Chapter 14 – Carboniferous Strata of the Western Canada Sedimentary Basin

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Introduction

The Carboniferous System of the southern and central parts of the Western Canada Sedimentary Basin (WCSB) is represented by a thick succession deposited on the downwarped and downfaulted western margin of the ancestral North American plate and the central to western cratonic platform (Figs. 14.1 - 14.4). These deposits, which are divided here into three main map units, are preserved in a region that includes much of the eastern Cordillera and southern to western parts of the Interior Platform (Fig. 14.3), extending from southwestern Manitoba into southwestern District of Mackenzie.

The succession comprises two main lithofacies associations. The lower association generally thickens southwestward or basinward and is dominated by shale, spiculite and bedded chert of basin to slope origin. Upward and northeastward, the lower array passes into an upper association of platform and ramp carbonates and sandstone-dominated siliciclastic facies that were deposited in slope to continental settings. Both associations consist of numerous formations, many of which are separated by regional disconformities.

Relatively thin intervals of Upper Devonian strata occurring in the Bakken, Exshaw, Banff and Besa River formations, which span the Devonian/Carboniferous boundary (Fig. 14.2), are mapped and discussed with the Carboniferous. The Devonian strata are included because they are widely separated from underlying Famennian strata by disconformities, and are lithologically indistinguishable from overlying Carboniferous facies that occur in these formations.

Subaerial erosion during the latest Carboniferous, Permian, and subsequent periods removed much of the Carboniferous succession, particularly on the northern Interior Platform and the region west of the Rocky Mountain Front Ranges. Where the Carboniferous remains, it is generally unconformably overlain by either Permian or Mesozoic strata.

The Carboniferous of the WCSB contains substantial accumulations of conventional oil and gas, ranking third in recoverable reserves after the Devonian and Cretaceous (Podruski et al., 1988; Hay, *this volume*, Chapter 32). Approximately 14 percent (365 x 10^6 m^3, 2295 million barrels) of the proven conventional oil reserves of the Western Canada Sedimentary Basin occur in the Carboniferous, and 16 percent (580 x 10^9 m^3, 20.5 TCF) of the marketable conventional natural gas reserves. Sulphur extracted from sour gas is of significant economic importance, as is limestone, used principally for manufacture of Portland cement and lime. In addition, potentially economic coal seams are present in upper Viséan deltaic deposits of the Mattson Formation in southwestern District of Mackenzie.

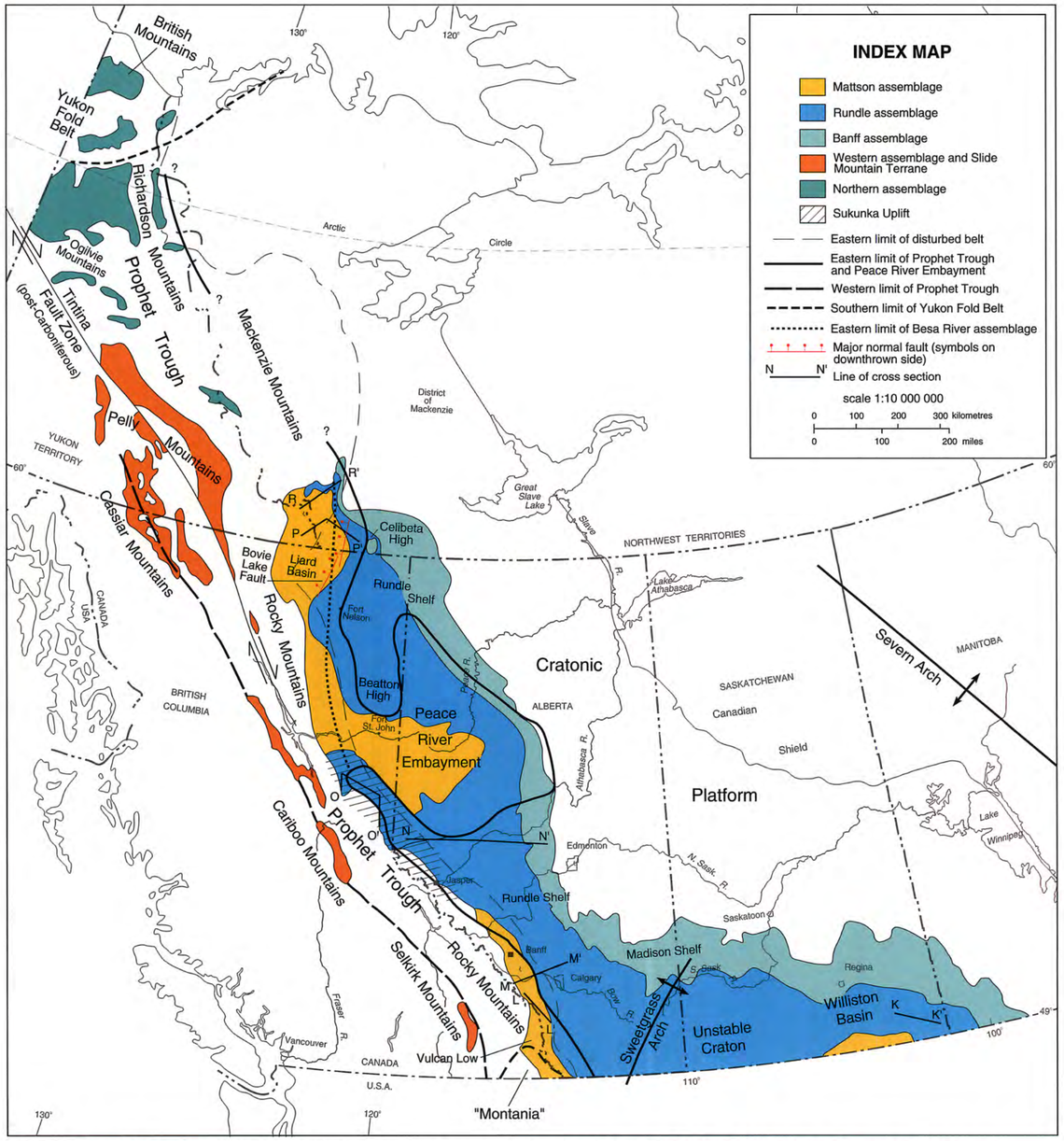


Figure 14.1 Map of Western Canada showing tectonic elements, lines of cross section for schematics (Figs. 14.10-14.16), and distribution of uppermost Devonian and Carboniferous lithofacies assemblages in the WCSB. See Figure 14.2 for the formational composition of lithofacies assemblages (modified from Richards, 1989b).

Previous Work

Geological studies on the Carboniferous of the WCSB date back to 1887 (McConnell). The current lithostratigraphic nomenclature and the depositional origins of major lithofacies have been established by numerous geologists including: Douglas (1958), Edie (1958), Macauley (1958), McCabe (1959), Halbertsma (1959), Christopher (1961), Scott (1964), Macqueen and Bamber (1968), Macqueen et al. (1972), Fuzesy (1960), Bamber and Mamet (1978), Chatellier (1988), Richards (1989a), O'Connell (1990), Barclay et al. (1990), and Savoy (1992). Regional stratigraphic syntheses were presented by Macauley et al. (1964), Douglas et al. (1970), Bamber et al. (1984), Henderson (1989), Richards (1989b), and Richards et al. (*in press*).

The biostratigraphy of the Carboniferous in the WCSB is established for several fossil groups (Fig. 14.2). Zonations are available for conodonts (Baxter and von Bitter, 1984; Higgins et al., 1991), foraminifers (Mamet and Skipp, 1970; Mamet, 1976; Mamet and Bamber, 1979; Mamet et al., 1986), corals (Sando and Bamber, 1985); ostracodes (Crasquin, 1984), and brachiopods (Nelson, 1961; Carter, 1987). International correlations have been established mainly by utilizing foraminifers and conodonts.

The concept of the Tournaisian Series used in this chapter (Fig. 14.2) differs substantially from that used in many recent papers about the Carboniferous of the WCSB. The Tournaisian Series was formerly divided into three parts (Tn1, Tn2 and Tn3), and its base was placed in the Upper Devonian (see Richards, 1989a, p. 3). Conil et al. (1976) formally restricted the type Tournaisian of Europe to make its base coincide with the Devonian/Carboniferous boundary. They also divided the Tournaisian into two parts, referred to as TI (= Hastarian Stage) and TII (= Ivorian Stage). These revisions, recently accepted by most European stratigraphers (see Paproth et al. 1983), are used here.

Geological Framework

During the Carboniferous, the principal tectonic elements in the WCSB were the Prophet Trough, the Peace River Embayment, the cratonic platform, the Williston Basin and the Yukon Fold Belt (Fig. 14.1; Richards, 1989b).

Prophet Trough

The Prophet Trough, which contains the thickest Carboniferous sections in Western Canada, developed during the latest Devonian to Early Carboniferous and persisted into the Late Cretaceous. The trough was connected to the Antler Foreland Basin of the western United States (Fig. 14.4), and extended from southeastern British Columbia to the Late Devonian and earliest Carboniferous Yukon Fold Belt (Fig. 14.1).

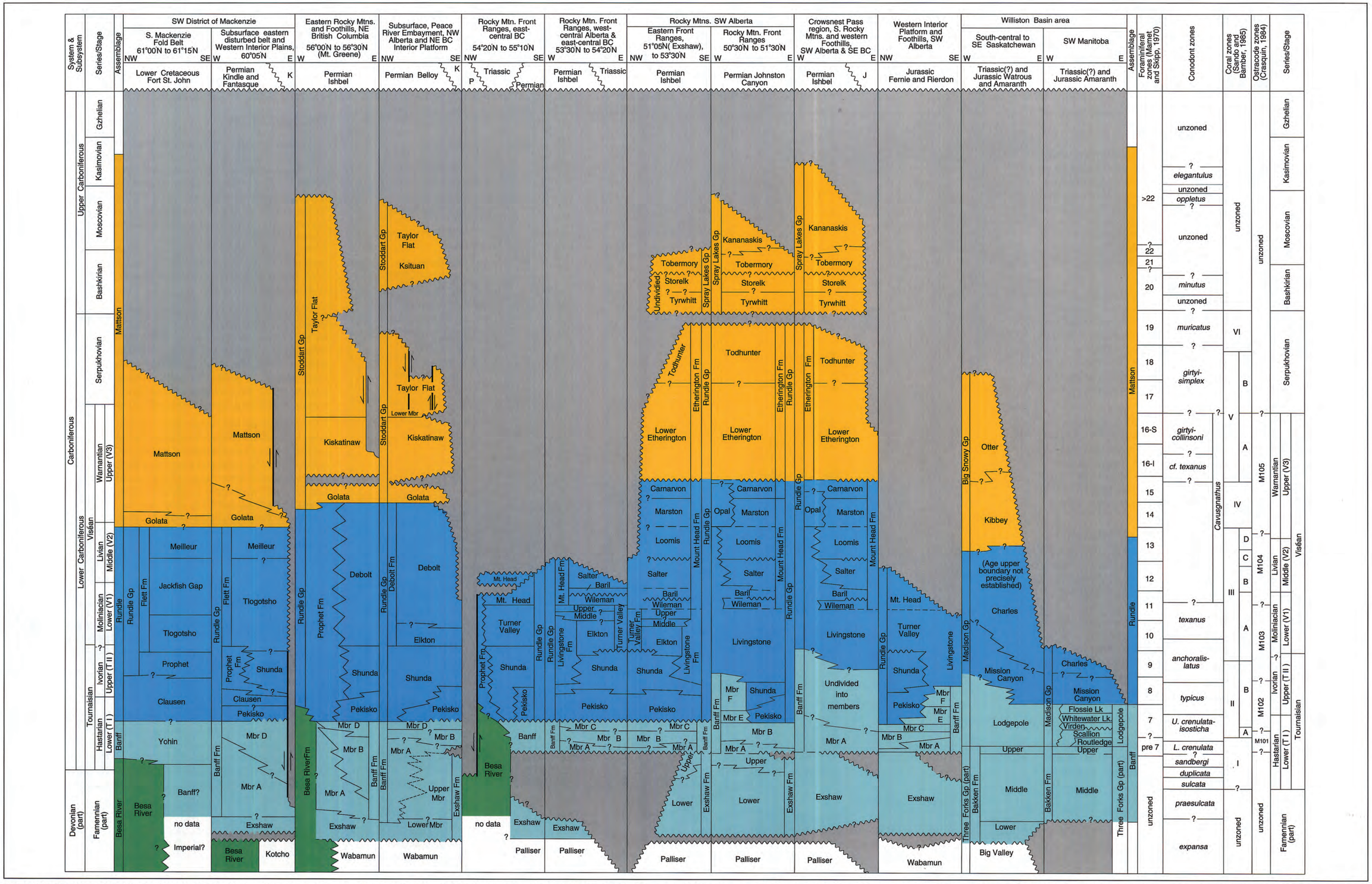


Figure 14.2 Correlation chart of Carboniferous lithostratigraphic units from southwestern Manitoba to southwestern District of Mackenzie, with standard chronostratigraphic units and Carboniferous zonal schemes. Dashed lines indicate nature of contact uncertain; question marks indicate position of line uncertain (modified from Richards, 1989b and Richards et al., *in press*).

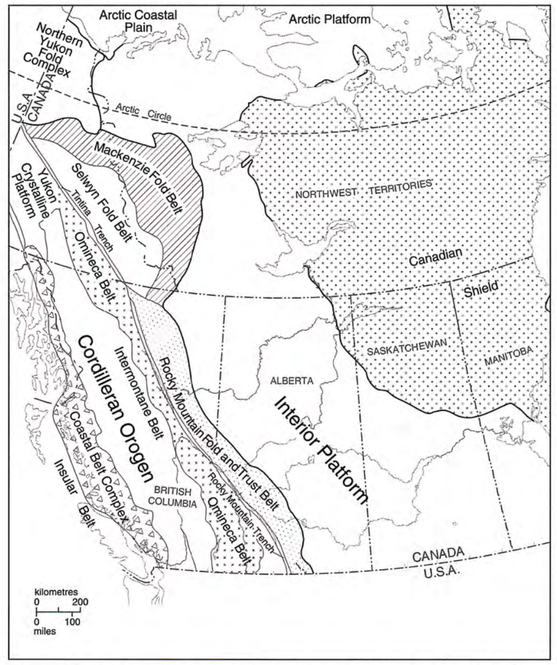


Figure 14.3 Principal present-day geological elements of Western Canada (after Douglas et al., 1970).

The western boundary of the trough is poorly defined but was an orogenic belt, extensively exposed from the Famennian into the early Viséan, subsequently largely transgressed. Late Devonian to Early Carboniferous volcanism, granitic plutonism, faulting and folding took place along the western rim (Richards, 1989b, Parrish, 1992; Smith and Gehrels, 1992).

A broad hinge zone, where water depths and sedimentation rates increased markedly basinward, formed the boundary between the cratonic platform and the Prophet Trough (Fig. 14.1). Along much of its length, the hinge was a foreland peripheral bulge during the late Famennian and Tournaisian.

Thickness trends of the Banff assemblage (see Fig. 14.33, and discussions of cross sections A-A′ and B-B′) demonstrate that the eastern hinge of Prophet Trough in the northwest lay west of the position indicated by Richards (1989b). Figure 14.33 also shows that northern Prophet Trough was separated from northwestern Peace River Embayment by a relatively low and broad, northwest-striking positive belt resembling the Sukunka Uplift (Fig. 14.1), which occurs on the southwestern side of the embayment. The positive belt on the northwestern side of the embayment is here named the Beatton High (Fig. 14.1), after the Beatton River of northeastern British Columbia (NTS 94A, H), where the positive belt was best developed and first recognized. Beatton High developed during the Tournaisian, or slightly earlier, and was episodically high into the Late Permian (Henderson et al., *this volume*, Chapter 15, Figs. 15.1, 15.14).

In the northwest, the Prophet Trough included the Liard Basin (Liard Trough of Douglas et al., 1970; Richards, 1989a), a northwest-trending feature with a depositional axis coinciding with the Yukon/District of Mackenzie border and the northern Rocky Mountain Foothills of British Columbia.

