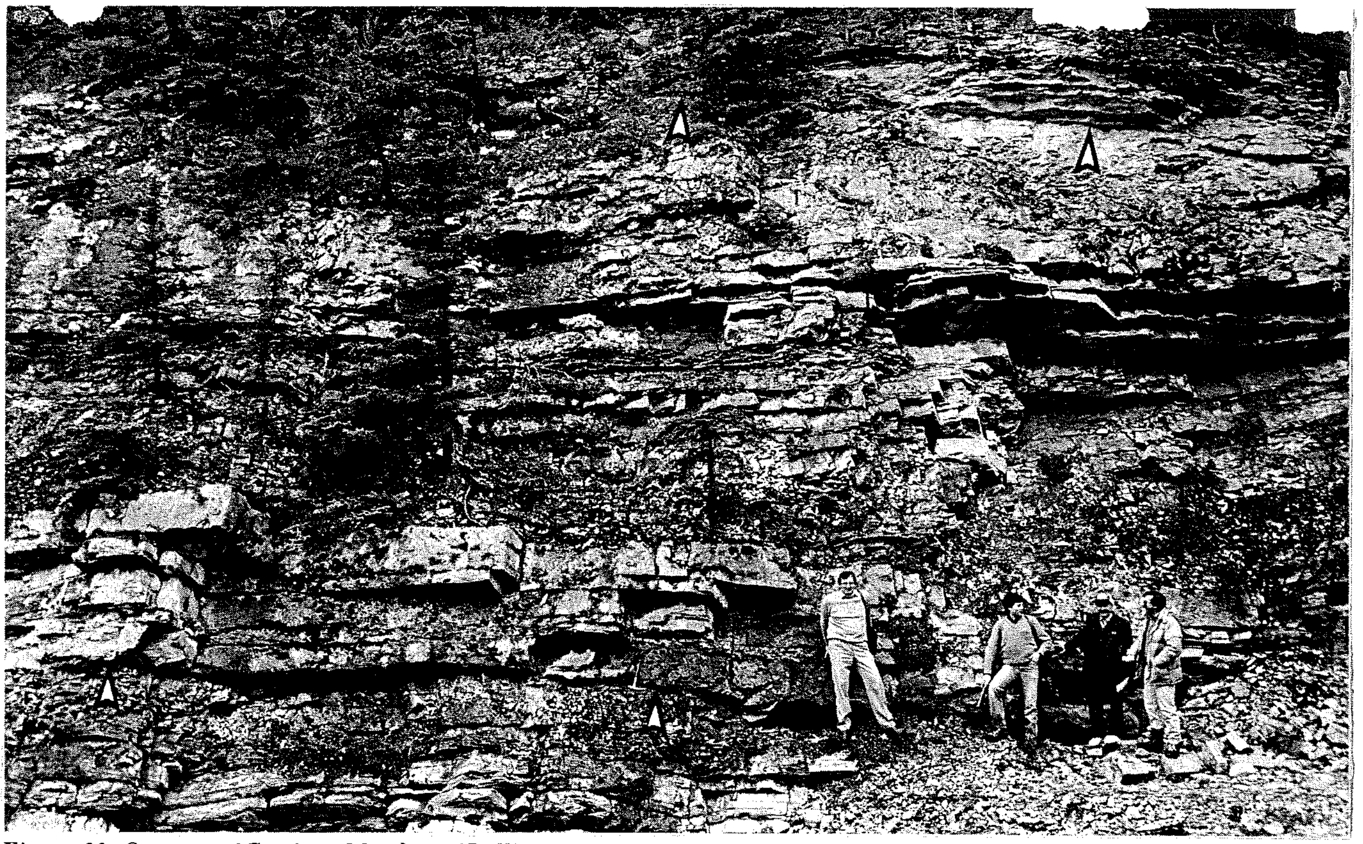


Figure 32. Outcrop of Costigan Member of Palliser Formation at stop 4, in valley slightly upstream from lower canyon of Jura Creek. Lower arrows indicate prominent erosion surface in middle Famennian restricted-ramp deposits of member; upper arrows indicate unconformity below upper Famennian, proximal-ramp deposits of upper transgressive unit (3.8 m thick, Big Valley Formation correlative) of uppermost Costigan.

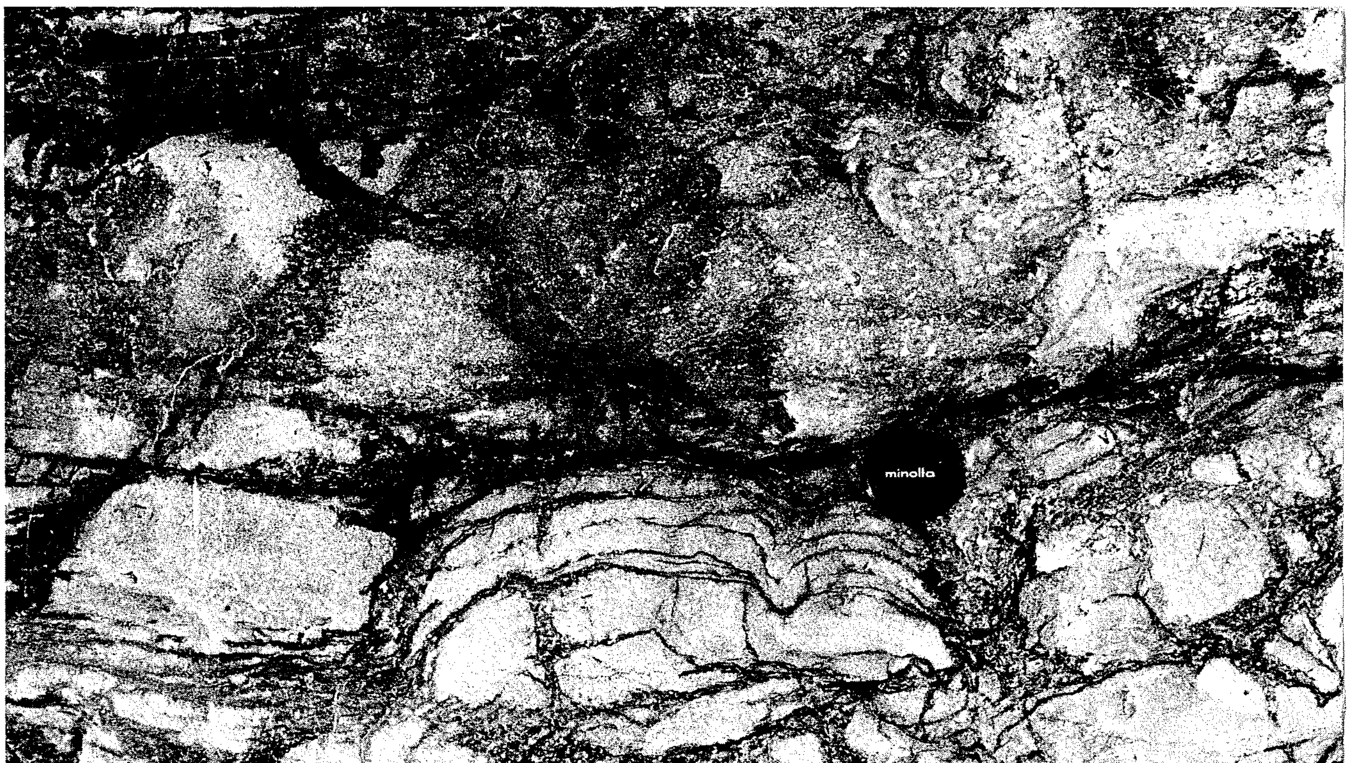


Figure 33. Stromatolites in middle Famennian, protected- to restricted-marine unit of Costigan Member. At stop 4 in valley of Jura Creek slightly upstream from head of lower canyon of the creek.

Figure 34. Soft-sediment deformation (convoluted bedding) resulting from instability (slumping) in lower Banff Formation at stop 5 on Jura Creek. Deposits comprise silty dolostone grading into dolomitic siltstone.

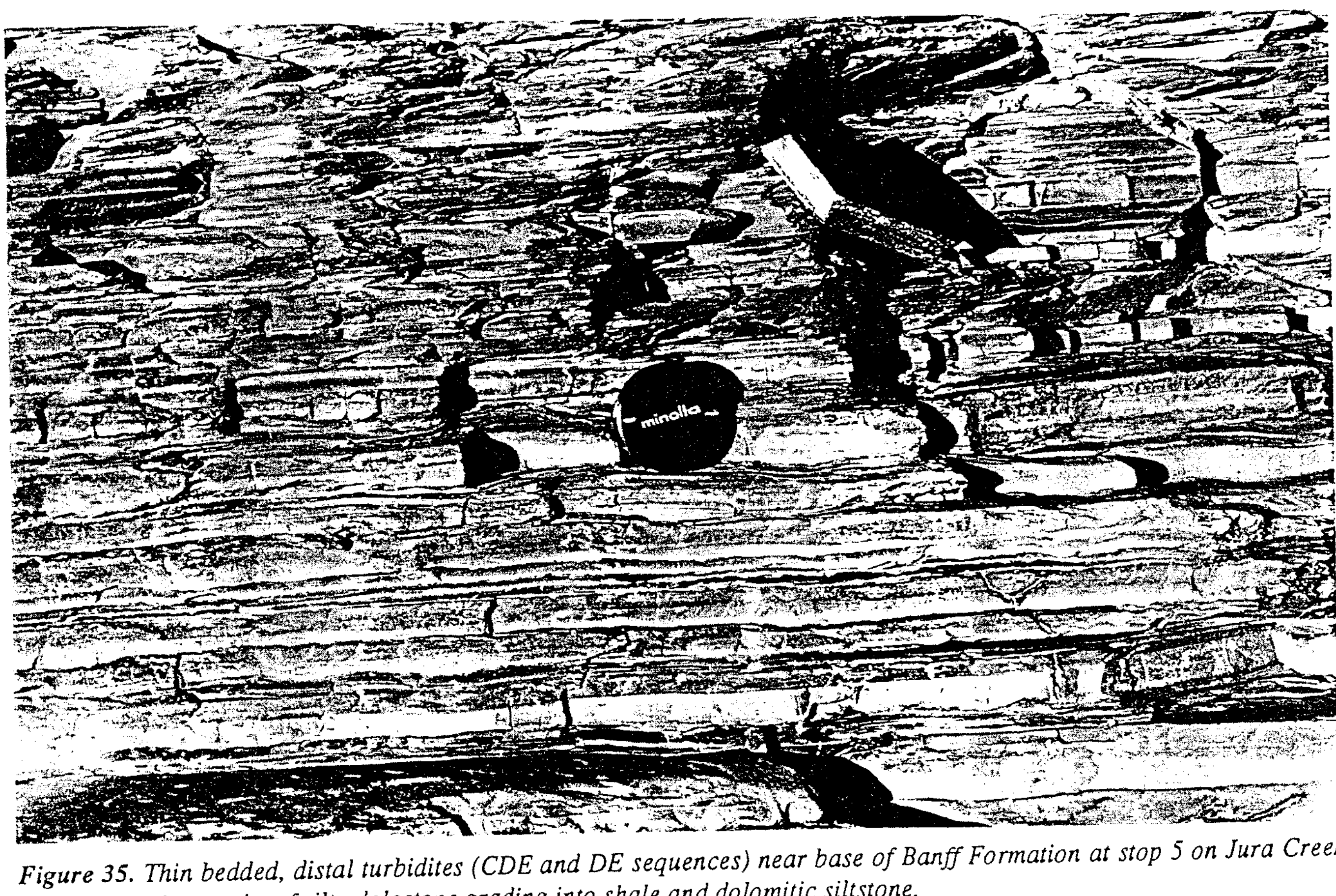


Figure 35. Thin bedded, distal turbidites (CDE and DE sequences) near base of Banff Formation at stop 5 on Jura Creek. Deposits consist of silty dolostone grading into shale and dolomitic siltstone.

37) 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. 38).

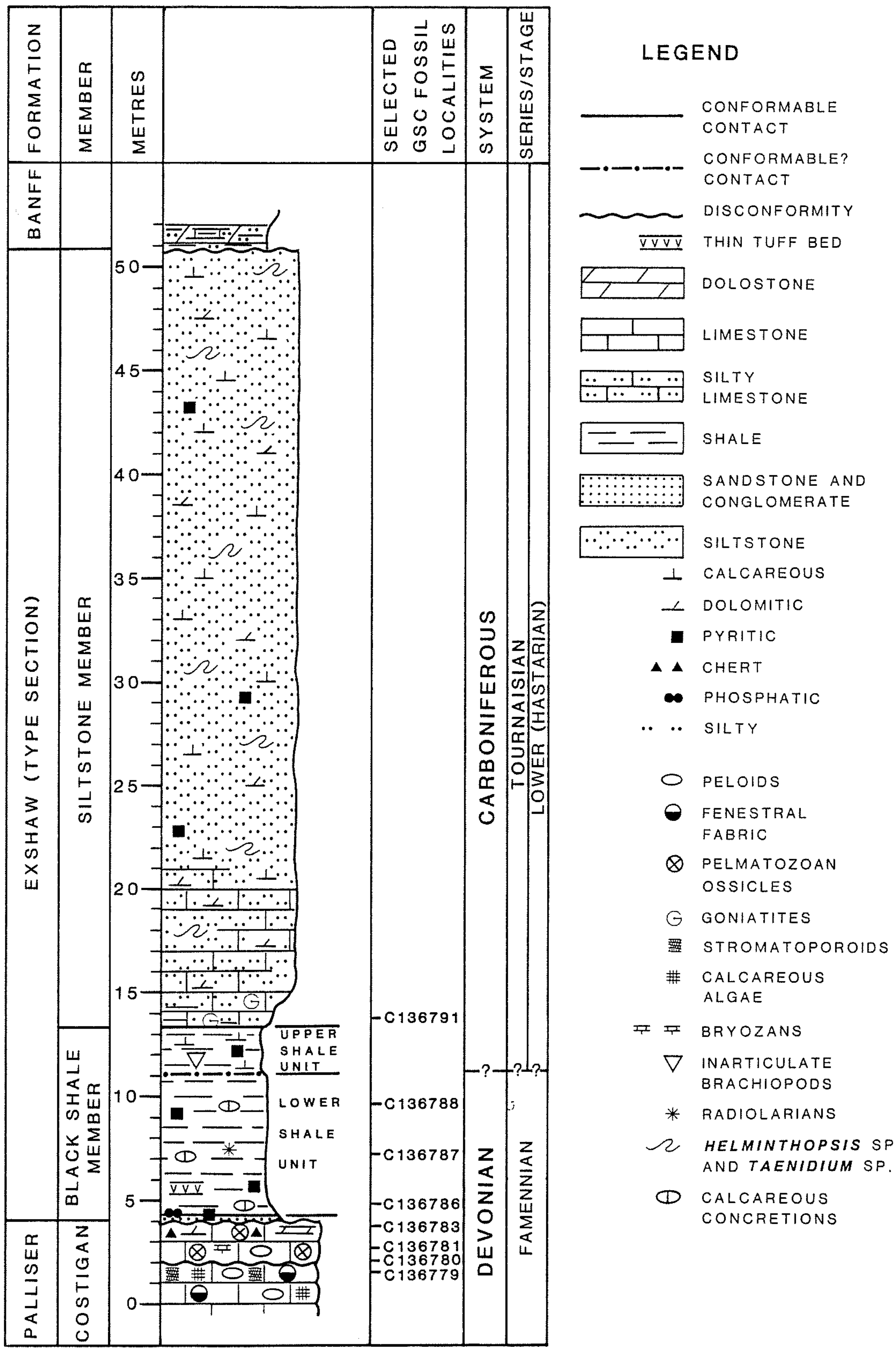


Figure 36. *Columnar section of uppermost Palliser Formation, type section of Exshaw Formation, and basal Banff Formation at stops 6 and 7, middle canyon of Jura Creek. Thickness of basal sandstone and conglomerate bed (1 to 6 cm thick) of the Exshaw is exaggerated (from Richards et al. 1991).*

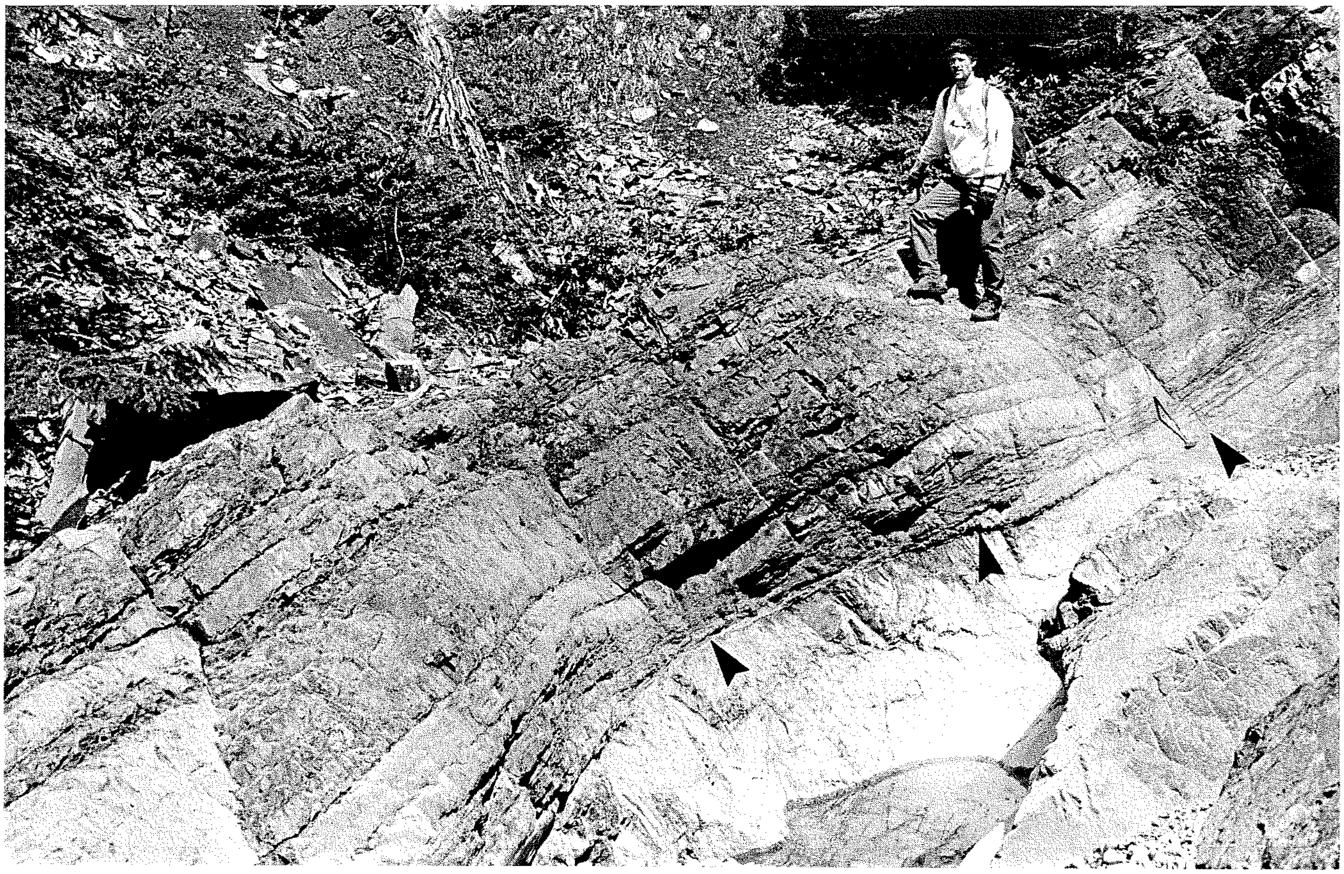


Figure 37. Upper part of Famennian Costigan Member below type section of Exshaw Formation at stop 6, middle canyon of Jura Creek. Arrows indicate unconformity between middle Famennian protected- to restricted-marine carbonates (algal lime wackestone, cryptalgal boundstone, stromatoporoid boundstone) and overlying upper Famennian, skeletal lime packstone and wackestone of upper transgressive unit (2.0 m thick). Base of Exshaw Formation lies on dipslope at top of low cliff.

Only the upper beds of the lower regressive unit of the Costigan, deposited in proximal- 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. The tabular stromatoporoid *Labechia palliseri* Stern is locally common at the top (Plate 3, Fig. 1).