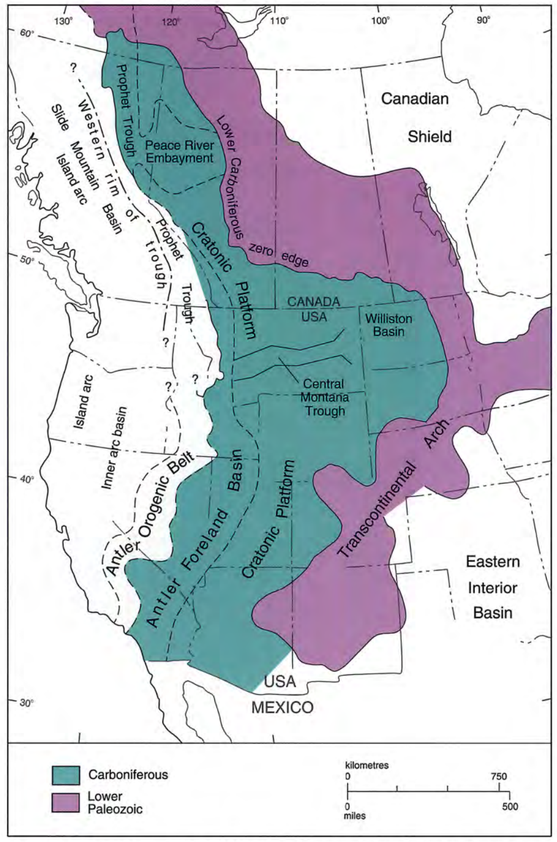


Figure 14.4 Map of western North America showing relation of Prophet Trough in Western Canada to Antler Foreland Basin in the western United States. An inner arc basin (Slide Mountain Basin) lies southwest of the western rim of Prophet Trough (modified from Sando et al., 1990).

In southernmost Canada and northern Montana, Prophet Trough included a slightly positive area on the site of the Cambrian landmass Montania (Fig. 14.1). This area, episodically positive into the Permian, is characterized by relatively thin Carboniferous and Permian successions. The positive area was bounded on the north by an unnamed, northeastward-striking trough or half-graben which contains an anomalously thick upper Paleozoic interval (Richards, 1989b). The latter negative belt developed in approximately the same region as the western part of the Precambrian Vulcan Low (Fig. 14.1) of Ross and Stephenson (1989).

Growing evidence indicates that southern Prophet Trough was a compressional foreland basin from the late Famennian to the early Viséan. Central Prophet Trough (from southern Peace River Embayment into the Yukon) was also a foreland basin, but subsidence in that area and on the adjacent cratonic platform was accompanied by widespread block faulting (Richards, 1989b; Smith et al., 1993).

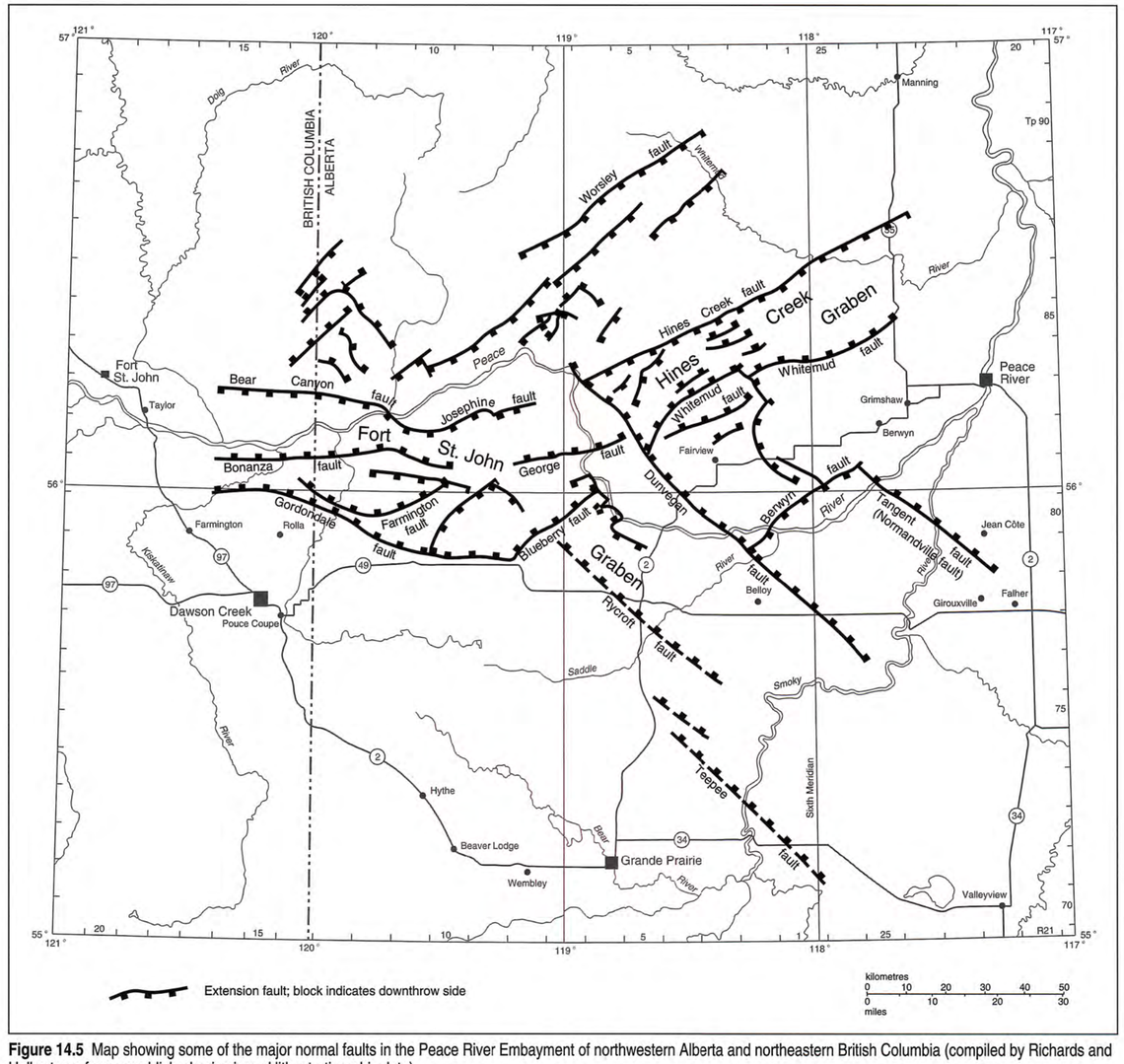


Figure 14.5 Map showing some of the major normal faults in the Peace River Embayment of northwestern Alberta and northeastern British Columbia (compiled by Richards and Halbertsma from unpublished seismic and lithostratigraphic data).

Peace River Embayment

The Peace River Embayment of northwestern Alberta and northeastern British Columbia opened into the Prophet Trough and was a broad, fault-controlled re-entrant into the western cratonic platform (Fig. 14.1). The principal depositional and structural axis of the embayment had an easterly trend and coincided approximately with that of the Late Devonian Peace River Arch; a subordinate northwest-trending axis was also present. Regional subsidence accompanied by extensive block faulting along northeasterly and northwesterly striking normal faults (e.g., Figs. 14.5, 14.6) facilitated deposition of a thick Carboniferous succession in the embayment, which included an extensive central graben system (Barclay et al., 1990).

The embayment, bounded on its southwestern side by the northwest-trending Sukunka Uplift and by the slightly elevated eastern hinge of Prophet Trough in the northwest (Beatton High), occupied an extensive region from the earliest Carboniferous into the late Serpukhovian. Higgins et al. (1991) stated that the embayment may have been of minor extent during the Late Carboniferous, based on the lack of documented occurrences of Upper Carboniferous strata. However, conodont data (Chung, *pers. comm.*, 1992) for the upper Taylor Flat Formation of the embayment indicate that Upper Carboniferous marine strata are widely preserved in that formation, thereby proving that the embayment was extensively developed during the Late Carboniferous. The Peace River Embayment was also widely developed in Permian time.

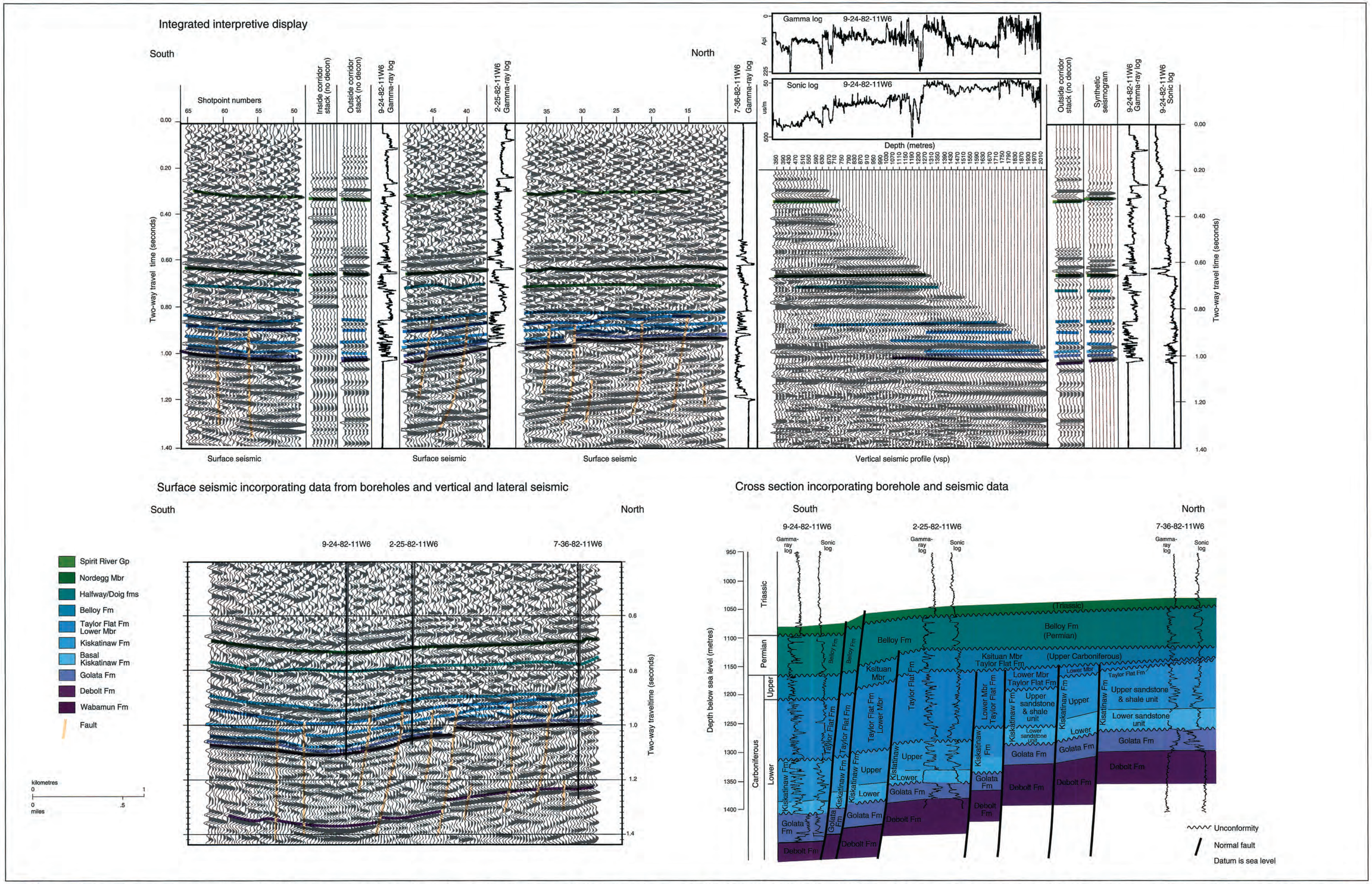


Figure 14.6 Integrated interpretive seismic display showing normal faults along northern margin of the Fort St. John Graben in Peace River Embayment. The sonic and gamma-ray logs for the borehole at 9-24-82-11W6, plotted in depth, tie to the zero-offset vertical seismic profile (VSP) and permit a precise correlation with the surface seisimc section. The surface seismic is also tied to boreholes at 7-36-82-11W6 and 2-25-82-11W6. The stratigraphic cross section (lower right) incorporates data from the surface seismic cross section, vertical and lateral seismic profiles, and borehole logs.

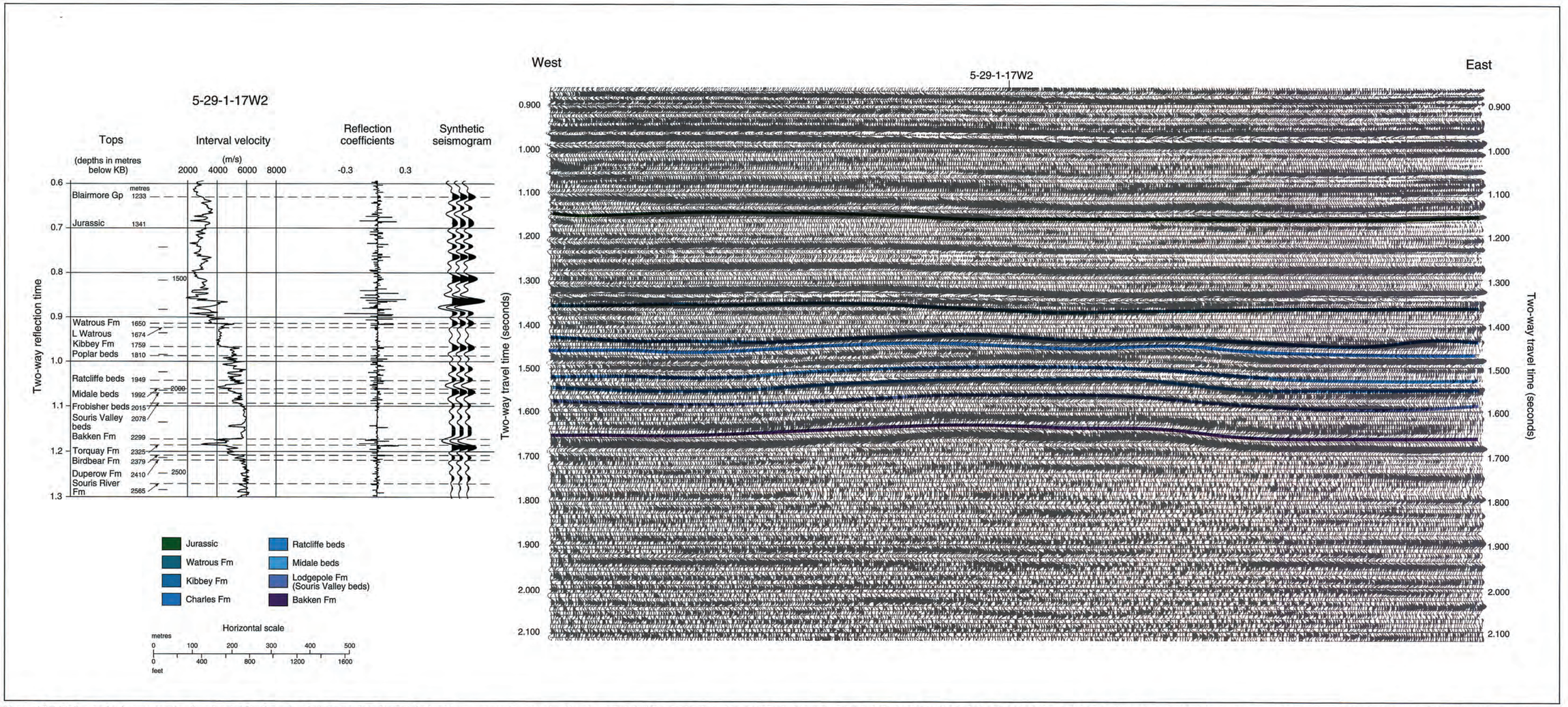


Figure 14.7 Surface seismic cross section (courtesy of PanCanadian Petroleum Ltd.) showing Carboniferous succession at Lake Alma in central Williston Basin of south-central Saskatchewan. Seismic is tied to the sonic log for the well at 5-29-1-17W2. The prominent arch-shaped structure resulted from post-Carboniferous dissolution of Devonian evaporites below the adjacent lows, and collapse of overlying deposits. The cross section shows the layer-cake nature of succession; poorly defined clinoforms are evident in eastern Lodgepole.

Cratonic Platform and Williston Basin

The western cratonic platform, which extended northward from the United States to the Yukon Fold Belt (Figs. 14.1, 14.4), included the Williston Basin and several broad arches. Williston Basin, centred in western North Dakota, originated during the Ordovician by downdropping along basement faults. It redeveloped in several subsequent periods. The basin was well developed during most of the Carboniferous, but regional mid-Carboniferous epeirogenic uplift and erosion occurred. The substantial Carboniferous subsidence resulted largely from sagging of the Paleozoic succession in response to reactivation of the basement faults. Movement on the faults also produced fault-controlled folds and sub-basins (Gerhard et al., 1991). Normal faults and uplifts (Fig. 14.7), resulting from post-Carboniferous dissolution of salt in underlying Devonian formations, are common in the basin (Fuzesy, 1960).