The lower regressive unit is unconformably overlain by upper Famennian deposits of the uppermost Costigan (2.0 m thick). This upper unit, recording a late Famennian regional transgression, comprises bryozoan-pelmatozoan lime packstone to wackestone with subordinate lime grainstone. Conodonts assigned to the Lower to Middle *expansa* zones were collected from this upper unit. The richest and most diverse assemblage was collected from GSC locality C-136780 (Fig. 25; 1.9 m below top of Costigan).

The Exshaw, which unconformably overlies the Costigan Member, comprises a lower shale-dominated member (9.3 m thick) gradationally overlain by an upper member (37.5 m thick) consisting of dolomitic siltstone and silty limestone (Figs. 36, 38).

The lower member, containing the Devonian/Carboniferous boundary, consists of a thin, basal phosphatic sandstone and conglomerate bed, a middle unit of noncalcareous black shale, and an upper unit of calcareous shale. The middle unit is mainly planar-laminated, pyritic, sparcely fossiliferous, shale. It also contains calcareous concretions and a thin tuff bed (Fig. 39) consisting mainly of mixed-layer clays, potassium feldspar, and quartz (Table 1). Sandstone of the basal Exshaw at this locality has a clast

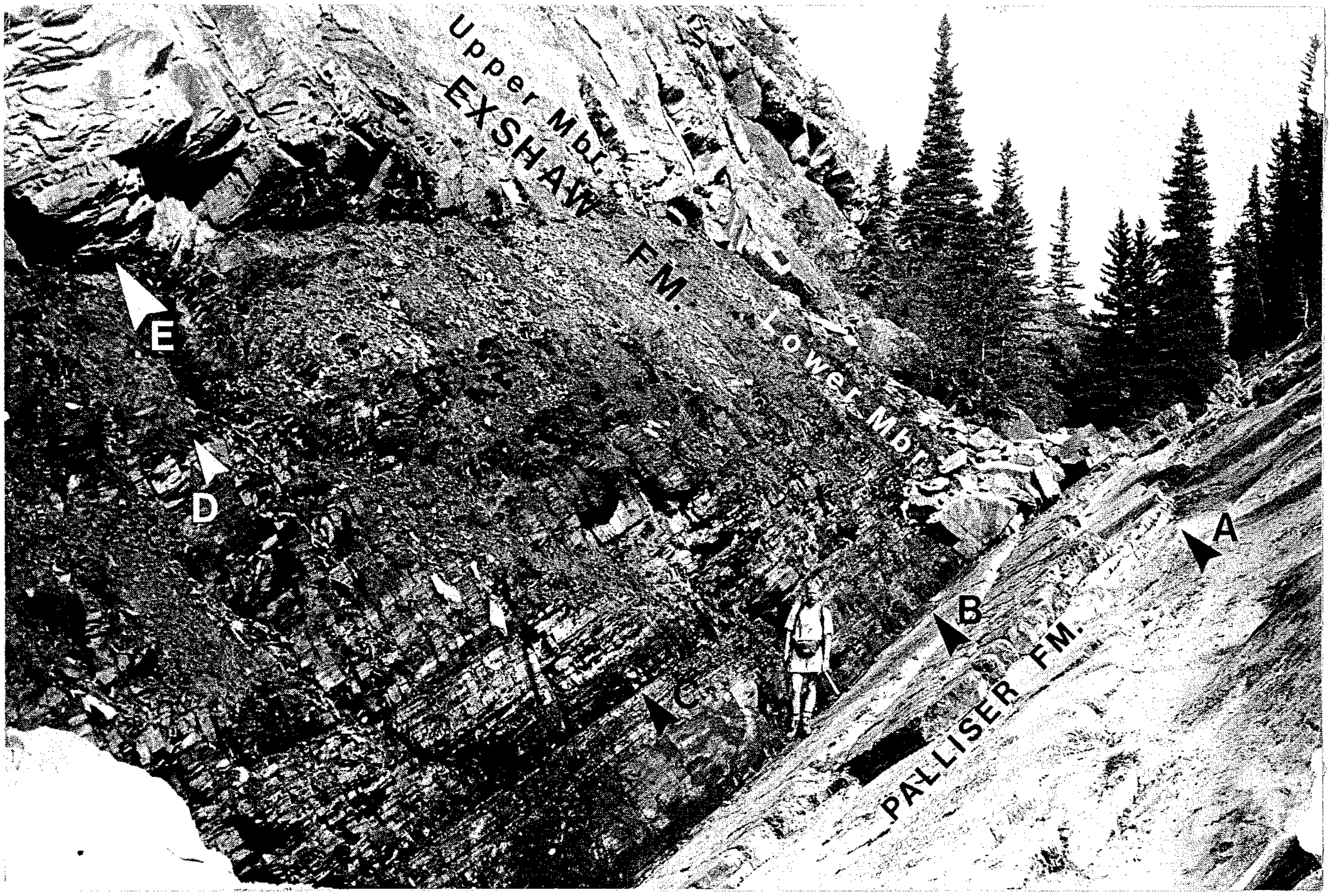


Figure 38. Upper Costigan Member of Palliser Formation and lower part of type section of Exshaw Formation at stop 6, middle canyon of Jura Creek. Arrows show: A- unconformable base of upper, transgressive limestone and dolostone unit of Costigan; B- disconformable base of noncalcareous black-shale unit of lower member of Exshaw; C- thin (5.5 cm thick) tuff bed in lower member of Exshaw; D- abrupt base of the calcareous black-shale unit of lower member; and E- gradational basal contact of the upper member (silty limestone and siltstone) of Exshaw. View is northwestward.

composition resembling that of the tuff bed and is probably reworked tuff. Geochemical analyses (Table 2) indicate that the concentrations of nickel, zinc, and molybdenum are highest in the basal sandstone bed and decrease upward within the black shale unit.

Conodont assemblages, assigned to the Middle *expansa* to Upper *praesulcata* zones, have been extracted from the concretions but have low species diversity and contain few specimens (Richards and Higgins, 1988; Richards et al., 1991). The calcareous upper shale unit contains pyrite, inarticulate brachiopods, and rare Carboniferous (Tournaisian) conodonts. Most of the lower member was deposited below storm wave base in the anerobic and dysaerobic zones.

The trace fossils *Taenidium* sp. and *Helminthopsis* sp. (Fig. 40) are abundant and conspicuous in the upper member, deposited in outer-neritic to upper-bathyal environments. Primary sedimentary structures other than subplanar bedding were not observed in the slightly pyritic, medium- to thick-bedded member. 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 third-order TR sequence. Regional deepening, transgression, and establishment of anoxic bottom conditions is 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).

Figure 39. *Noncalcareous black shale in lower member of Exshaw Formation at stop 6 on Jura Creek. Exposure shows laminae, a calcareous concretion, and a thin (2.0 to 5.5 cm thick) recessive bed of volcanic tuff (arrow). The tuff bed contains expandable, mixed-layer clays and lacks montmorillonite. A tuffaceous lamina underlies the concretion.*

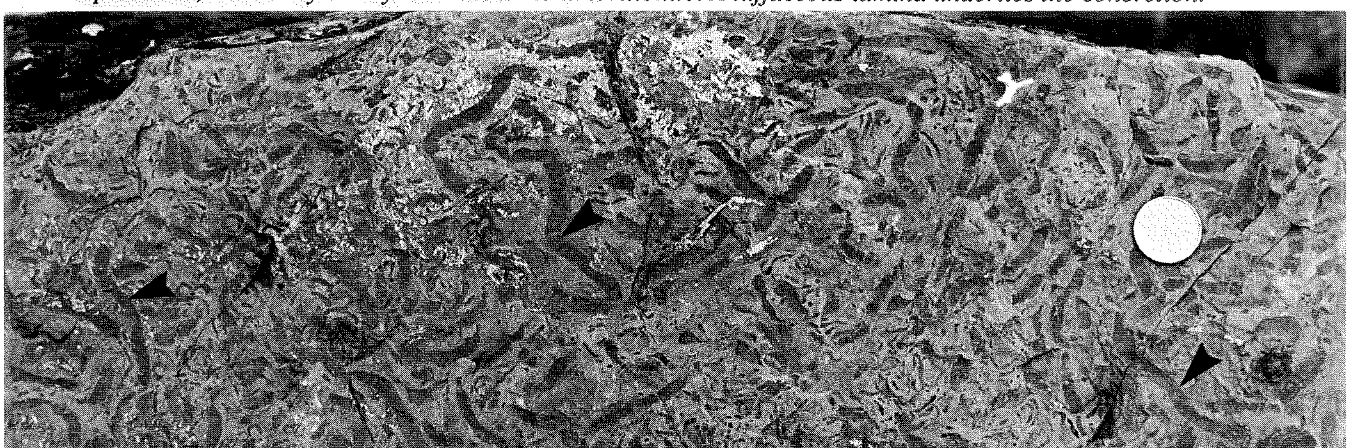


Figure 40. *Slab (talus) of calcareous siltstone showing abundant* Taenidium *sp. (arrows); numerous* Helminthopsis *sp. (small sinuous trace fossils) are also present. From upper member of the Exshaw Formation at stop 7 on Jura Creek. Scale is a Canadian penny.*

The pyroclastics in the lower member of the Exshaw Formation resulted from latest Devonian volcanism and plutonism in western Prophet Trough and to the west.

Stop 7. Abrupt and disconformable(?) contact between the Exshaw and Banff formations (Figs. 36, 41) on west side of middle canyon of Jura Creek, about 3.1 km upstream from Highway 1A. To reach this outcrop from stop 6, head upstream to head of middle canyon of Jura Creek, then trek southwestward and up slope over the partly covered and deeply weathered upper Exshaw to the first prominent break in slope above stop 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, deposited in basin and slope environments, record a regional transgression and episode of marked deepening that culminated with deposition of the thick overlying unit of hemipelagic, thinly planar-laminated silty dolostone. Subsidence, recorded by the deepening, resulted from the Antler Orogeny and related Cariboo event along the westen margin of ancestral North America (Richards et al., in press b)

Stop 8. Upper part of lower Tournaisian Banff Formation and lower deposits of overlying lower and upper Tournaisian Pekisko Formation (Figs. 25, 42), about 150 m west of Jura Creek in side canyon, 3.3 km northwest of Highway 1A. To reach this stop from stop 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 8.

Figure 41. *Sharp contact between siltstone member of the Exshaw Formation and basal dark-grey shale (member A) of Banff Formation at stop 7, type section of Exshaw Formation on Jura Creek. Overlying deposits in lower Banff are thin-bedded turbidites comprising silty dolostone and siltstone grading upward into shale. Base of 1.5 m long Jacob's staff rests on top of Exshaw.*

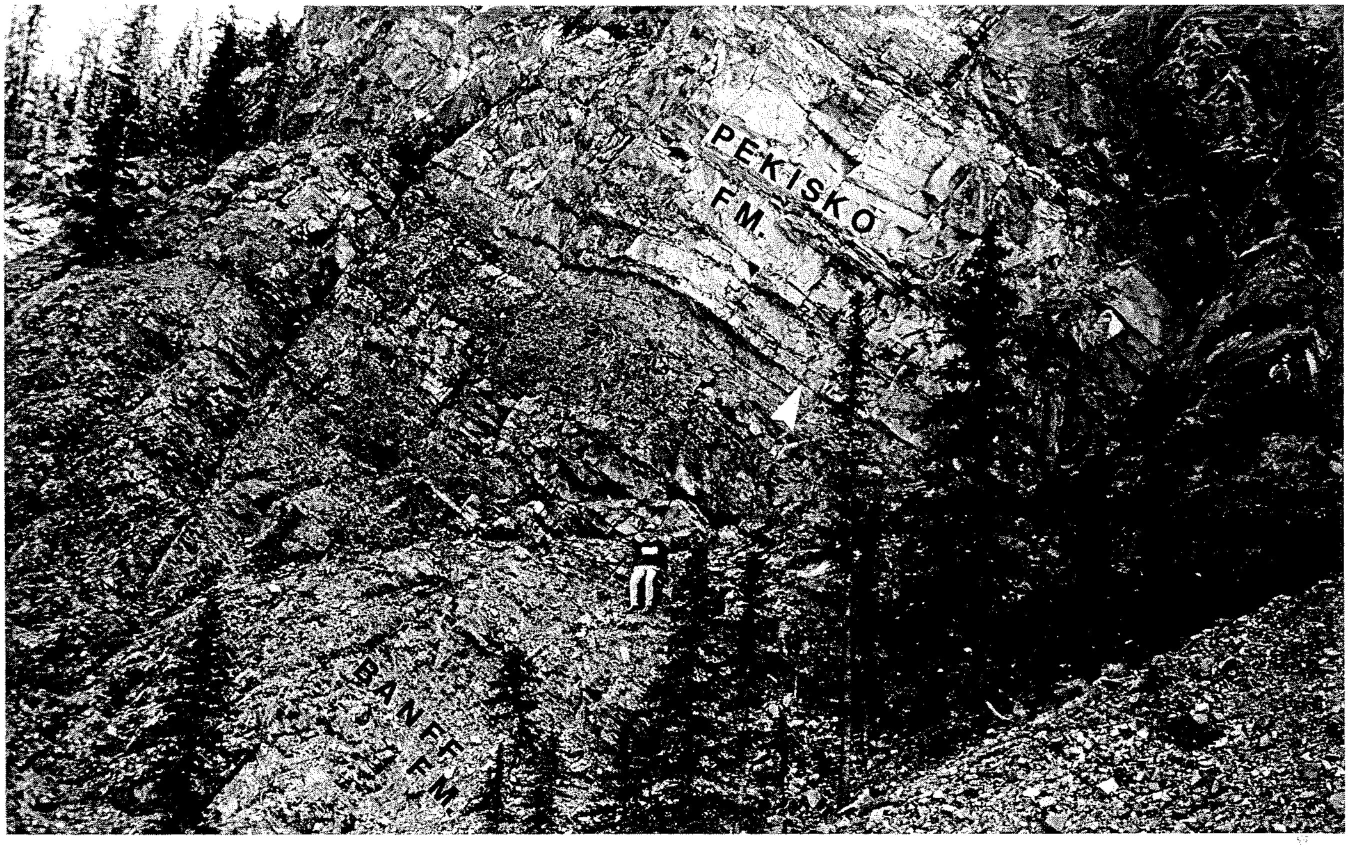


Figure 42. Sharp contact (arrow) between member B of the lower Tournaisian Banff Formation and the lower to upper Tournaisian Pekisko Formation at stop 8 above type section of the Exshaw Formation on Jura Creek. Upper member B comprises sharp-based beds of bryozoan-pelmatozoan lime wackestone, packstone and grainstone that grade upward into marlstone and were deposited in upper slope (distal ramp environments). The lower Pekisko comprises bryozoan-pelmatozoan lime grainstone of upper-slope to shelf-margin origin.

At stop 8, the Banff Formation (192.4 m thick) comprises two main units. The lower unit (lower member B) consists of thin-bedded, sparsely fossiliferous, partly bioturbated, silty dolostone turbidites. The lower interval is conformably overlain by rhythmically bedded upper member B, which consists of sharp-based limestone beds (tempestites or turbidites of wackestone to bryozoan-pelmatozoan lime grainstone) grading upward into marlstone. Member B of the Banff, a TR sequence, was deposited on the slope of a carbonate ramp. Conodont faunas belonging to either the highest Lower *crenulata* Zone or lower part of the Upper *crenulata-isosticha* Zone were collected from upper member B at Princess Margaret Mountain (Fig. 21) and from this locality (Richards et al. 1991; Savoy and Harris, 1993).

The medium- to thick-bedded Pekisko Formation (68.7 m thick) abruptly overlies the Banff and comprises bryozoan-pelmatozoan lime grainstone with subordinate fossiliferous, ooid lime grainstone and dolostone. Medium to large-scale crossbedding and large scours are locally evident in the lower Pekisko, The middle Pekisko (Fig. 43) comprises ooid-skeletal lime grainstone and two main subsequences consisting of finely crystalline, recessive dolostone overlain by wackestone and grainstone. The lower and middle Pekisko jointly constitute a shallowing-upward package deposited in upper-slope to shelf-margin environments on a carbonate platform (Fig. 25).

Most of the Pekisko Formation at this stop is within the Upper *crenulata-isosticha* Zone. The richest (25 elements per kilogram) and most diverse fauna was collected at GSC locality C-195304, between 49.74 and 50.04 m above the base of the Pekisko. Calcareous algae and foraminifers assigned to zone 8 of Mamet and Skipp (1970) were collected from the Pekisko at 28.24 and 31.34 m above its base.

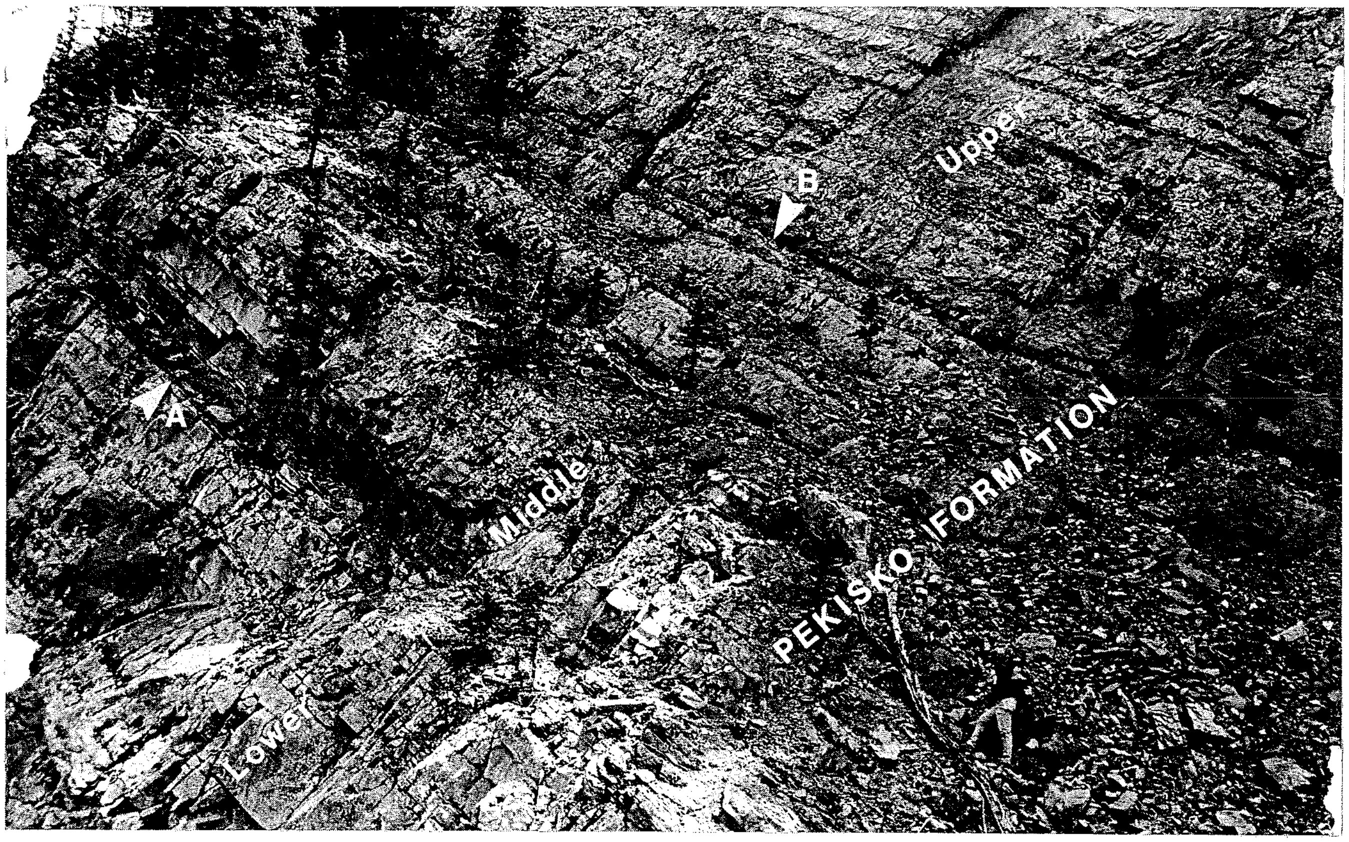


Figure 43. Looking southward to carbonates of middle Pekisko Formation (arrrows A and B mark base and top, respectively) between stops 8 and 9 in side canyon above western side of Jura Creek. Cyclic middle Pekisko comprises recessive units of dolostone overlain by resistant units of ooid-skeletal and bryozoan-pelmatozoan lime grainstone of inner-shelf margin to outer protected-shelf origin.