During the Tournaisian, the Williston Basin constituted part of an extensive embayment that was connected to the Prophet Trough and the Antler Foreland Basin by a broad seaway, extending from southeastern Alberta into Wyoming. This connection had an axial graben system called the Central Montana Trough (Fig. 14.4; Roberts, 1979; Precht and Shepard, 1988). In the early and middle Viséan, the Williston Basin became a topographical basin as a broad, northeast-trending uplift (Sweetgrass Arch of Douglas et al., 1970) developed across the seaway in southeastern Alberta and southwestern Saskatchewan while a karst plain (Sandberg et al. (1982) developed to the south. During the Carboniferous, the axis of the (proto-) Sweetgrass Arch probably was approximately coincident with that of its present-day expression (Figs. 14.1 and 14.8).

Early Carboniferous shelf regions that extended from the Leadville-Redwall Shelf of the southwestern United States to northern Montana were called the Madison Shelf by Sando et al. (1990). The name, Madison Shelf (Fig. 14.1), is herein extended northward to Early Carboniferous shelf areas that formed between southern Alberta and Manitoba, in the seaway connecting the Williston Basin and Prophet Trough. The name Rundle Shelf (Fig. 14.1), named after the Rundle Group, is introduced here for Carboniferous shelf regions that lay north of the seaway and extended into southwestern District of Mackenzie.

The Precambrian Canadian Shield was exposed along the northwest-trending Severn Arch of Manitoba and the north-trending Wisconsin Arch of Ontario (Porter et al., 1982). These arches, along with the Transcontinental Arch of the north-central United States (Figs. 14.1, 14.4), controlled the positions of the eastern and northeastern shorelines of the latest Devonian and Carboniferous seas.

Stratigraphy

Stratigraphic Nomenclature and Lithostratigraphy

The uppermost Devonian and Carboniferous succession from southwestern Manitoba into the District of Mackenzie was divided by Richards (1989b) into a number of mappable lithofacies assemblages (Figs. 14.1, 14.2). Lithofacies that lie west of the Rocky Mountains are called the western assemblage and were deposited in western Prophet Trough and on its western rim. This assemblage, which is not included on the isopach maps and cross sections, includes carbonates, volcanics, and remnants of an easterly thinning clastic wedge that was largely removed by post-Carboniferous erosion.

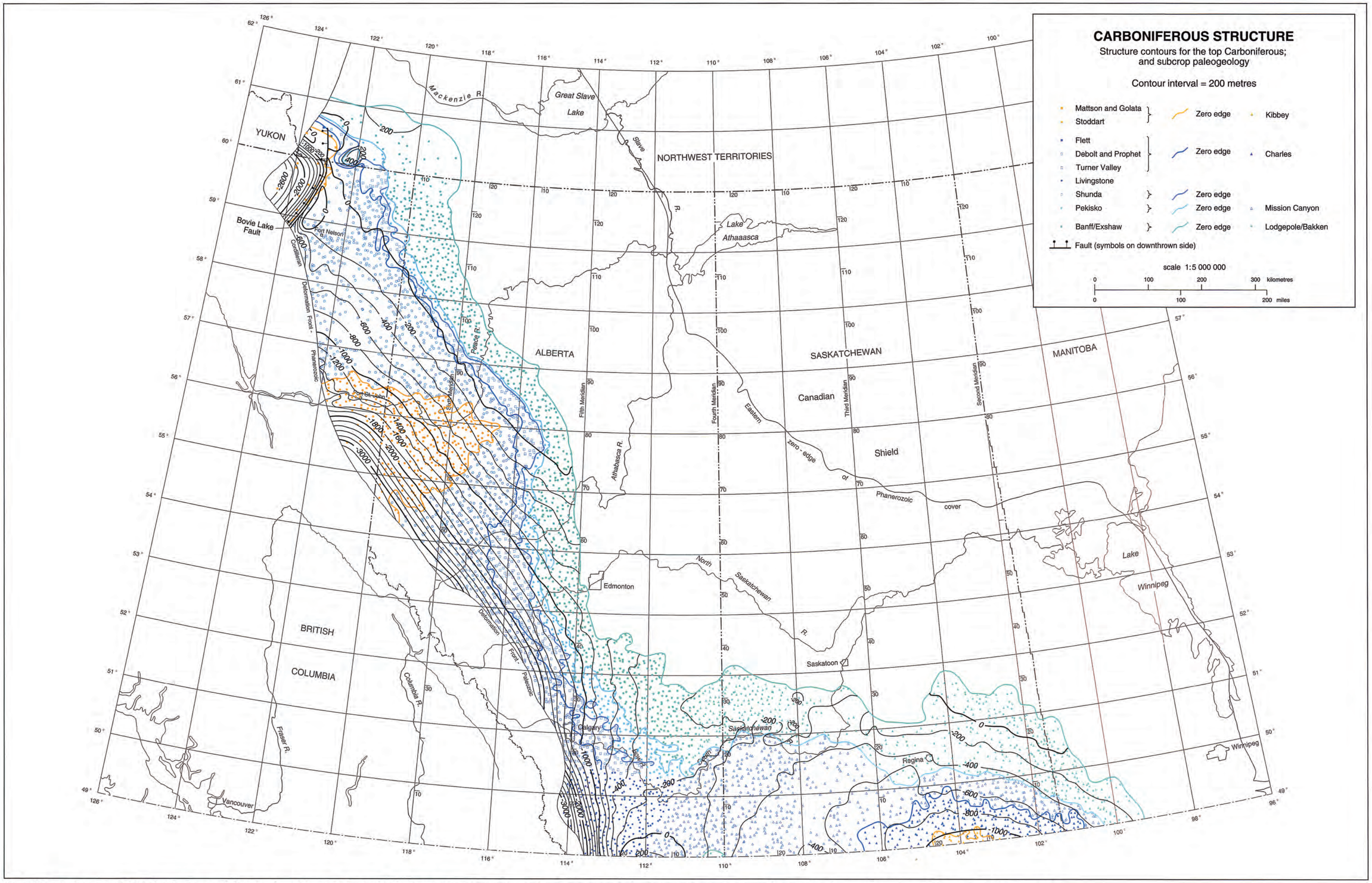


Figure 14.8 Structure on top of the Carboniferous map unit. Map also shows subcrop distribution of Carboniferous units and erosional zero edges. The prominent northeast-plunging structure in southern Alberta and southwestern Saskatchewan is the present-day Sweetgrass Arch.

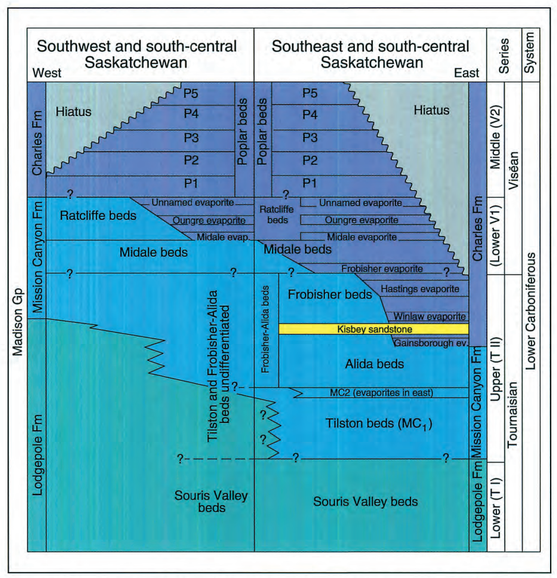


Figure 14.9 Formal and informal lithostratigraphic units in Lower Carboniferous Madison Group of southern Saskatchewan (modified from Fuzesy, 1973). A question mark on a boundary indicates uncertainty in its position with respect to the chronostratigraphic units.

The succession to the east, which comprises platform to ramp carbonates and deltaic terrigenous clastics, includes the Banff, Rundle and Mattson assemblages (Figs. 14.1, 14.2). These three assemblages, widely preserved in the Rocky Mountain Fold and Thrust Belt and on the Interior Platform, constitute the three main divisions of the Carboniferous that are dealt with in this chapter. Fine-grained siliciclastics and cherty to argillaceous carbonates of the Banff assemblage are widely overlain by carbonates of the Rundle assemblage, which in turn are partly overlain by sandstone and subordinate carbonates of the Mattson assemblage. Following Higgins et al. (1991), the Mattson assemblage of Richards (1989b) is expanded to include the sandstone-dominated Upper Carboniferous succession. From east-central British Columbia into the District of Mackenzie, the three assemblages overlie and pass basinward into the shale-dominated Besa River Assemblage.

Stratigraphic relations, lithology and depositional environments of the lithostratigraphic units that constitute the Banff, Rundle, Mattson, and Besa River assemblages are illustrated in schematic cross sections (Figs. 14.10-14.16) and in detailed stratigraphic cross sections (Figs. 14.19-14.30).

The lower boundary of the uppermost Devonian and Carboniferous succession in the WCSB is locally conformable, but in most areas it is a minor unconformity caused largely by transgressive ravinement (Fig. 14.2). In western Manitoba and southeastern Saskatchewan and in parts of the central Rocky Mountains (Sukunka Uplift) and foothills, it is a subaerial unconformity (Richards, 1989b).

The Carboniferous succession is unconformably overlain by Permian deposits in most of the eastern Cordillera, and on the western Interior Platform of the Peace River Embayment area and locally to the northwest. Northward and eastward of the erosional zero edge of the Permian deposits, the Carboniferous is unconformably overlain by progressively younger strata of Triassic to Cretaceous age (Figs. 14.2, 14.19-14.30).

The unconformity between the Carboniferous and overlying systems shows pronounced diachroneity, with the top of the Carboniferous becoming gradually older northeastward and northward (Fig. 14.8) as basal strata of the overlying systems become younger. The diachroneity resulted largely from southwestward epeirogenic tilting of the craton accompanied by several periods of erosional bevelling.

Banff Assemblage

Distribution and Regional Lithostratigraphy. The uppermost Famennian to upper Tournaisian Banff assemblage (Fig. 14.2) comprises carbonates and fine-grained siliciclastics of the Bakken, Exshaw, Lodgepole, Banff, and Yohin formations (see Fig. 14.33). An arbitrary nomenclatural boundary along the axis of the Mesozoic expression of the Sweetgrass Arch divides the assemblage into two successions (Figs. 14.8, 14.27, 14.30). The Bakken Formation and overlying Lodgepole Formation lie east of the arch and were deposited on the cratonic platform and in the Williston Basin. The Exshaw, Banff and Yohin formations, deposited on the western cratonic platform and in the Prophet Trough and the Peace River Embayment, lie west of the Sweetgrass Arch and extend into the District of Mackenzie.

In Manitoba, the Lodgepole Formation comprises formal members (Fig. 14.2; McCabe, 1959), whereas in Saskatchewan, it was divided by the Saskatchewan Geological Society (1956) into informal marker-defined units called beds (Fig. 14.9; Fuzesy, 1960). The Banff Formation of Alberta is here divided into several informal members that are similar to those used by Richards (1989b) and Richards et al. (*in press*).

Assemblage Boundaries and Unconformities. In most areas, the Banff assemblage unconformably overlies Famennian strata, but in some areas the boundary is either conformable or its nature uncertain. In the northwest, the assemblage overlies and passes basinward into the Besa River assemblage. In southeastern British Columbia, the latter assemblage is represented by the Lussier shale (Savoy, 1992) and underlies the Banff assemblage in one syncline.

Unconformities have been recognized at two levels in the Banff assemblage. An unconformity commonly separates the Exshaw Formation and overlying Banff Formation in extensive areas from east-central British Columbia to southern Alberta. An equivalent but minor unconformity may be locally present between the middle and upper members of the Bakken Formation from southeastern Alberta into Manitoba (Macqueen and Sandberg, 1970; Richards, 1989b). Higher in the assemblage in Manitoba, a subaerial unconformity separates the Scallion and Virden members of the Lodgepole Formation (Sereda, 1990).

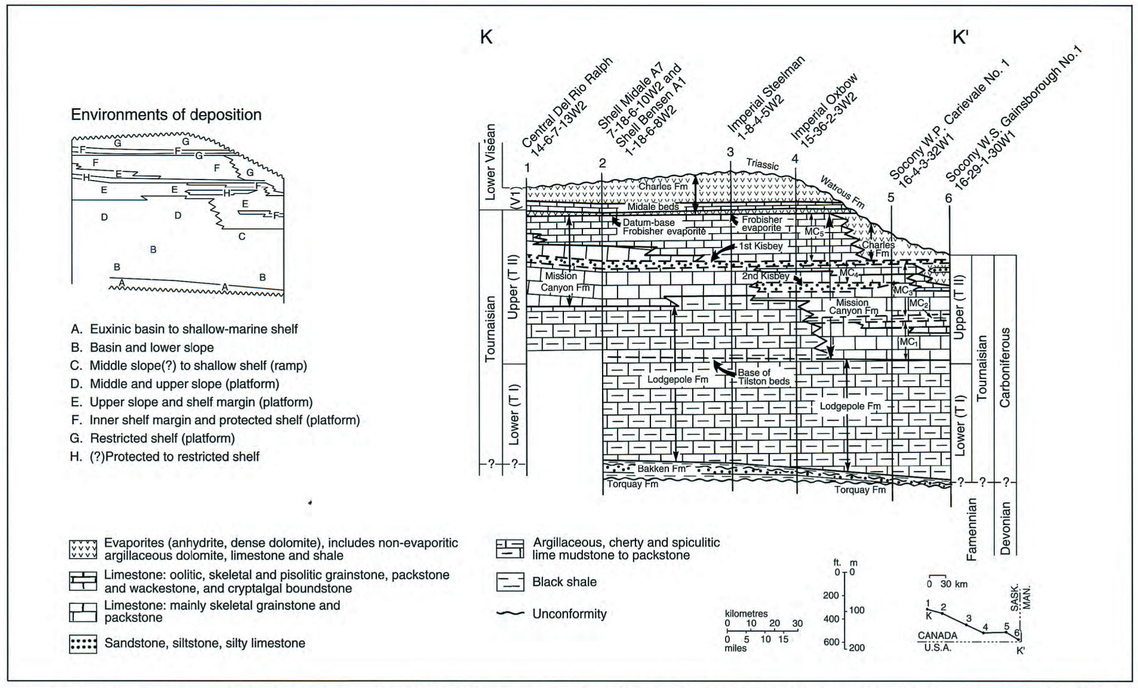


Figure 14.10 Stratigraphic cross section K-K′ showing uppermost Devonian and Lower Carboniferous in northeastern Williston Basin (after Edie, 1958). See Figure 14.1 for line of section K-K′. Note that the vertical scale (1:12 000) is condensed relative to the Atlas cross section standard (1:6000).

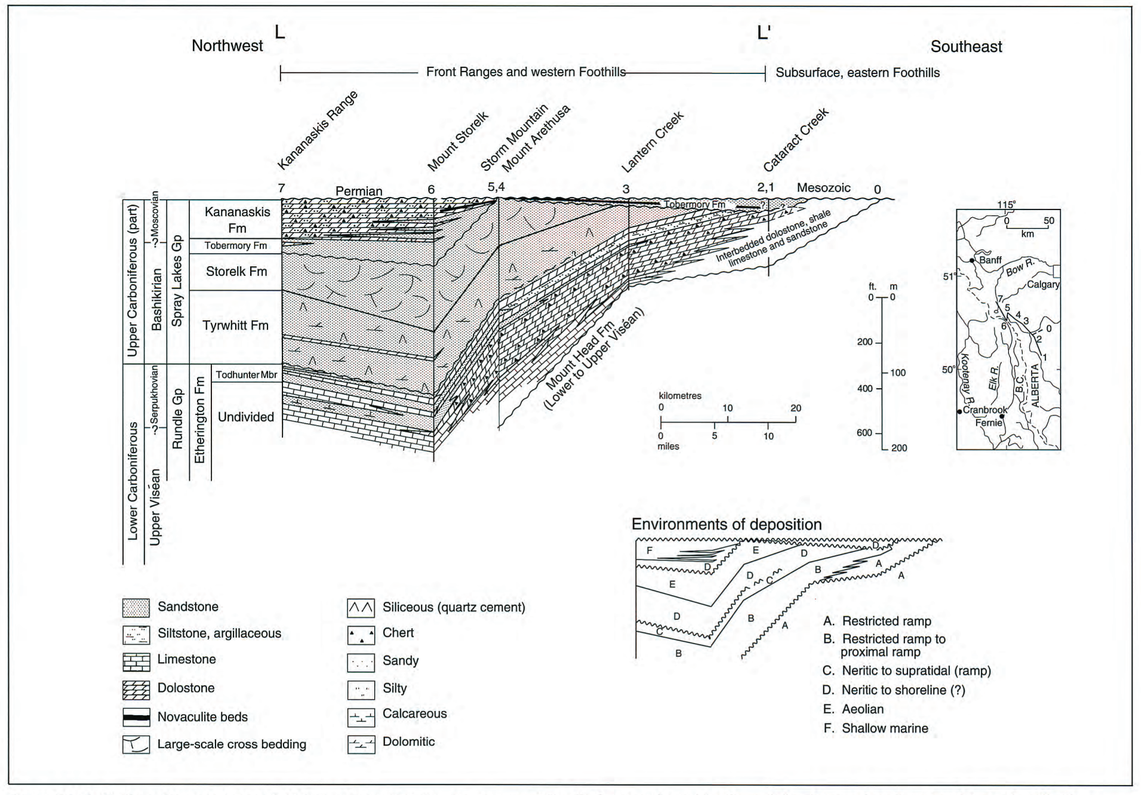


Figure 14.11 Stratigraphic cross section L-L′ (non-palinspastic) showing uppermost Rundle Group and overlying Spray Lakes Group of southwestern Alberta (modified from Scott, 1964). See Figure 14.1 for line of section L-L′. Vertical scale (1:6000) is Atlas cross section standard.

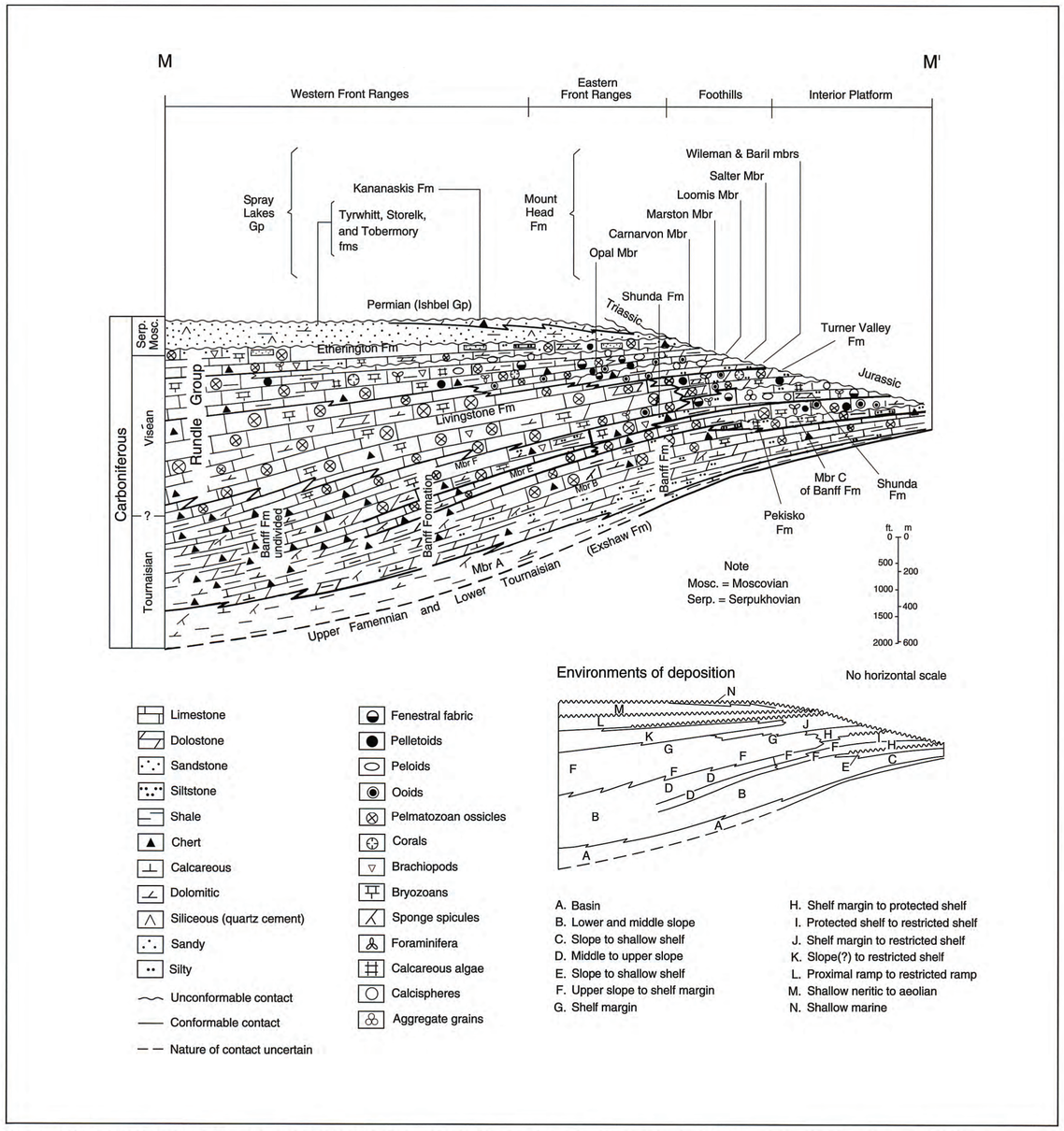


Figure 14.12 Partly schematic stratigraphic cross section M-M′ (non-palinspastic) showing Carboniferous of southwestern Alberta (modified from Richards, 1989b). See Figure 14.1 for line of section M-M′. Note that the vertical scale (1:24 000) is very markedly condensed relative to the Atlas cross section standard (1:6000).

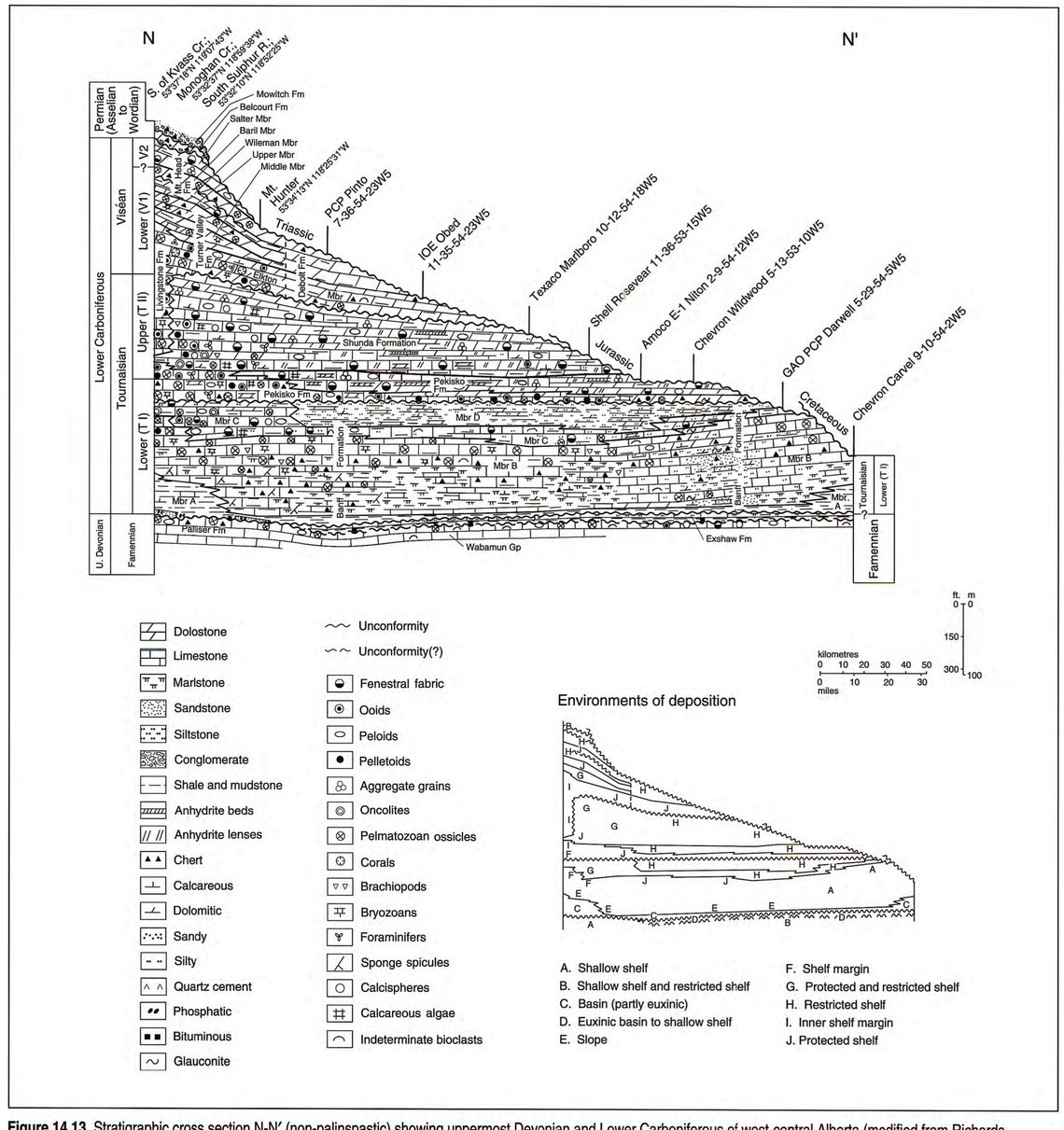


Figure 14.13 Stratigraphic cross section N-N′ (non-palinspastic) showing uppermost Devonian and Lower Carboniferous of west-central Alberta (modified from Richards, 1989b). See Figure 14.1 for line of section N-N′. Vertical scale (1:6000) is Atlas cross section standard.

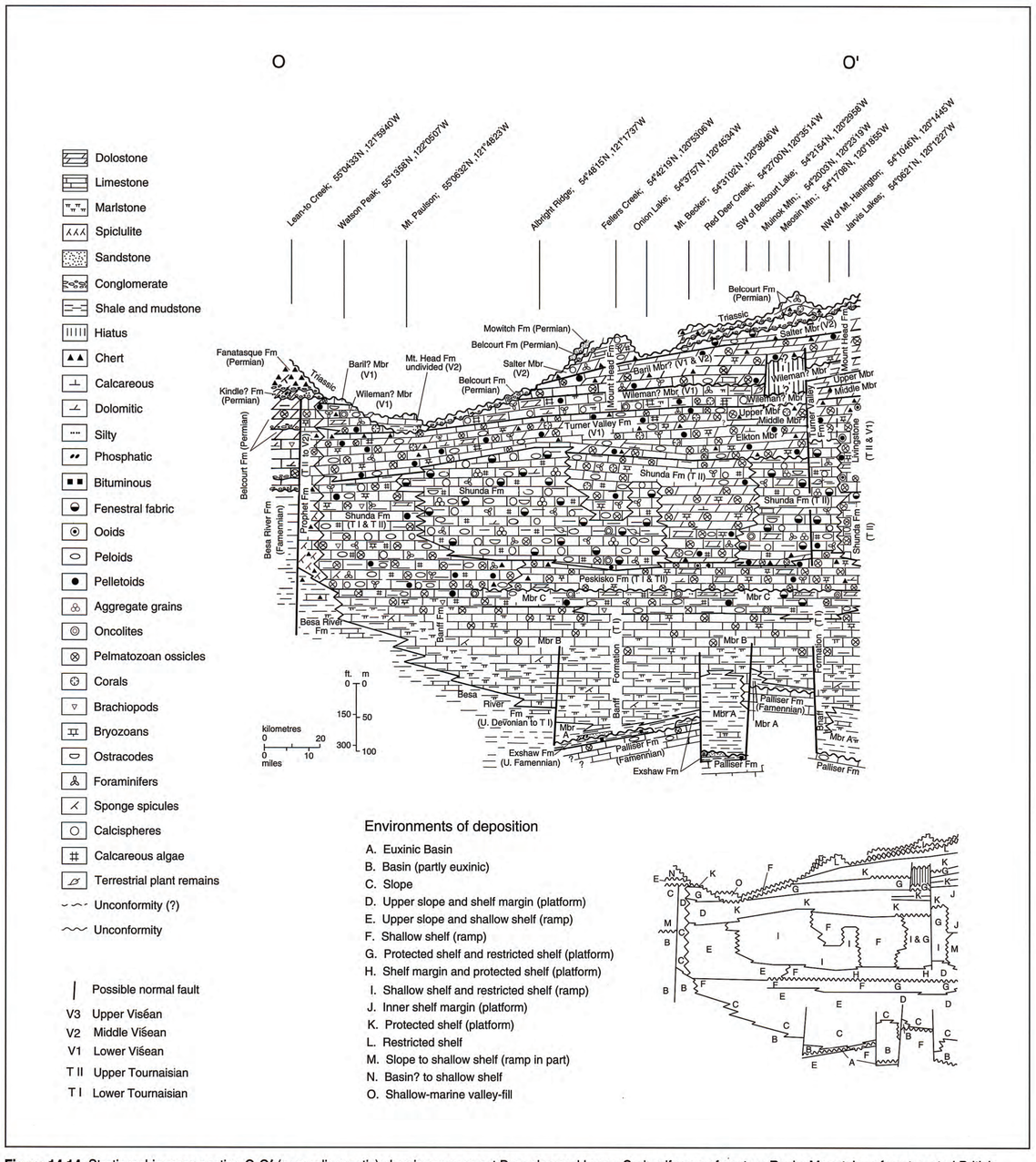


Figure 14.14 Stratigraphic cross section O-O′ (non-palinspastic) showing uppermost Devonian and Lower Carboniferous of eastern Rocky Mountains of east-central British Columbia. Locations of late Paleozoic normal faults are based on changes in thickness and lithology between stratigraphic sections; actual faults not observed (modified from Richards, 1989b). See Figure 14.1 for line of section O-O′. Vertical scale (1:6000) is Atlas cross section standard.

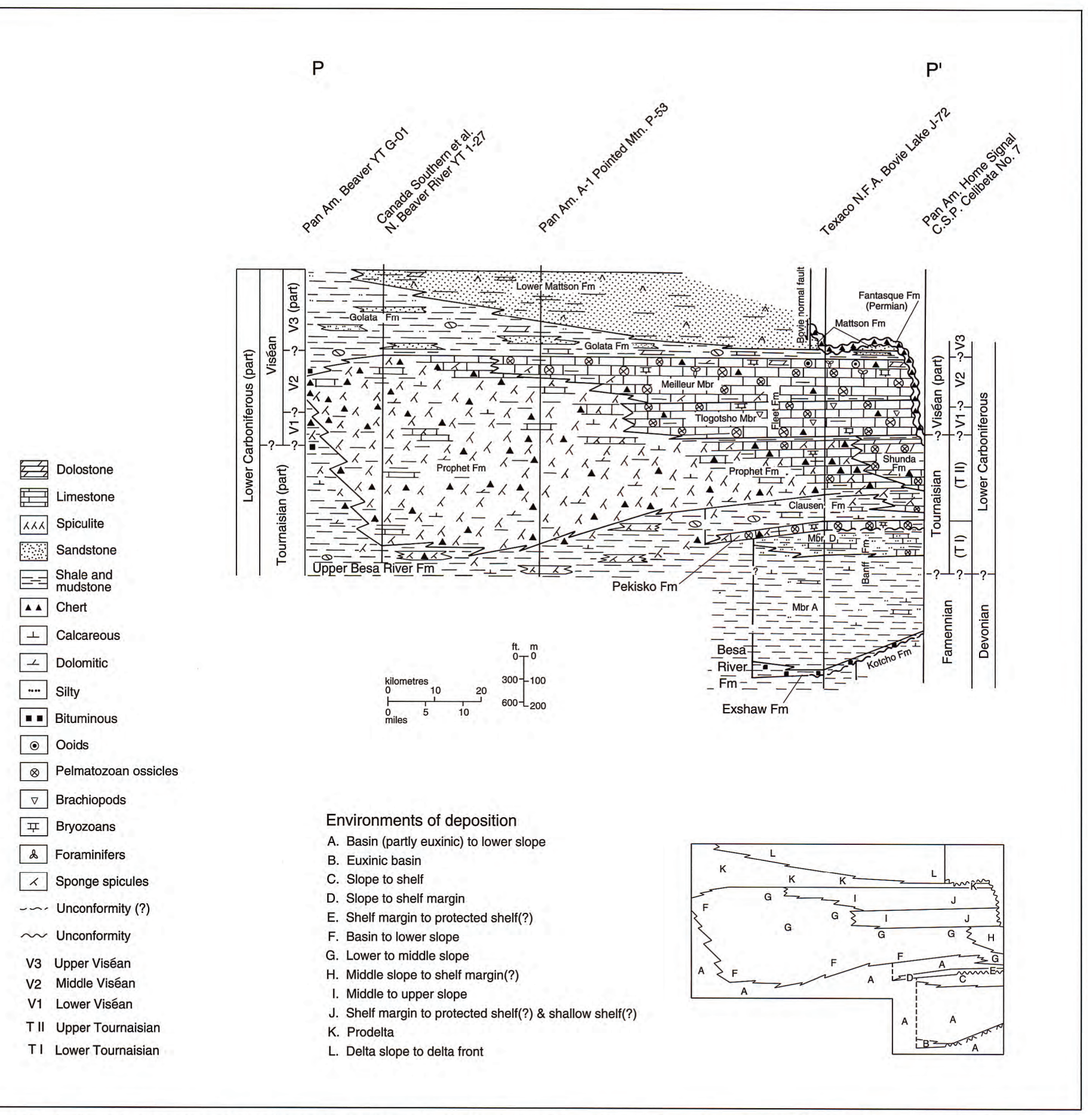


Figure 14.15 Stratigraphic cross section P-P′ (palinspastic) showing uppermost Devonian and Lower Carboniferous of southwestern District of Mackenzie and southeastern Yukon Territory (modified from Richards, 1989b). See Figure 14.1 for line of section P-P′. Note that the vertical scale (1:18 000) is markedly condensed relative to the Atlas cross section standard (1:6000).