Stop 9. Upper part of Pekisko Formation and lower deposits of overlying Shunda Formation, 75 to 100 m up the side canyon above stop 8 (Figs. 25, 43, 44).

The slightly recessive middle Pekisko is abruptly overlain by the cliff-forming upper Pekisko Formation, of early late Tournaisian age. A unit of ooid-skeletal lime grainstone is present in the basal part of the upper Pekisko, which is dominated by cherty, bryozoan-pelmatozoan lime grainstone of inner shelf-margin to upper-slope origin. This upper unit indicates a moderate increase in water depth subsequent to deposition of the regressive middle Pekisko.

Conodont faunas belonging to the Upper *crenulata-isosticha* and *typicus* zones are present in the upper Pekisko; the boundary between the two zones lies between 50.0 and 64.5 m above the base of the Pekisko. A rich and diverse assemblage (46 elements per kilogram) assigned to the *typicus* Zone was collected at GSC locality C-195305, between 4.0 and 4.3 m. below the top of the Pekisko (Richards et al., 1991).

The Pekisko is abruptly and, therefore, possibly unconformably, overlain by upper Tournaisian carbonates of the Shunda Formation, which comprises parts of two main TR subsequences within the Pekisko/Shunda sequence (Fig. 25). The lower sequence, which includes the upper Pekisko and members D, G, and lower H of the Shunda, extends to the top of a sandy dolostone bed 7.2 m below the overlying Livingstone Formation. 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 proximal-ramp settings on a carbonate ramp developing into a poorly differentiated platform. The silty to sandy dolostone and dolomitic siltstone of lower member H records a major regional regression.

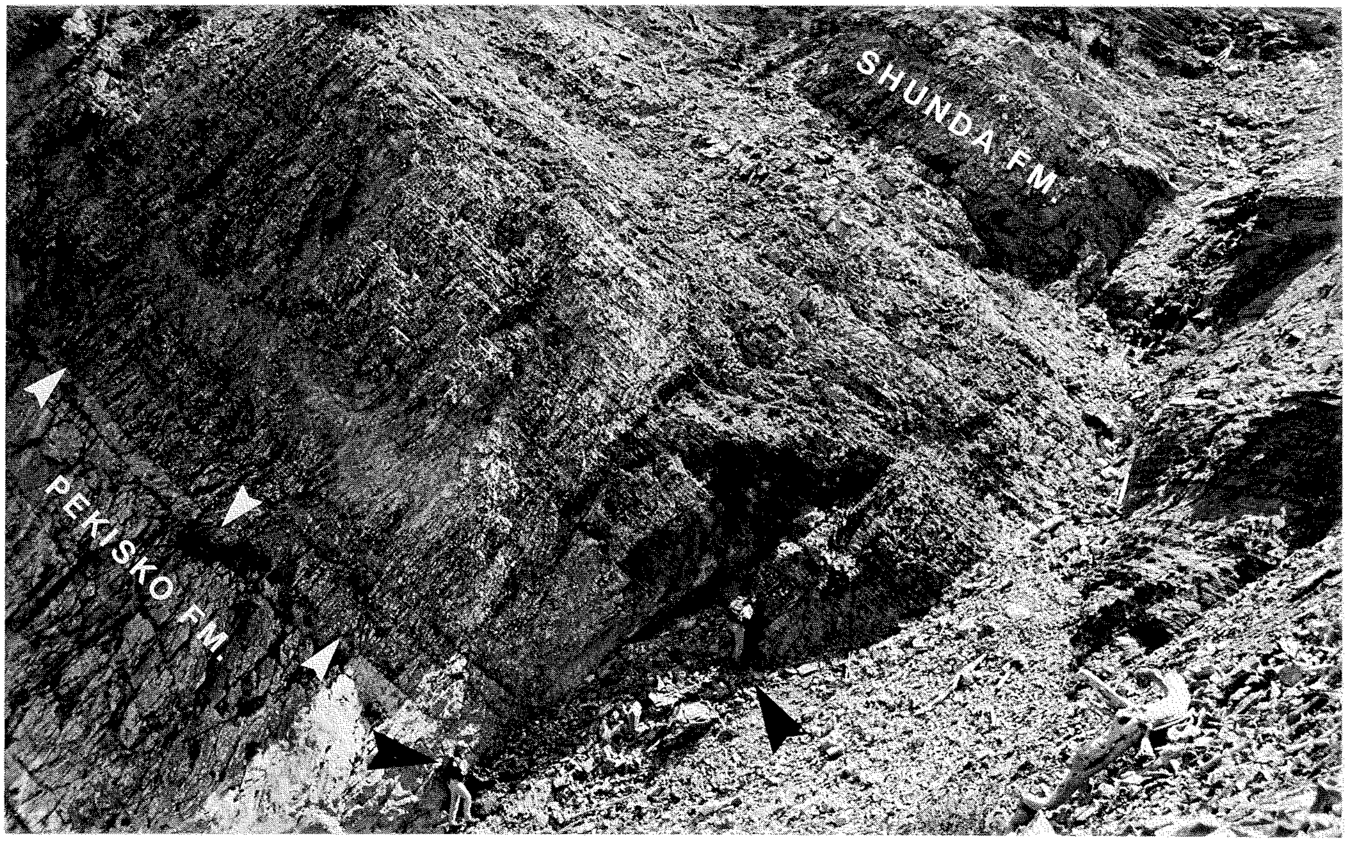


Figure 44. *Sharp and possibly unconformable contact (white arrows) between shelf-margin, bryozoan-pelmatozoan lime grainstone of Pekisko Formation and overlying slope to distal-ramp deposits (chert-rich, dolomitic lime wackestone) of member D of the Shunda Formation. At stop 9, canyon above western side of Jura Creek; men (black arrows) indicate scale.*

Deposits in the lower subsequence of the Shunda are within the *typicus* 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).

The lime packstone and grainstone in the upper part of the lower sequence locally contains abundant calcareous algae and foraminifers assigned to zone 8 of Mamet and Skipp (1970). Colonial rugose corals, assigned to coral zone IIB of Sando and Bamber (1985) are moderately common at GSC locality C-195318 (13.06 to 13.86 m below the base of the Livingstone Formation).

Stop 10. Upper Shunda Formation (upper 7.2 m) and basal beds of the Livingstone Formation (Figs. 25, 45), 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 75 to 100 m westward and upward from stop 9 to the light-grey cliffs of the basal Livingstone.

Lithofacies of the upper Shunda Formation (upper member H) overlie an unconformity and comprise mixed-skeletal lime packstone and subordinate grainstone grading upward into lime wackestone and shale. Calcareous algae and foraminifers assigned to zone 8 of Mamet and Skipp (1970) are locally common in the limestone near the base of this interval. The solitary rugose coral *Vesiculophyllum* sp. is also moderately common, as is the tabulate coral *Syringopora* sp.. Deposition took place on the drowned shelf of a ramp during a transgression.

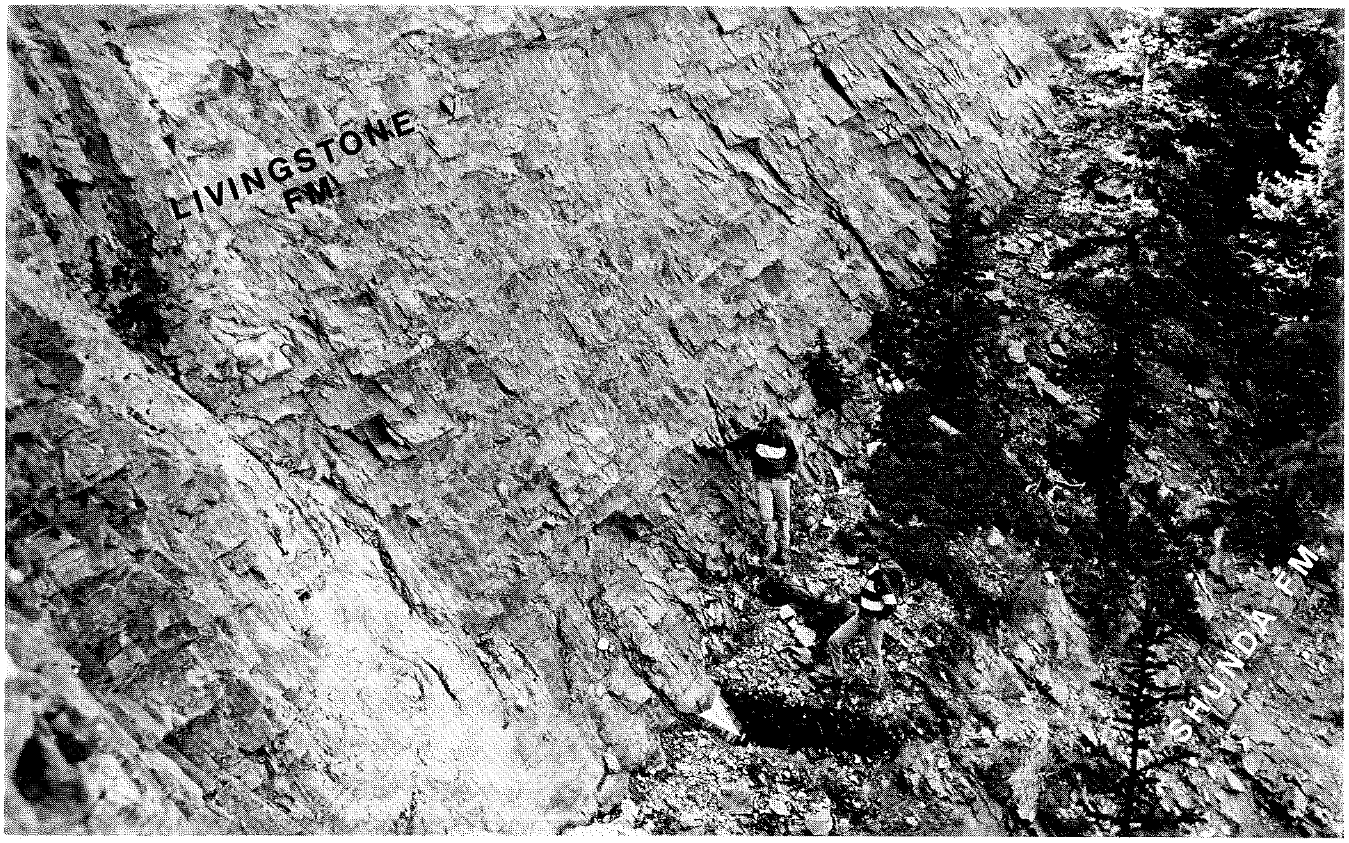


Figure 45. Conformable contact (arrow) between upper Tournaisian Shunda Formation and overlying upper Tournaisian and lower Viséan Livingstone Formation. At stop 10, above type section of Exshaw Formation on Jura Creek. Uppermost Shunda (exposed in trench) comprises shale grading upward into dolomitic lime wackestone. Basal Livingstone consists of dolomitic lime packstone grading upward into bryozoan-pelmatozoan lime grainstone.

Cliff-forming carbonates of the Livingstone Formation, gradationally overlie the Shunda Formation. The basal Livingstone comprises dolomitc, bryozoan-pelmatozoan lime packstone grading upward into lime grainstone. Overlying deposits of the formation (300 to 320 m thick in this area) are mainly lime grainstone of shelf-margin origin.

Upper member H constitutes the lower transgressive part of a high-order TR subsequence within the Pekisko/Shunda sequence. The shale bed of the member may contain the maximum flooding surface of the subsequence. The subsequent regression is recorded by uppermost Tournaisian deposits of the middle Livingstone Formation.

At stop 10 and at Princess Margaret Mountain, the upper Shunda Formation and basal Livingstone Formation contain conodonts assignable to either the uppermost part of the *typicus* Zone or basal part of the *anchoralis-latis* Zone. The richest (8 elements per kilogram) and most diverse assemblage collected at this stop is from member H at GSC locality C-195316, (between 6.36 and 6.16 m below the Livingstone).

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

Stop 11. Overview of Famennian and Tournaisian succession from Highway 1A above Bow River and Gap Lake; examine Tournaisian carbonates in road cut along western side of road.

A thick succession of Famennian and Lower Carboniferous strata, similar to that exposed along Jura Creek, is well exposed on the southeastern side of Grotto Mountain (Fig. 1) and can be viewed from the road.

The Famennian is represented by the Palliser Formation and lower Exshaw Formation; the Lower Carboniferous comprises the Banff, Pekisko, Shunda, Livingstone, Mount Head and Etherington formations.

The uppermost Banff Formation, Pekisko, and overlying basal Shunda Formation are exposed in a high rock cut along the western side of the road. The Pekisko, which is slightly thinner than at Jura Creek, comprises units of bryozoan-pelmatozoan lime grainstone separated by units of chert-rich lime wackestone. Near the southwestern end of the exposure, a chert-rich wackestone interval in the upper Pekisko contains an impressive submarine debris-flow deposit. The latter contains limestone blocks that are commonly more than .5 m long and show internal soft-sediment deformation.

From this stop, continue along 1A and drive, via Canmore, to the southwestern side of Mount Rundle for stops 12 and 13 (Fig. 3). While you are in Canmore, observe the impressive exposures of the Palliser, Banff and Livingstone formations on the northeastern side of Mount Rundle (Fig. 27). In western Canmore, take the Spray Lakes Road, which leads to the Smith-Dorrien/Spray Trail (Highway 742), and travel southwestward along the northwestern side of the deep canyon containing Canmore Creek and Grassi Lakes. Park in the parking lot situated .6 km west of the reservoir in the high gap (White Man Gap) above Canmore, and hike to stop 12 using the Goat Creek hiking trail and stream bed below the field trip stop.

Stop 12. 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).

At this locality (Fig. 46), the upper Famennian and lower Tournaisian Exshaw Formation is extensively exposed. It unconformably overlies the burrow-mottled, skeletal lime wackestone of the upper Palliser

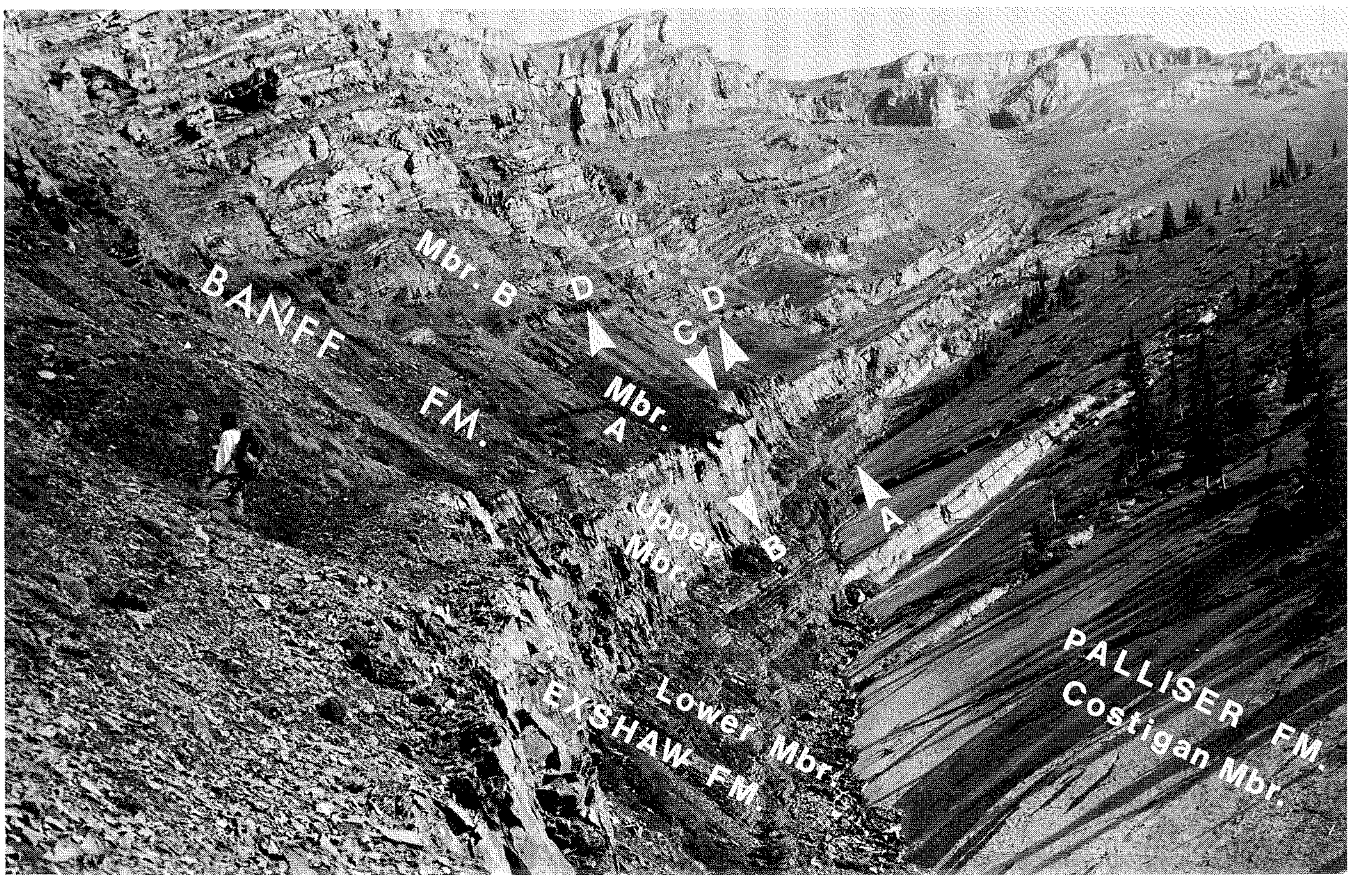


Figure 46. *Upper Palliser Formation, Exshaw Formation (20.4 m thick), and Banff Formation at stops 12 and 13 on the southwestern side of Mount Rundle (Fig. 3). Stop 12 is in the foreground, whereas 13 is by the last trees in upper part of canyon. Both the lower member of the Exshaw and member A of the Banff are black shale. The view is toward the north.*

Formation (only 3.05 m are exposed). 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 differs from that of the type Exshaw by containing abundant black, bedded chert. Calcareous concretions are moderately common in the siliceous shale unit. A thin (5 to 6 cm thick) sandstone bed is present in the black shale member 1.09 m above its base, and a thin (3 cm thick) bed of volcanic tuff lies 6.58 m above the Exshaw's base.

The Exshaw's upper member 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. 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 metre of the upper member grades upward into the overlying black, phosphatic shale and mudstone of member A of the Banff Formation (Fig. 47). Member A contains a thin (2 to 3 cm thick) bed of light grey volcanic tuff at 5.36 m above its base.

Stop 13. Upper Palliser Formation and overlying basal Exshaw Formation; upstream from stop 12 and on eastern side of the gulch at an elevation of approximately 7,100 ft (2,164 m). To reach this locality from stop 12, either hike up the extensive dip slope developed on the Palliser Formation (Fig. 46) or walk along the ledge on top of the lower Exshaw.