In most of the Williston Basin, the southern Rocky Mountain Fold and Thrust Belt, and on the Interior Platform of southernmost Alberta, the top of the Banff assemblage becomes younger basinward as it grades into the overlying Rundle assemblage. Elsewhere, the boundary between the Banff and Rundle assemblages is commonly a minor unconformity resulting largely from transgressive ravinement (Richards, 1989b).

Rundle Assemblage

Distribution and Regional Stratigraphy. The Tournaisian to upper Viséan Rundle assemblage comprises the upper Madison Group and all of the Rundle Group except the Etherington Formation (Fig. 14.2; see also Fig. 14.34). In Canada, an arbitrary nomenclatural boundary along the axis of the Mesozoic Sweetgrass Arch separates the Madison and Rundle groups (Figs. 14.8, 14.27).

The upper Madison Group, comprising the Mission Canyon Formation and overlying Charles Formation, extends from southwestern Manitoba into southeastern Alberta (Figs. 14.10-14.20, 14.27, 14.28) and to the south. During 1956, the Mission Canyon and Charles formations of Saskatchewan were divided into informal marker-defined units called beds by the Saskatchewan Geological Society (Fig. 14.9; Fuzesy, 1973).

The Rundle Group, which consists of numerous formations and members (Fig. 14.2), extends from the District of Mackenzie into southeastern British Columbia (Figs. 14.19, 14.23-14.27). South of the Peace River Embayment, the principal formations within the Rundle Group are the Pekisko, Shunda, Turner Valley, Mount Head, and Livingstone (Fig. 14.8). In the southwestern part of this southern region, the Pekisko and commonly most of the lower to middle Shunda pass basinward (generally southwestward) into the Banff Formation, whereas most of the upper Shunda, Turner Valley, and the lower to middle Mount Head grade into the Livingstone Formation (Figs. 14.12, 14.29, 14.30). On the Interior Platform (Madison Shelf) of southernmost Alberta, the Pekisko generally passes southward into the Banff Formation, but locally the upper Pekisko grades basinward into the Livingstone.

In the Peace River Embayment and northward, the principal constituent formations of the Rundle assemblage are the Pekisko, Clausen, Shunda, Debolt, and Flett (Fig. 14.2), which grade basinward (generally southwestward) into the Prophet Formation of the Rundle assemblage. Along the southwestern side of the Peace River Embayment, the Turner Valley Formation is also present (Fig. 14.14).

The Pekisko Formation (Douglas, 1958; Penner, 1958) is here restricted to include only the lower, clean carbonate unit of the type Pekisko. The Pekisko is restricted because its definition, as manifest by its subsurface stratotype (borehole in 2-25-19-3W5), overlaps that of the Shunda Formation of Stern (1956), which has priority of publication. The middle and upper units of the type Pekisko are here included in the Shunda Formation (members D and G, respectively). The concept of the Pekisko utilized here has been widely used by others (see Macauley, 1958; Martin, 1967; Mamet et al., 1986; Richards, 1989b).

The Shunda Formation includes unnamed formation F of Richards (1989a,b), Higgins et al. (1991), and Richards et al. (1991). Earlier, most strata assigned to formation F had been included either in the Shunda Formation (Macauley, 1958; Macauley et al., 1964) or informally called "Shunda" (Bamber and Mamet, 1978; Beauchamp et al., 1986). Formation F, dominated by open-marine, skeletal limestone, can be readily differentiated from the restricted-marine Shunda of Richards (1989b) in outcrop but not in the subsurface. The Shunda as used herein is characterized by its lithological heterogenity and by the predominance of argillaceous carbonates and shale.

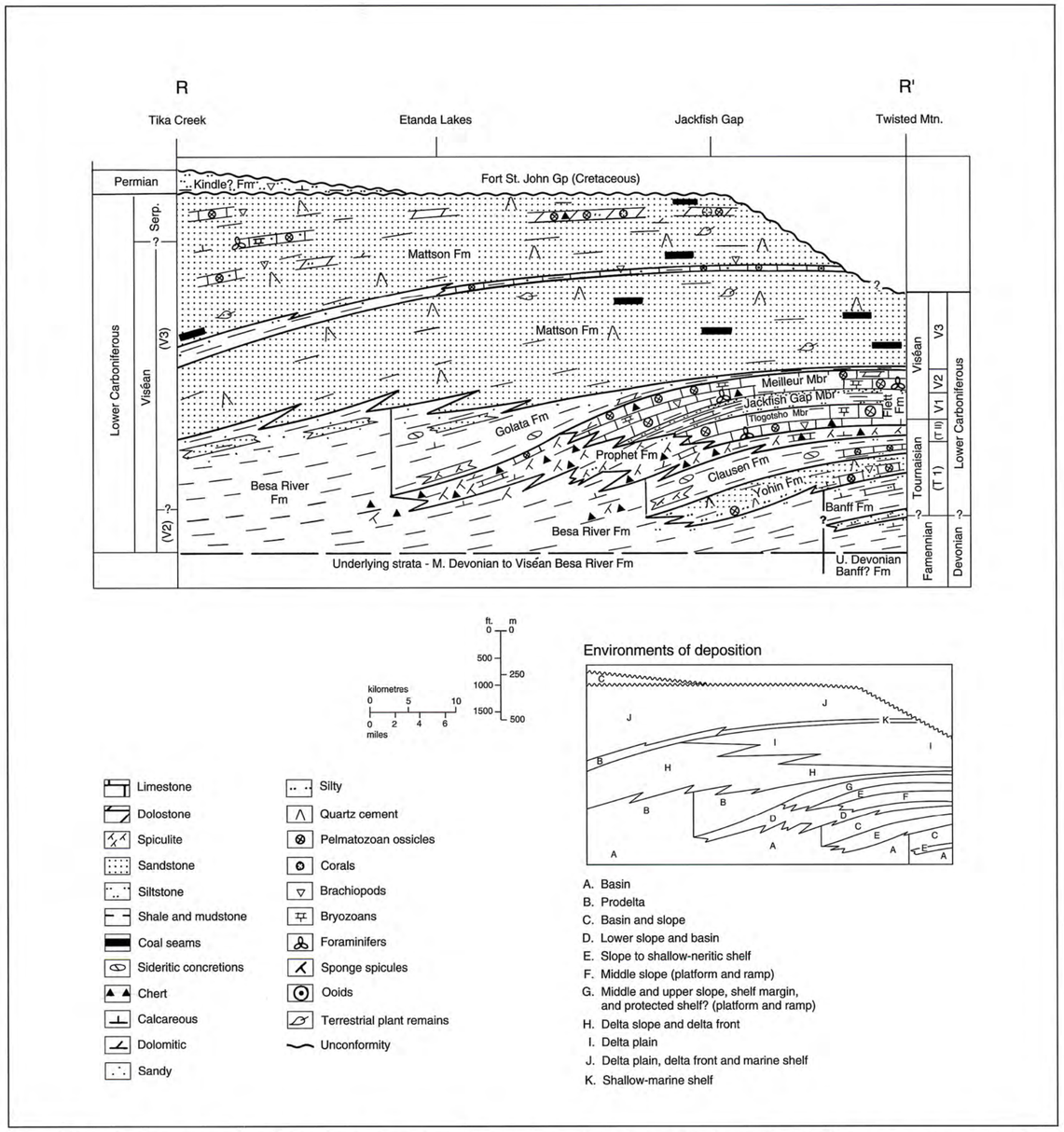


Figure 14.16 Stratigraphic cross section R-R′ (palinspastic) showing Lower Carboniferous in eastern Cordillera of southwestern District of Mackenzie (from Richards, 1989b). See Figure 14.1 for line of section R-R′. Note that the vertical scale (1:24 000) is very markedly condensed relative to the Atlas cross section standard (1:6000).

The Debolt Formation, extending from west-central Alberta into northeastern British Columbia (Figs. 14.8, 14.13, 14.19, 14.23, 14.24), presents several stratigraphic problems. At its type section in central Alberta and over wide areas to the south and northwest, the Debolt includes stratigraphic and lithological equivalents of the Mount Head and Turner Valley formations and is currently separated from them by arbitrary nomenclatural boundaries. Most of the Debolt of British Columbia closely resembles the stratigraphically equivalent Flett Formation of the District of Mackenzie, and is separated from it by a strictly nomenclatural boundary.

The Mount Head and Flett formations are divided into formal members (Douglas, 1958; Richards, 1989a), but most formations within the Rundle assemblage have not been formally divided. The Pekisko Formation of west-central Alberta (Figs. 14.26, 14.31c) is locally divided here into lower, middle and upper members. The Elkton Member constitutes the lower Turner Valley Formation; the middle and upper members of the latter resemble the middle dense and upper porous members of Penner (1958) and the Mt1 and Mt2 of Rupp (1969). The Shunda and Prophet formations are here divided into informal members with letter designations. Members of the Prophet resemble those of Sutherland (1958), but the members in the Shunda are new. The lower Debolt is equivalent to the Turner Valley Formation and comprises the lower carbonate, lower argillaceous, and middle carbonate members of Law (1981), whereas the middle and upper Debolt are equivalent to the upper argillaceous and upper carbonate members of Law, respectively.

Assemblage Boundaries and Unconformities. The Rundle assemblage generally overlies and passes basinward into the Banff assemblage, but from east-central British Columbia into southwestern District of Mackenzie, its western deposits overlie and pass basinward into the Besa River assemblage.

The contact between the Rundle assemblage and overlying Mattson assemblage is probably conformable in central Williston Basin, where the Kibbey Formation overlies evaporites of the Madison Group (Maughan and Roberts, 1967). On the unstable craton of central Montana, however, the Big Snowy Group and its correlatives unconformably overlie a karst surface developed on the Madison Group (Sando, 1988). A minor subaerial unconformity separates the Rundle assemblage from the Etherington Formation in southeastern British Columbia and southwestern Alberta (Richards, 1989b). The boundary between the Rundle and Mattson assemblages is a subaerial unconformity in southwestern Peace River Embayment and locally near the subcrop edge of the Mattson assemblage elsewhere in the embayment. In the axial region of the embayment, the contact is mainly conformable. Farther northwestward, the Rundle assemblage is generally conformably overlain by the Mattson asemblage at a contact that becomes older northward.

Most of the numerous unconformities within the Rundle assemblage are at formation and member boundaries and either lie within one foraminiferal zone or form the boundary between consecutive zones (Fig. 14.2). Transgressive ravinement produced at least part of the hiatus below the Turner Valley Formation and those below the Baril and Loomis members. Subaerial unconformities are locally present below the Wileman, Salter, and Marston members.

Mattson Assemblage

Distribution and Formational Composition. In the Williston Basin, the Mattson assemblage (Fig. 14.2; see also Fig. 14.35) is represented by the Kibbey and Otter formations (Big Snowy Group). In the Rocky Mountains and western foothills of southwestern Alberta, it is represented by the Etherington Formation and by the overlying Spray Lakes Group (Tyrwhitt, Storelk, Tobermory and Kananaskis formations; Fig. 14.11). In the Peace River Embayment, the Mattson asssemblage comprises the Golata, Kiskatinaw, and Taylor Flat formations of the Stoddart Group (Figs. 14.2, 14.25). Farther northwestward in northeastern British Columbia and in the District of Mackenzie, the assemblage is represented by the Golata and overlying Mattson Formation (Figs. 14.15, 14.16, 14.22).

New conodont data (Chung, *pers. comm.*, 1992) indicate that a new carbonate and sandstone unit herein informally called the Ksituan member and assigned to the upper Taylor Flat Formation (Figs. 14.2, 14.25) is of late Bashkirian and Moscovian age instead of Permian as indicated by Halbertsma (1959). The conodonts were extracted from core obtained near Ksituan Lake, west-central Alberta, and the adjacent Dawson Creek region of British Columbia (Fig. 14.6). The new unit, which was also included in the Taylor Flat at some localities by Naqvi (1972, Fig. 4; Higgins et al., 1991), is named after Ksituan Lake (Sec 36, Tp78, R10W6; NTS 83M-14). The interval between 2585.5 m and 2719.5 m in the borehole at 11-18-79-16W6 (Fig. 14.31e) and the extensively cored section between 7316 and 7554 ft at 16-19-77-10W6 are designated as refer-

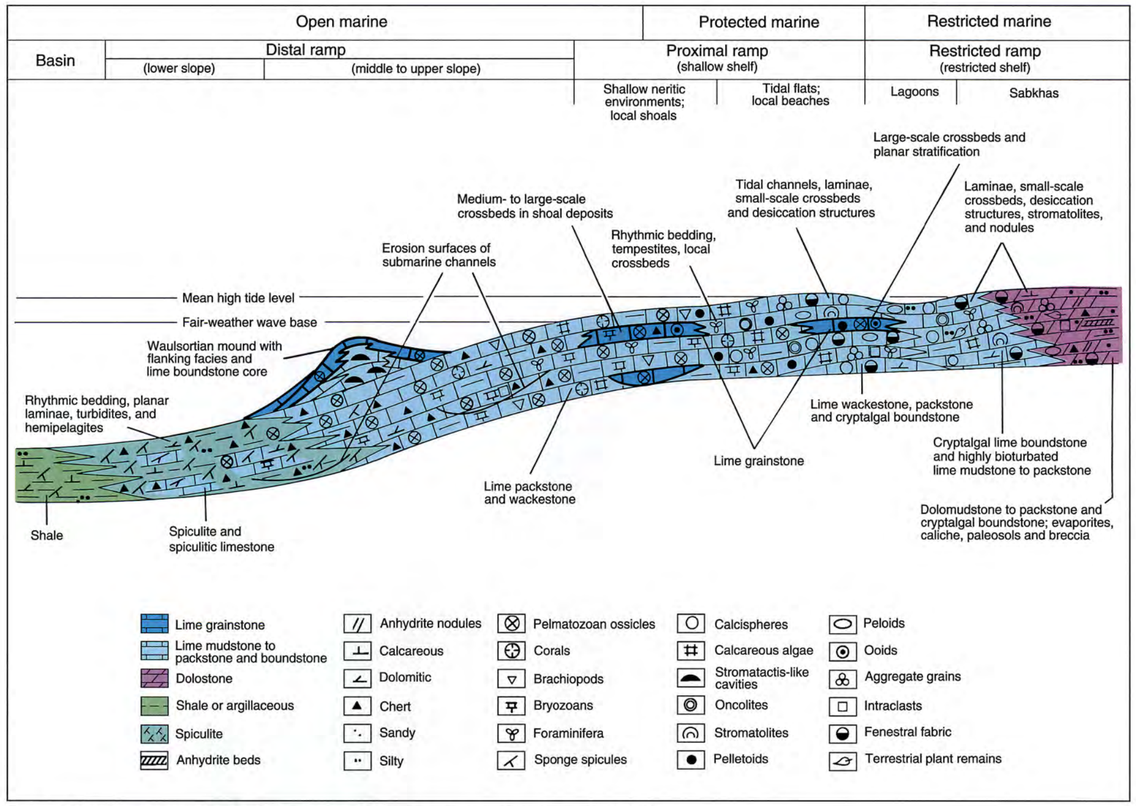


Figure 14.17 Generalized model of a Carboniferous carbonate ramp (modified from Richards, 1989a).