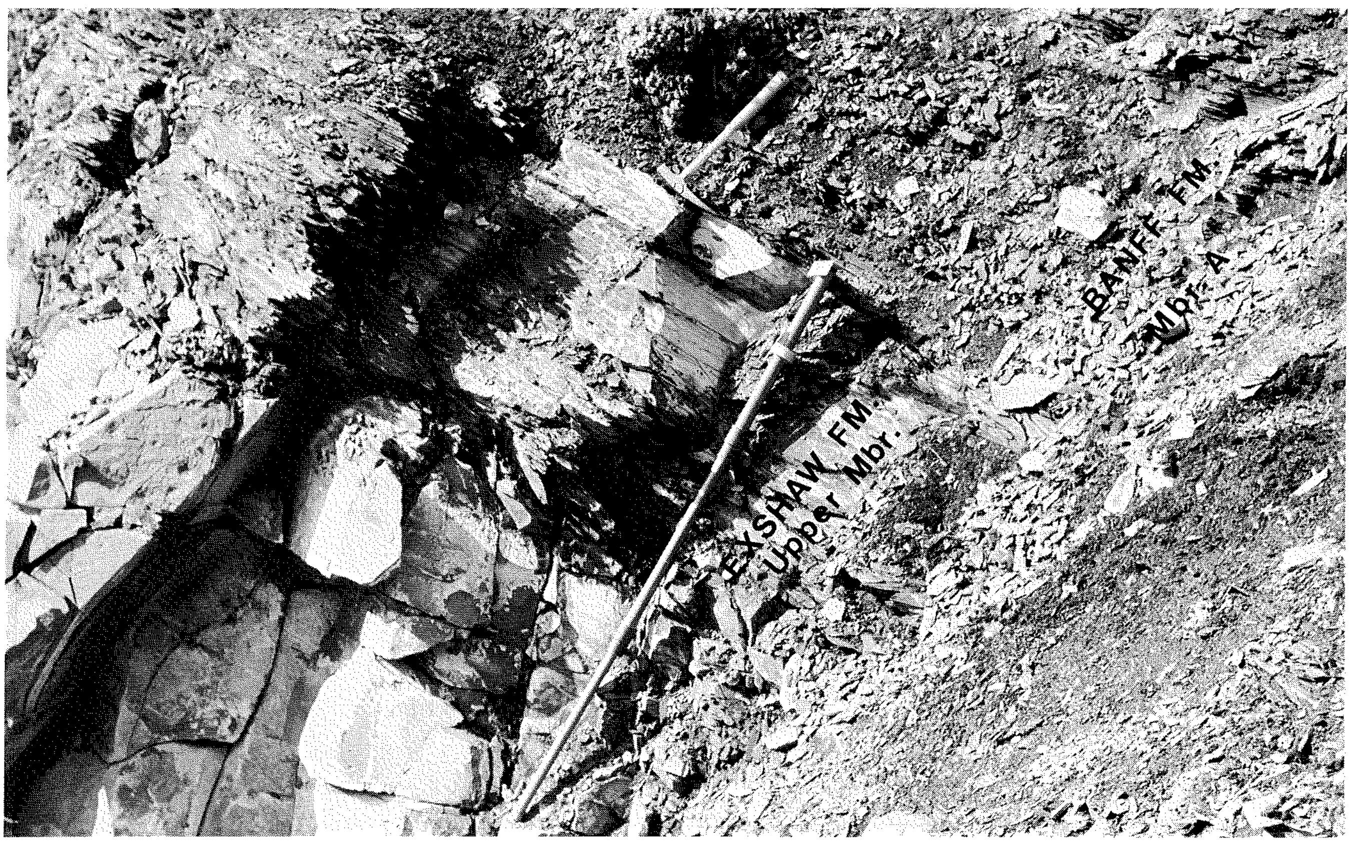


Figure 47. *Gradational contact between dolomitic siltstone of the upper member of the Exshaw Formation and overlying lower black shale of member A of the Banff Formation. Head of hammer rests on top of Exshaw; scale is 1.5 m long Jacob's staff. At stop 12 (Fig. 3) on the southwestern side of Mount Rundle.*

The upper 14.3 m of the Costigan Member are well exposed along the escarpment of a high-angle, northeasterly striking fault (Fig. 48). 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 abruptly overlies the underlying deposits and closely resembles the upper transgressive unit of the Costigan along Jura Creek.

The restricted-ramp lithofacies that dominated the Costigan along Jura Creek are not present, and most of the member comprises open-marine facies characteristic of the proximal-ramp setting of Famennian carbonate ramps (Fig. 14). Between Grotto Mountain and this locality, the restricted marine deposits have graded basinward into open-marine facies.

Return to the bus at White Man Gap for the trip to the western-style barbecue at the Kananaskis Guest Ranch on the Bow River by Seebe (across river from stop 1).

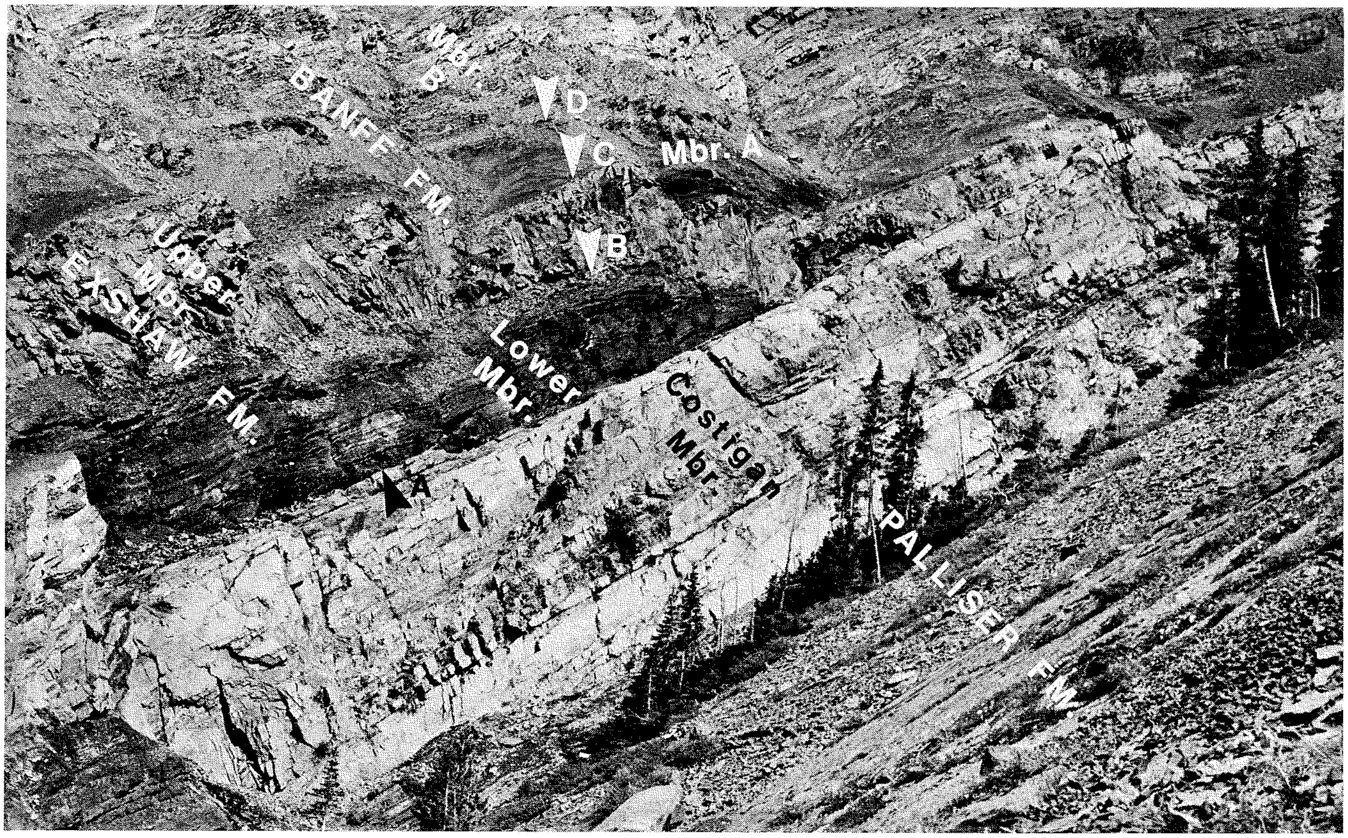


Figure 48. Famennian Costigan Member of Palliser Formation and overlying Famennian and lower Tournaisian Exshaw formation are well exposed along the escarpment of a northeasterly striking fault at stop 13, southwestern side of Mount Rundle. Strata in foreground have been dropped down 14 m relative to the light grey Costigan carbonates in the cliff face. Black shale of the lower Exshaw Formation unconformably overlies the Costigan.

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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 the conodont 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. 2) 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. 2) 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. 2) 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. 8) 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. 8) 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. 2) in side canyon entering Jura Creek from Loader Peak, Morro Member of Palliser Formation, 109 m above base of Palliser Formation, Famennian.