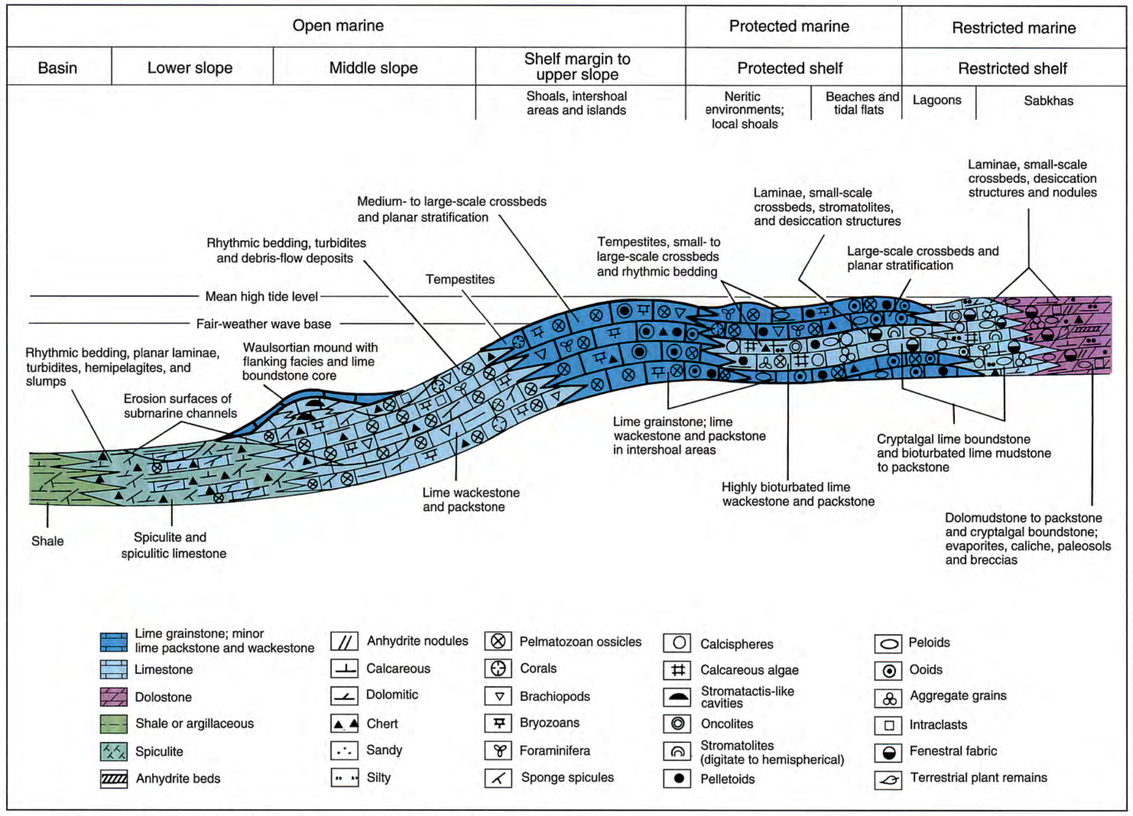


Figure 14.18 Generalized model of a Carboniferous carbonate platform (from Richards, 1989a).

ence sections. Moscovian conodonts were extracted from the lower Ksituan at the latter locality, from its middle unit at 6-18-80-15W6, and from its upper unit at 3-29-83-18W6. Although it is Late Carboniferous in age, it should be emphasized that most of the Ksituan is herein mapped with Permian strata (Henderson et al., *this volume*, Chapter 15) because its age was recognized after mapping had been completed.

Halbertsma (1959) included the Ksituan member in the Belloy Formation of Peace River Embayment; however, assignment of the member to the Carboniferous Taylor Flat Formation is warranted. The lower Ksituan of the reference sections is correlative with the upper part of the type Taylor Flat at 3-29-83-18W6, whereas the Ksituan is absent in the Belloy's Permian stratotype at 12-14-78-1W6. The middle and upper Ksituan at 11-18-79-16W6 (Fig. 14.31e) are correlative with most of the succession that Halbertsma (1959) included in the Belloy above the type Taylor Flat. Therefore, the concept of the latter stratotype requires revision, with the top of the Taylor Flat placed at 6278 ft instead of the present 6630 ft.

Assemblage Boundaries and Unconformities. The Mattson assemblage overlies mainly the Rundle assemblage, but northwestern occurrences of the Mattson assemblage overlie and grade basinward into the Besa River assemblage. In most of the eastern Cordillera and in the Peace River Embayment area of the western Interior Platform, the boundary with overlying Permian strata is a subaerial unconformity. Northeastward of the erosional edge of the Permian, Mesozoic deposits unconformably overlie the Mattson assemblage.

Several unconformities are present in the Mattson assemblage. In the southwest, the most important of these are partly of subaerial origin and occur at the base of the Spray Lakes Group, and base of the Tobermory Formation (Fig. 14.11; Scott, 1964; Stewart and Walker, 1980). In the Peace River Embayment, substantial breaks (partly subaerial) occur between the Golata and Kiskatinaw formations and at the base of the Taylor Flat Formation (Figs. 14.21, 14.25). A major subaerial unconformity separates the Upper Carboniferous Ksituan member of the Taylor Flat Formation from the Kiskatinaw, Golata, and Debolt formations (Figs. 14.19, 14.21, 14.25).

Besa River Assemblage

The Besa River assemblage was deposited in the Prophet Trough and western Peace River Embayment (Fig. 14.1). In the southwest, the assemblage is represented by the Famennian to Tournaisian Lussier shale, known only from the Rocky Mountain Main Ranges of southeastern British Columbia (Savoy, 1992). Elsewhere, the assemblage is represented by the Middle Devonian to upper Viséan Besa River Formation, which is widely distributed in the eastern Cordillera from east-central British Columbia to southeastern Yukon Territory (Figs. 14.2, 14.14-14.16; Pelzer, 1966; Bamber and Mamet, 1978). Prior to deep, post-Early Carboniferous erosion, the Besa River Formation was part of a more extensive shale lithosome that included much of the Earn and Black Stuart groups in the western assemblage of Prophet Trough (Richards, 1989b; Gordey et al., 1987). The Besa River Formation, which is up to 1655 m thick, is generally thickest in the foothills.

In most areas, the Besa River assemblage conformably overlies Middle Devonian strata and is conformably overlain by Tournaisian to upper Viséan strata of the Banff, Rundle and Mattson assemblages. In east-central and northeastern British Columbia, the Besa River Formation is locally unconformably overlain by Permian deposits (Fig. 14.14).

Stratigraphic History and Environmental Interpretations

Banff Assemblage

The Bakken and Exshaw formations comprise fine-grained siliciclastics deposited in euxinic-basin to shallow-neritic environments during late Famennian and earliest Tournaisian time (Hays, 1985; Richards and Higgins, 1988). Black shale of the lower Exshaw and its coeval correlatives in the lower member of the Bakken and basal part of the northern Banff Formation (Figs. 14.10, 14.12-14.16) record the culmination of a regional transgression that commenced with deposition of the Famennian Big Valley Formation and correlative strata in the upper Costigan Member of the Palliser Formation (Richards et al., 1991). Subsequent regional shallowing during the early Tournaisian climaxed with the subaerial erosion of most of the Exshaw Formation and part of the underlying Palliser Formation on the Sukunka Uplift (Richards, 1989b).

Lower Tournaisian black shale in the upper member of the Bakken, and correlatives in the basal Banff Formation south of 56°N, record the early phase of a second transgression (Richards, 1989b). The overlying Banff and Lodgepole formations are mainly heterogeneous associations of carbonate ramp deposits (Fig. 14.17) and siliciclastics, but facies deposited on poorly differentiated carbonate platforms (Fig. 14.18) are commonly preserved in the upper Lodgepole Formation and in the middle to upper Banff Formation. Shale, spiculite, and fine-grained carbonates in the lower parts of these suites record the continuation of the second transgression and the establishment of widespread, moderately deep-water basin, distal-ramp, and slope environments. At this time, Waulsortian mounds, consisting largely of lime mudstone and submarine cement and lacking an organic framework, developed in Williston Basin and the Central Montana Trough (Smith, 1977; Precht and Shepard, 1988; Sereda, 1990).

The early Tournaisian transgression was followed by regional shallowing and basinward progradation of slope and distal ramp to supratidal carbonates and siliciclastics of the Lodgepole, Banff, and Yohin formations. On most of the stable cratonic platform and in eastern Peace River Embayment, this trend culminated with deposition of the restricted-shelf lithofacies of the uppermost Banff Formation and its correlatives during the late early Tournaisian. On the unstable craton of southernmost Alberta and in most of central Williston Basin and the Prophet Trough, the trend culminated during the late Tournaisian and Viséan with sedimentation of the Rundle assemblage.

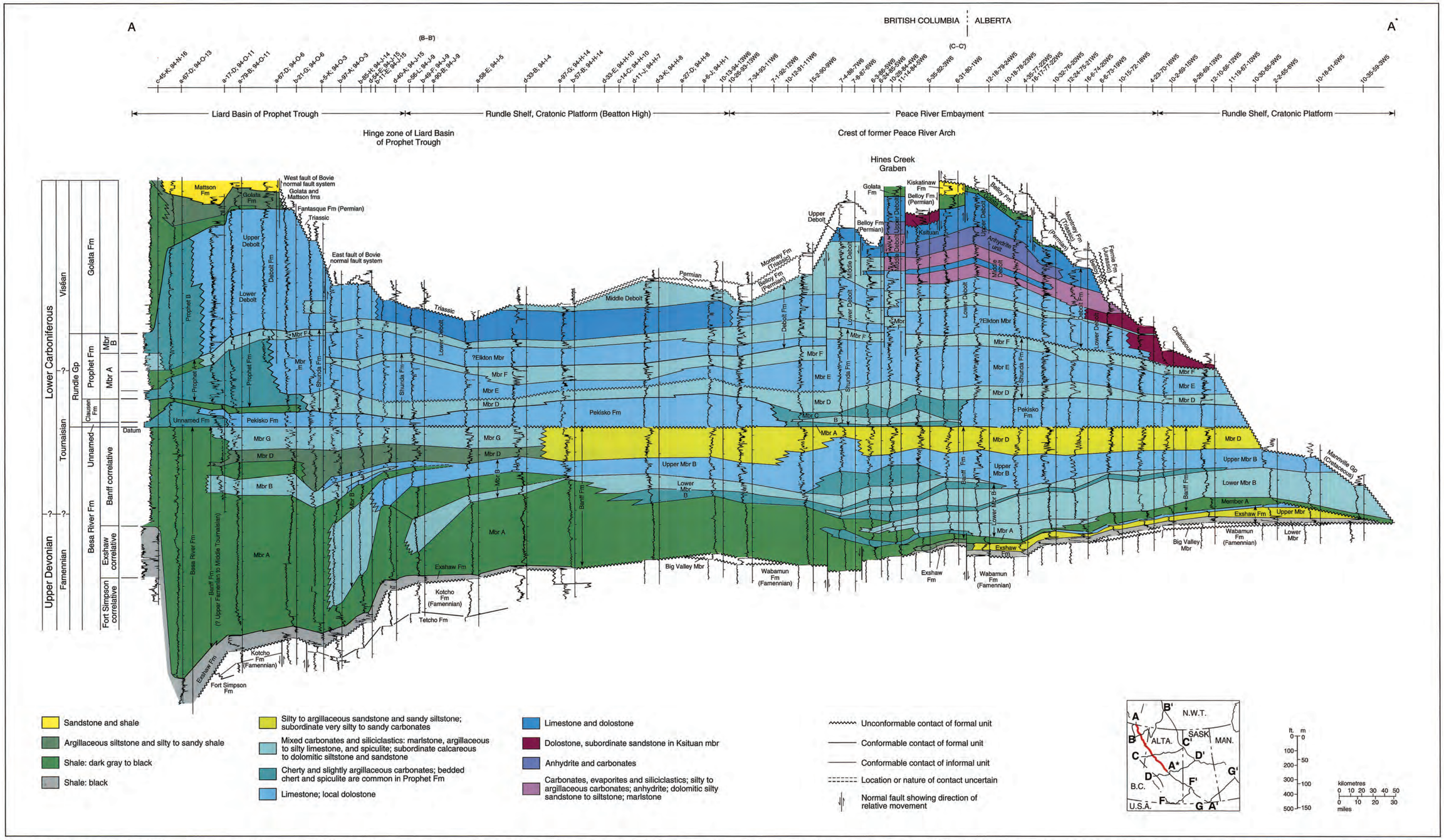


Figure 14.19 Lower stratigraphic slice for northwestern panel of cross section A-A′, showing uppermost Devonian and Lower Carboniferous (Besa River, Banff and Rundle assemblages) from east-central Alberta to northeastern British Columbia. See Figures 14.21 and 14.22 for upper slice and Figures 14.31d and 14.31f for reference logs. Note that block faulting was complex and occurred throughout deposition of the illustrated succession. Because the base of the Pekisko Formation is the datum, strata that overlie the Pekisko and were deposited as thick graben fills appear here as apparent horst areas.

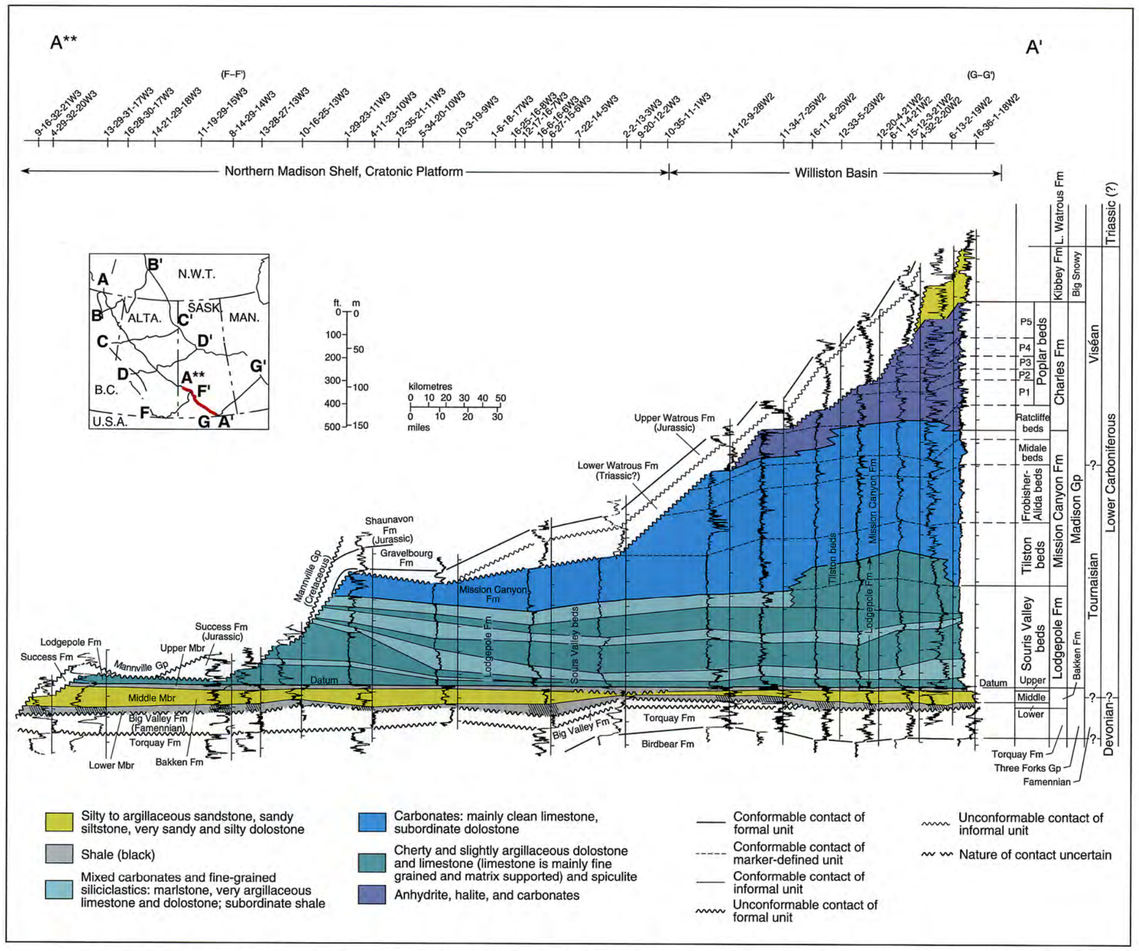


Figure 14.20 Southeastern panel of cross section A-A′ showing uppermost Devonian and Lower Carboniferous (Banff and Rundle assemblages) deposited in central Williston Basin and on the northern Madison Shelf, southern Saskatchewan. Figure 14.31a shows reference logs.

In southern Prophet Trough, progradation and shallowing during the late early Tournaisian to early Viséan regression discussed above were interrupted by an early late Tournaisian regional transgression and episode of marked water deepening. The latter resulted in deposition of slope deposits of lower member F of the Banff Formation and its coeval correlatives in lower member D of the Shunda Formation (Figs. 14.12, 14.27, 14.29, 14.30).

Rundle Assemblage

The Rundle assemblage was deposited from the late early Tournaisian to the late Viséan and comprises carbonate-platform lithofacies with subordinate carbonate-ramp lithofacies and basinal to supratidal siliciclastics (Figs. 14.10-14.16). On the platforms, the slope lithofacies were deposited on relatively low-gradient slopes basinward of rimmed shelves characterized by high-energy shelf-margin sand belts (Fig. 14.18). The ramps (Fig. 14.17) lacked an obvious shelf-slope break and rimmed shelves.

In most of the Prophet Trough, the western graben system of the Peace River Embayment, and on westernmost parts of the cratonic platform, the dominantly shallow-marine platform and ramp carbonates of the Rundle Group prograded basinward (mainly southwestward) over deeper water shale and carbonates of the Banff and Besa River assemblages (Figs. 14.12, 14.15, 14.19, 14.23). In the seaway connecting the Williston Basin and Prophet Trough, the Rundle Group and Mission Canyon Formation prograded southward over the deeper-water deposits of the Banff assemblage (Figs. 14.27, 14.29). In central Williston Basin, carbonate-platform facies of the Mission Canyon and lower Charles Formation prograded basinward (southward to westward) over deeper-water carbonates of the Lodgepole Formation (Figs. 14.10, 14.20, 14.28). Elsewhere, carbonates of the Rundle assemblage were mainly deposited above shallow-marine facies of the upper Banff assemblage.

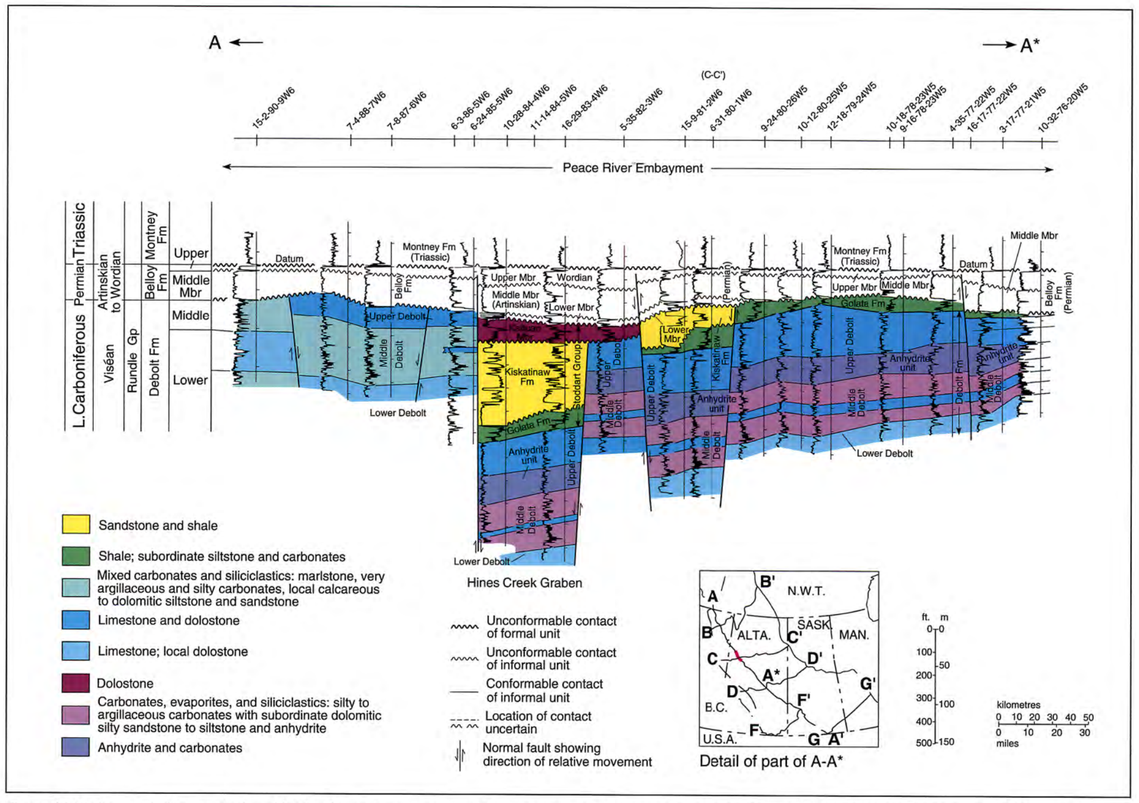


Figure 14.21 Segment of upper stratigraphic slice for northwestern panel of cross section A-A′, emphasizing Carboniferous Mattson assemblage and overlying Permian in eastern Peace River Embayment, northwestern Alberta. Note that the horizontal scale is here expanded from the Atlas norm.

The Rundle assemblage, particularly in the central Williston Basin, western Peace River Embayment, and the Prophet Trough, is an overall shallowing-upward succession, although it formed during several transgressive/regressive cycles (Richards, 1989b).

Most of the Prophet Trough deposits and those formed in central Williston Basin and the western Fort St. John Graben of Peace River Embayment record continuation of the general progradational, shallowing-upward trend established during sedimentation of the upper Banff assemblage. Elsewhere, the Pekisko Formation and its coeval open-marine correlatives in the Clausen Formation and lower Shunda and Mission Canyon formations record a regional transgression during which Waulsortian mounds developed in the Peace River Embayment (Davies et al., 1988). The latter transgression, which took place in latest early to earliest late Tournaisian time, preceded several regional regressions and transgressions.

The first major regression subsequent to the Pekisko transgression occurred during the late Tournaisian and is recorded by widespread restricted-marine carbonates and anhydrite in the Shunda Formation. Subsequent regional regressions resulted in deposition of the Wileman, Salter, Marston, Carnarvon, and upper Opal members of the Mount Head Formation and their correlatives in the Debolt and Flett formations, and upper Madison Group (Richards, 1989a,b). During the Salter regression, most of the cratonic platform of western Montana was exposed (Sando, 1988), resulting in an extensive karst plain that probably extended into southeastern Alberta.

After the Pekisko transgression, there were three main regional transgressions. The first of these occurred in the latest Tournaisian to earliest Viséan, as recorded by the lower Turner Valley Formation and its coeval correlatives in the lower Debolt and Flett formations and Midale beds of the Mission Canyon Formation. The second transgressive event took place during the late middle Viséan and is represented by the Loomis Member of the Mount Head and by its correlatives in the upper Debolt and Flett formations. A subsequent transgression occurred in the early late Viséan (foraminiferal zone 14). The latter event is recorded by the middle Opal Member of the Mount Head and by the uppermost Debolt Formation and overlying lower Golata Formation (Richards, 1989b).

Subsequent to deposition of the Mount Head and Debolt formations, an extensive region south of the axis of the Peace River Embayment was subaerially exposed. This produced widespread but minor unconformities at the base of the Etherington Formation in southwestern Alberta and the locally substantial hiatus between the Rundle Group and Kiskatinaw Formation in southwestern Peace River Embayment and on the Sukunka Uplift. The unconformity at the top of the Golata Formation in the Peace River Embayment apparently developed at this time as well.

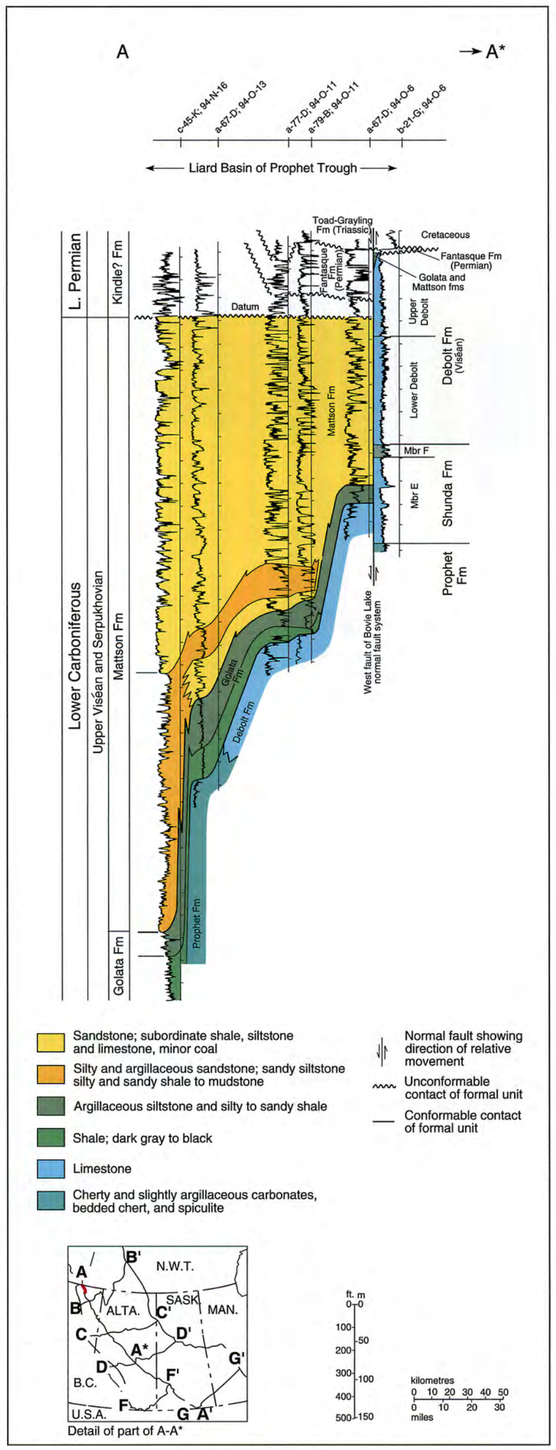


Figure 14.22 Segment of upper stratigraphic slice for northwestern panel of cross section A-A′, emphasizing Lower Carboniferous Mattson assemblage in eastern Liard Basin, northeastern British Columbia.

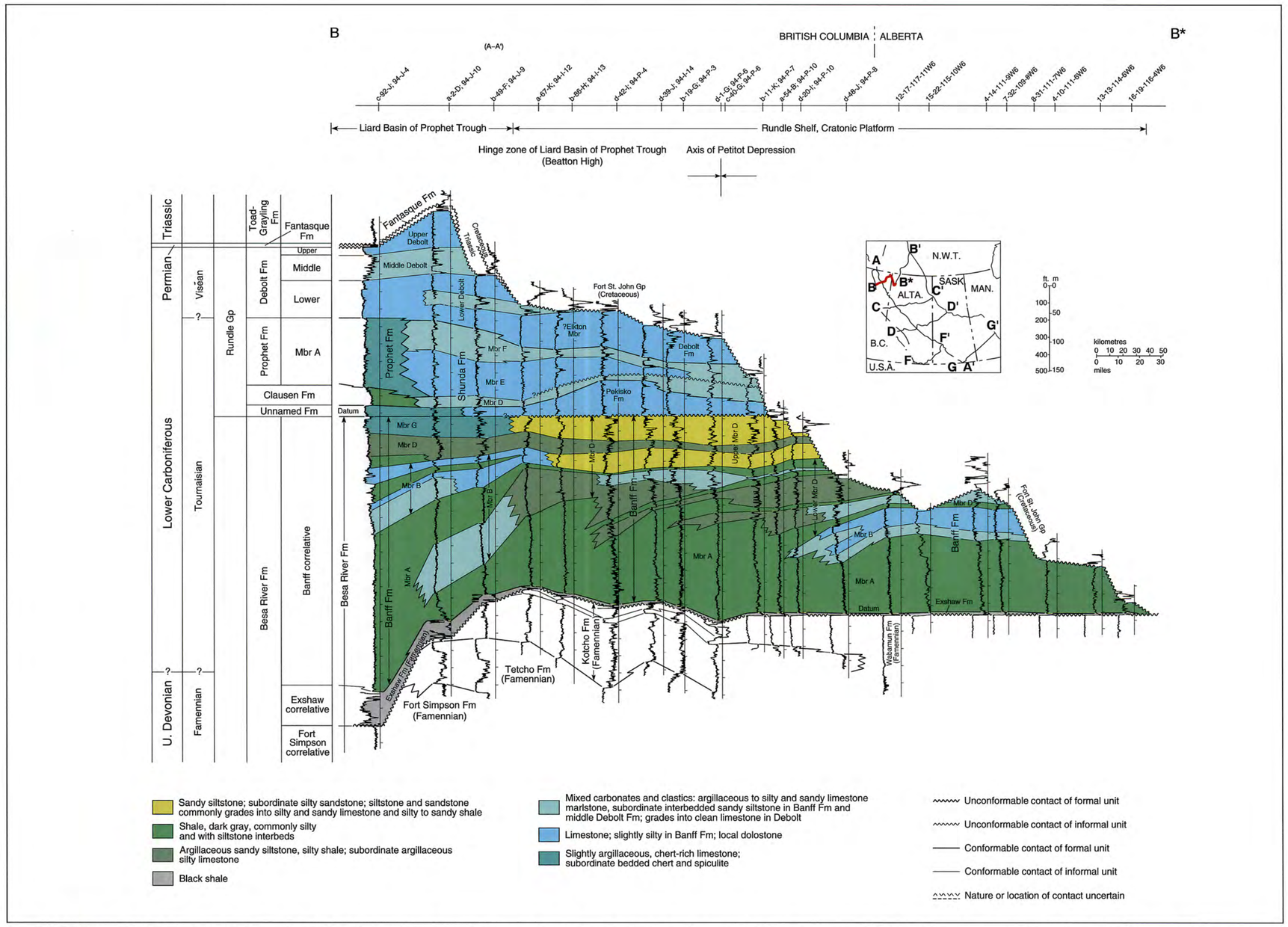


Figure 14.23 Cross-section B-B* showing Carboniferous (Banff and Rundle assemblages) deposited in eastern Prophet Trough and on the northern cratonic platform, northeastern British Columbia and northwestern Alberta. Figure 14.31f illustrates reference logs.

Mattson Assemblage

The Mattson assemblage (Fig. 14.2; see also Fig. 14.35) was deposited from the late Viséan to the Moscovian and possibly into the Kasimovian. This assemblage is dominated by deltaic and delta-related deposits, but includes non-deltaic marine to continental siliciclastics and carbonate ramp deposits (Figs. 14.11, 14.15, 14.16). Sandstone-dominated estuarine, deltaic, and delta-related slope to peritidal deposits constitute most of the Kiskatinaw and Mattson formations. The Mattson Formation and western occurrences of the Kiskatinaw Formation that were deposited in Prophet Trough prograded southwestward (basinward) over basinal to marine shelf and prodelta shale of the Golata and upper Besa River formations (Richards, 1989a, b). Within Peace River Embayment and on eastern Sukunka Uplift, estuarine sandstone and related siliciclastic facies of the Kiskatinaw Formation onlapped a regional unconformity developed on the Rundle Group and Golata Formation (Barclay et al., 1990). Sandstone of neritic to continental origin constitutes most of the Tyrwhitt, Storelk, Tobermory, and Kibbey formations, and the upper part of the Etherington Formation (Stewart and Walker, 1980; Richards, 1989b; Henderson, 1989). Shallow-marine sandstone grading northwestward into outer-shelf and slope facies constitutes part of the Taylor Flat Formation.