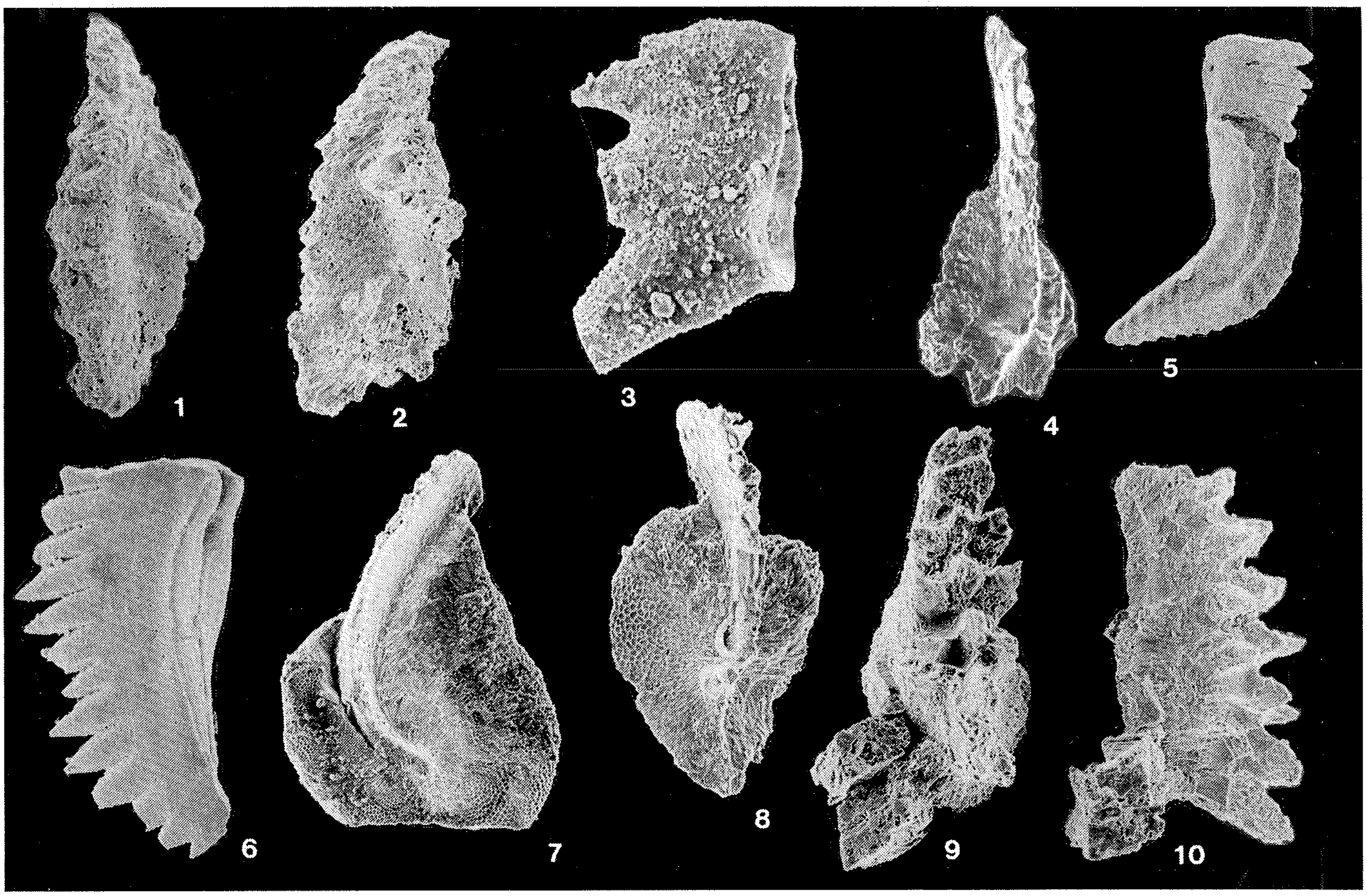

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Plate 2

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 to 10, Fig. 2) measured in side canyon entering Jura Creek from west at point immediately north of the type section of the Exshaw Formation; 51°05'30"N, 115°09'37"W, UTM 5661500N, 628850E, zone 11u; map area NTS 82 O/3; eastern Rocky Mountains, southwestern Alberta. All specimens are hypotypes; they are housed in the National Type Collection of Invertebrate and Plant Fossils at the Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario KiA OE8.

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 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; 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.

Figure 7. *Gnathodus cuneiformis* Mehl and Thomas, upper surface view, GSC 100610; 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.

Figures 8, 9, 10. *Gnathodus typicus* Cooper morphotype 2 of Lane, Sandberg and Ziegler, upper surface views; 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. 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 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 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 in side canyon entering Jura Creek from west, Pekisko Formation at 19.0 to 18.7 m below top, lower upper Tournaisian.


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Plate 3

All specimens are hypotypes; they are housed in the National Type Collection of Invertebrate and Plant Fossils at the Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario, K1A 0E8.

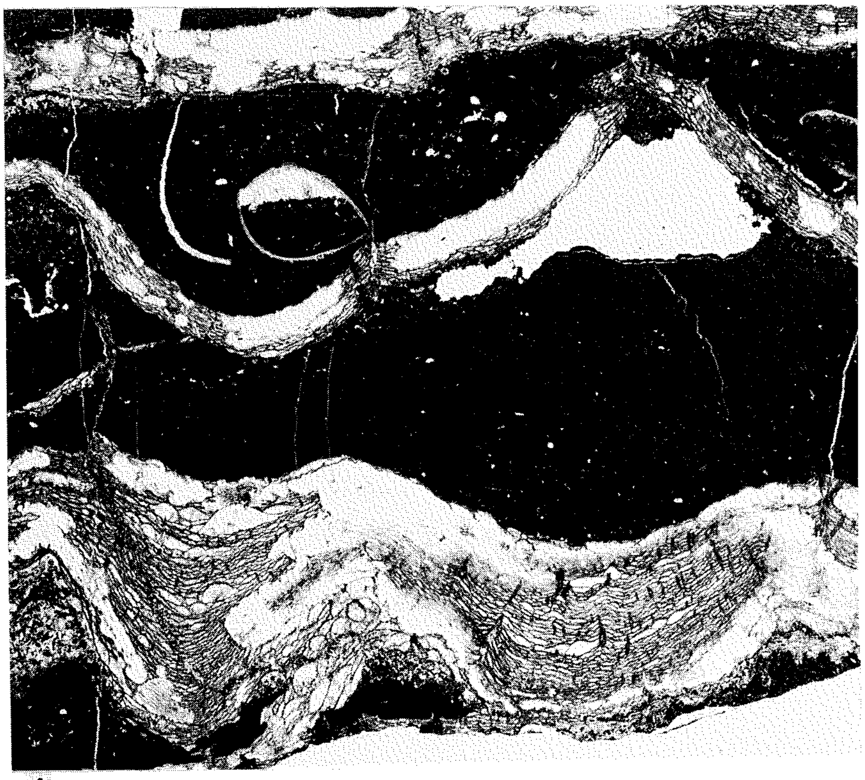
Figure 1. *Labechia palliseri* Stern; GSC 106787; GSC loc. C-195032, from Costigan Member of Palliser Formation at 2.05 m below top, upper Famennian, x3. From section 86RAH5 (stop 6, Fig. 2) in Jura Creek below type section of Exshaw Formation, 51°05'29"N, 115°09'29"W, UTM 5661500mN, 628950mE, zone 11u; map area 82 O/3; eastern Rocky Mountains, southwestern Alberta.

Figure 2. *Vesiculophyllum* sp., transverse thin section; GSC 106788; GSC loc. C-195318, 13.06-13.68 m below top of Shunda Formation; upper part of coral Zone IIB, late Tournaisian; x2. From section 90RAH8 (stop 10, Fig. 2) measured in side canyon entering Jura Creek from west at point immediately north of type section of Exshaw Formation; 51o05'30"N, 115o09'37"W, UTM 5661500mN, 628850mE, zone 11u; map area 82 O/3; eastern Rocky Mountains, southwestern Alberta.

Figure 3. *Sychnoelasma* sp., transverse section of silicified, weathered specimen; GSC 106789; GSC loc. C-195318, 13.06-13.68 m below top of Shunda Formation; upper part of coral Zone IIB, late Tournaisian; x3. From same locality as Figure 2.

Figures 4a,b,c. *Stelechophyllum circinatus* (Easton and Gutschick); GSC 106790; GSC loc. 62109, 15.2 m below top of Shunda Formation; upper part of coral Zone IIB, late Tournaisian; a, b, longitudinal thin sections; c, transverse thin section; x2. From section measured in side canyon entering Jura Creek at point immediately south of type section of Exshaw Formation; eastern Rocky Mountains, southwestern Alberta.

Figures 5a-c. *Stelechophyllum micrum* (Kelly); GSC 106791; GSC loc. C-41867, 85.4 m below top of Shunda Formation; lower to middle part of coral Zone IIB, late early to early late Tournaisian; a and b, longitudinal thin sections; c, transverse thin section; x3. From same locality as Figures 4a-c.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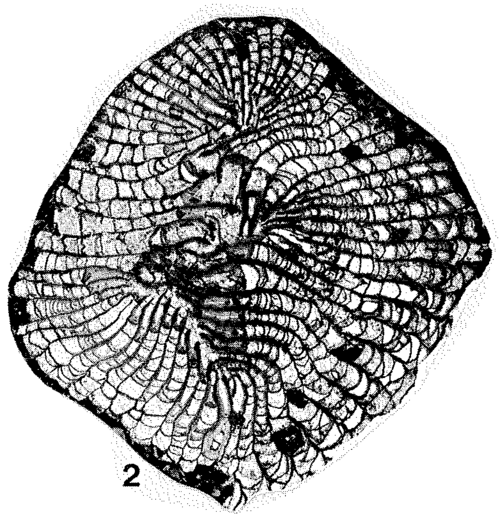
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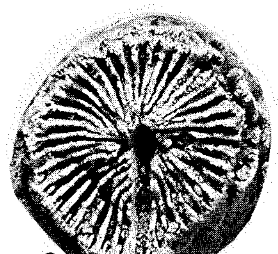
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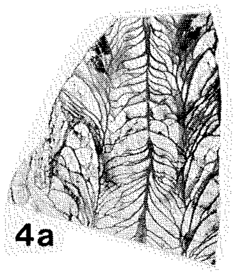
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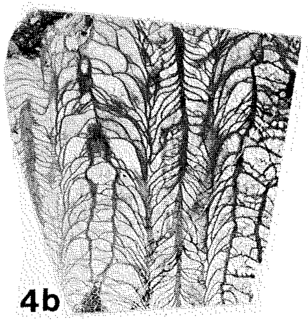
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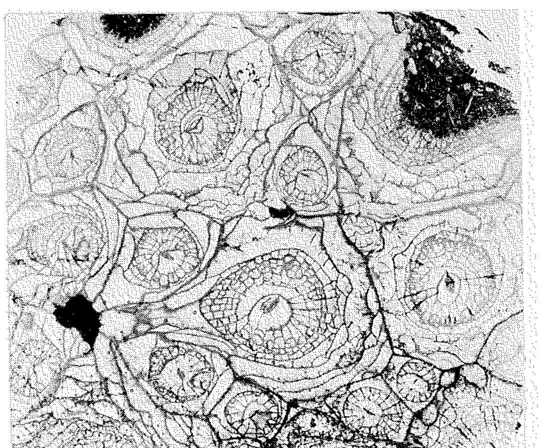
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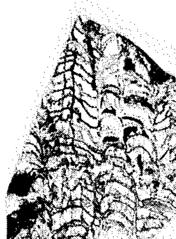
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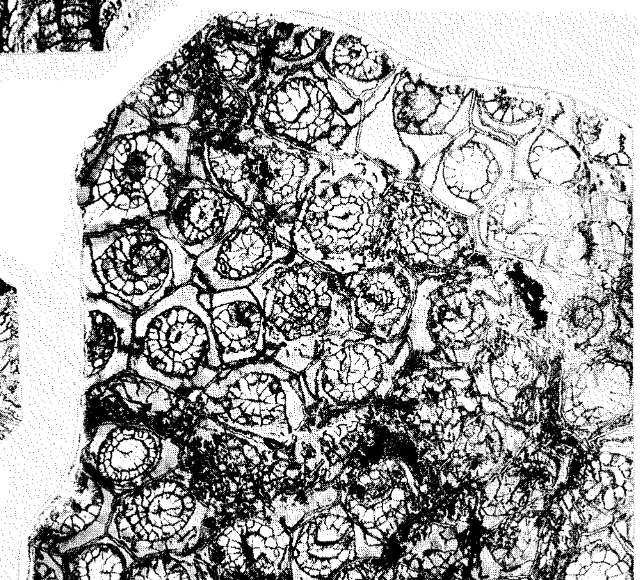
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