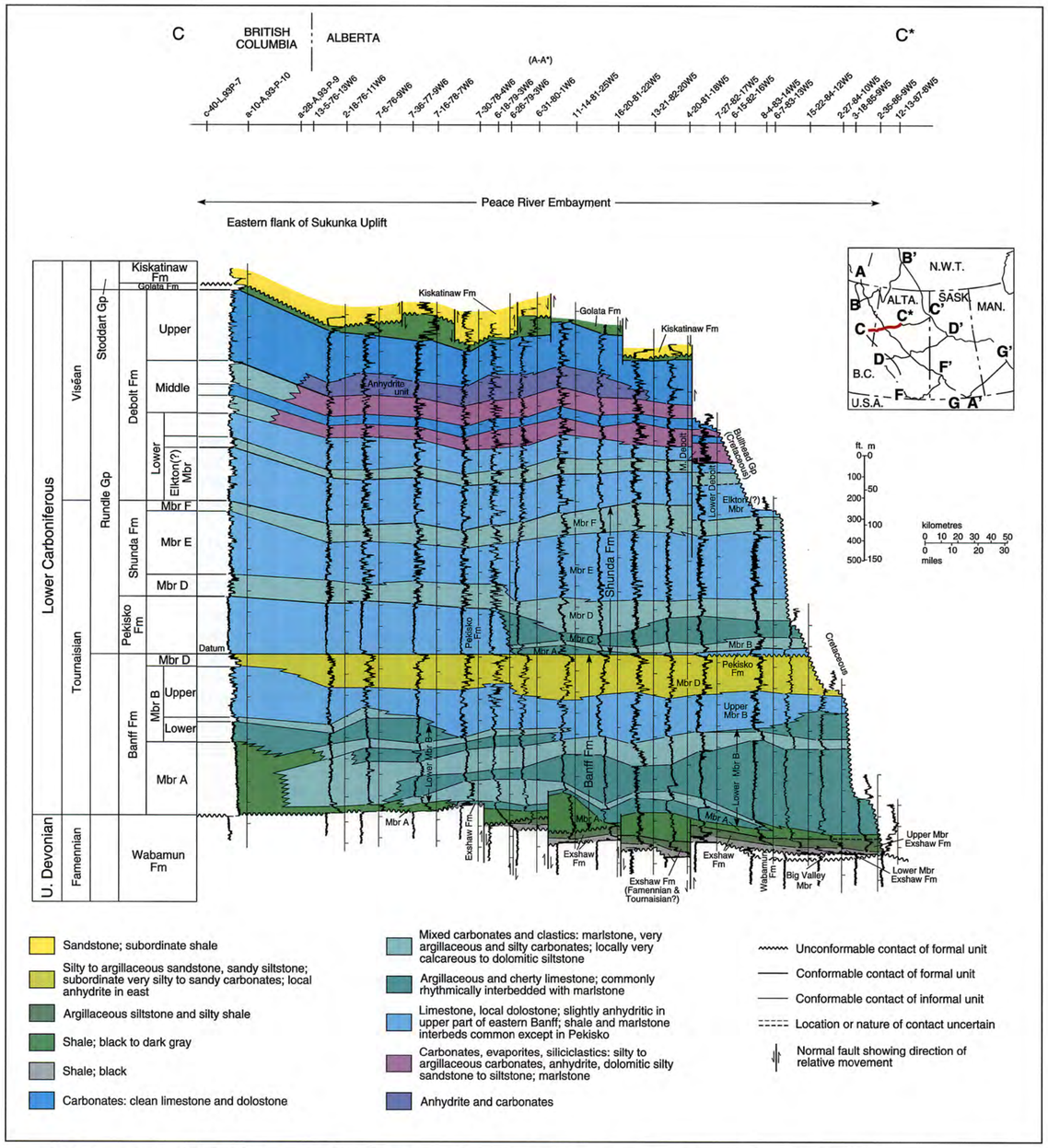


Figure 14.24 Lower stratigraphic slice of cross section C-C*, showing Lower Carboniferous (Banff and Rundle assemblages) in Peace River Embayment, northwestern Alberta and northeastern British Columbia. Figure 14.25 shows upper slice; Figure 14.31d shows reference logs. Note that block faulting occurred throughout deposition of the illustrated succession. Because the base of the Pekisko Formation is the datum, strata that overlie the Pekisko and were deposited as thick graben fills appear here as apparent horst areas.

In the Mattson assemblage, carbonate lithofacies, which commonly grade into marine sandstone and shale, predominate in the lower Etherington Formation and much of the Taylor Flat Formation. They also form the middle Kibbey Formation and parts of the upper Kiskatinaw and Mattson formations. Carbonates of the lower Etherington Formation, the Kananaskis Formation, the southwestern occurrences of the lower Taylor Flat Formation, and the Ksituan member are probably of carbonate ramp origin (Figs. 14.11, 14.17), but those preserved elsewhere in the assemblage do not constitute either well-defined carbonate ramps or platforms.

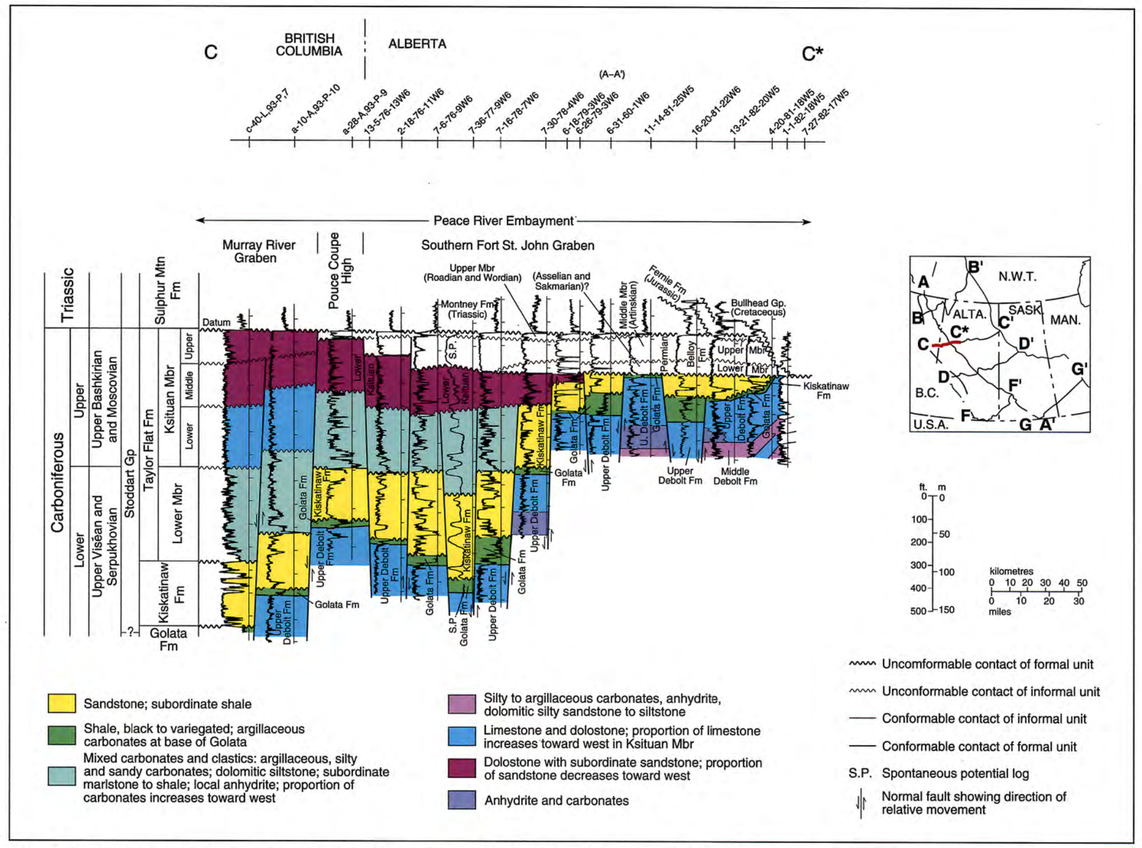


Figure 14.25 Upper stratigraphic slice of cross section C-C*, emphasizing Carboniferous Mattson assemblage and Permian succession in Peace River Embayment, northwestern Alberta and northeastern British Columbia. Figure 14.24 shows lower slice; Figures 14.31d and 14.31e illustrate reference logs.

Lower Carboniferous deposits of the Mattson assemblage record the culmination of the general regressive trend that predominated during sedimentation of the Rundle assemblage. They also record numerous minor and some major transgressions and regressions. The Upper Carboniferous lithofacies of this assemblage record two main transgressive/regressive cycles.

In the Big Snowy Group of central Williston Basin, the lower Kibbey Formation represents continental deposition and the culmination of a regional regression, whereas the middle to upper Kibbey Formation and overlying Otter Formation indicate a subsequent transgression. The transgression was followed by late Serpukhovian regression and subaerial erosion (Maughan and Roberts, 1967; Sando et al., 1975).

In the Prophet Trough and Peace River Embayment and on the adjacent stable craton, the first major regression recorded by the Mattson assemblage occurred during the late Viséan (foraminiferal zones 15 and 16I). In the south, the culmination of this regression is recorded by the disconformity between the Mount Head and Etherington formations, and by subaerial unconformities associated with paleosols in the basal Etherington. In the Peace River Embayment/Sukunka Uplift region, the major late Viséan regression followed a late Viséan transgression, recorded by carbonates and black shale of the lower Golata Formation. The regression is indicated by redbeds in the upper Golata Formation (Barclay, 1988) and by the subaerial unconformity between the Kiskatinaw Formation and underlying Debolt and Golata formations. Deltaic and related lithofacies of the lower and middle Mattson Formation (Figs. 14.16, 14.22) record this regression in the Liard Basin. The late Viséan regression was followed by a gradual transgression, interrupted by numerous minor regressions, during deposition of uppermost Viséan to Serpukhovian carbonates and marine to continental sandstone in the Etherington, Kiskatinaw, lower Taylor Flat and upper Mattson formations.

The latest Viséan to early Serpukhovian transgression preceded three principal Carboniferous regressions and two intervening Late Carboniferous transgressions. The first of the regressions took place during the late Serpukhovian to early Bashkirian. In the south it is represented by Serpukhovian sandstone in the upper Todhunter Member of the Etherington Formation and by the overlying sub-Tyrwhitt unconformity (Fig. 14.11). In the Peace River Embayment, the mid-Carboniferous regression resulted in deposition of restricted-shelf carbonates and minor evaporites in the upper part of the lower Taylor Flat Formation and later erosion below the Ksituan member (Fig. 14.25). In the south, a subsequent transgression is recorded by Bashkirian, shallow-marine sandstone of the Tyrwhitt Formation, but subaerial erosion probably continued in most of the Peace River Embayment.

The onset of the second post-early Serpukhovian regression is recorded by aeolian sandstone of the Bashkirian Storelk Formation (Fig. 14.11). The culmination of this event resulted in the unconformity below the overlying upper Bashkirian to lower Moscovian Tobermory Formation. Bashkirian shallow-marine siliciclastics in the Tobermory resulted from the initial phase of the second Late Carboniferous transgression, which climaxed with deposition of Moscovian to lower Kasimovian(?) carbonates of the Kananaskis Formation (Stewart and Walker, 1980; Henderson, 1989). In the Peace River Embayment, the latter transgression is recorded by ramp carbonates of the Ksituan member.

A final regression, which exposed all of the WCSB from the District of Mackenzie southward, took place after the Moscovian and prior to the Early Permian (Richards et al., *in press*).

Besa River Assemblage

The Besa River assemblage consists mainly of black shale and records prolonged deposition in anaerobic to dysaerobic environments basinward of the slope to shelf and deltaic lithofacies of the Banff, Rundle and Mattson assemblages. Northwestern occurrences were deposited in a deep, starved basin, as indicated by pronounced southwestward depositional thinning (Pelzer, 1966; Richards, 1989a).

Regional Cross Sections

Cross Section A-A′

Cross section A-A′ comprises a northwestern segment showing the succession in west-central Alberta and northeastern British Columbia (Fig.14.19) and a southeastern segment representing southern Saskatchewan (Fig. 14.20). The northwestern segment is subdivided into a lower slice, dominated by the Banff and Rundle assemblages (Fig. 14.19), and an upper slice highlighting the Mattson assemblage (Figs. 14.21, 14.22). Figures 14.31a, e and f illustrate the relations between the gamma-ray logs and rock types. Figures 14.10, 14.13 and 14.15 provide environmental interpretations, and Figures 14.6 and 14.7 illustrate the seismic expression of the succession.

The succession represented by A-A′ is thickest in the Liard Basin (Figs. 14.19, 14.22), but thick, relatively complete sections also occur in central Williston Basin (Fig. 14.20) and the Peace River Embayment (Fig. 14.21). The hinge zone of the Prophet Trough is clearly displayed in the northwest (Fig. 14.19), and thickness and lithofacies trends indicate that the Peace River Embayment, lying between 4-23-70-16W5 and 10-13-94-13W6, was moderately well defined during deposition of the Banff assemblage and well developed during deposition of the Rundle and Mattson assemblages (Fig. 14.19). Major facies changes and several of the normal faults characteristic of the Peace River Embayment and Liard Basin are displayed.

In Saskatchewan (Fig. 14.20), the Lodgepole Formation thickens gradually southeastward toward the center of Williston Basin, but near the southeastern end of A**-A′, the formation thins abruptly as slope wackestone in its upper part grades eastward into upper-slope to shelf-margin grainstone of the Mission Canyon Formation. The Lodgepole displays southward-dipping clinoforms that resulted from the progradation of sequences toward the centre of Williston Basin and the Central Montana Trough. Similar clinoforms occur in the Lodgepole of eastern Williston Basin (Sereda, 1990).

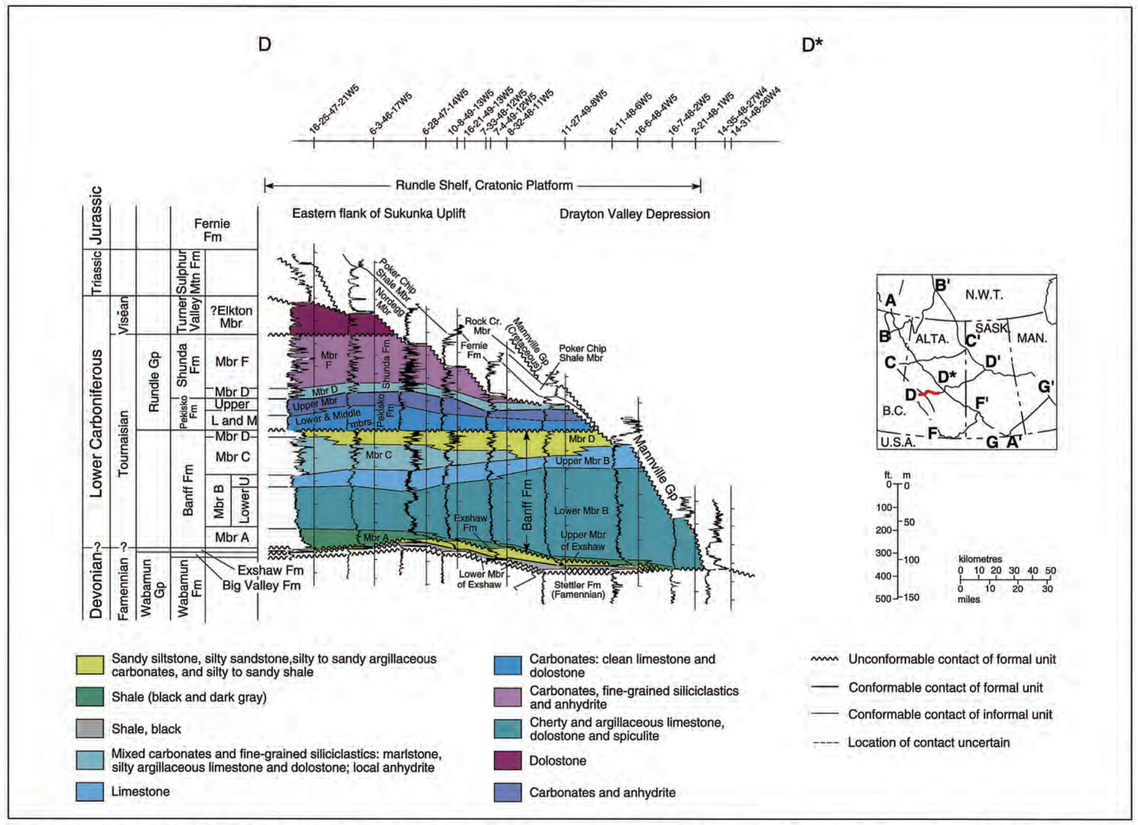


Figure 14.26 Cross section D-D*, showing uppermost Devonian and Lower Carboniferous (Banff and Rundle assemblages) deposited on western cratonic platform, west-central Alberta. Figure 14.31c shows reference logs.

In the Banff Formation of northwestern Alberta and northeastern British Columbia (Fig. 14.19), shelf carbonates (members B and G) and shallow-water to slope terrigenous clastics (member D) grade northwestward into shale-dominated lower-slope and basin facies of member A and the Besa River Formation. This resulted in the development of the northwestward offlapping transgressive/regressive sequences of the Banff Formation.

Toward the axis of the Peace River Embayment, from both the southeast and the northwest, lime grainstone-dominated shelf and shelf-margin lithofacies of the Pekisko Formation thin and grade into argillaceous slope carbonates and shale of the lower Shunda Formation (Fig. 14.19; members A to D). In the Liard Basin, the Pekisko passes northwestward into slope spiculite and cherty wackestone to packstone of an unnamed formation.

Higher in the northwestern panel of A-A′ (Fig. 14.19), the inner protected-shelf to restricted-shelf carbonates, evaporites, and siliciclastics of the southern Shunda Formation pass northwestward into open-marine Shunda lithofacies occurring in the axis of Peace River Embayment and on the Rundle Shelf to the northwest. Within the overlying Debolt Formation, which includes a widespread unit of restricted-shelf anhydrite in the Peace River Embayment, the proportion of open-marine carbonates increases northwestward. In the axial region of eastern Peace River Embayment (Figs. 14.19, 14.21), the Golata Formation is moderately widespread, but the overlying Kiskatinaw Formation and Ksituan member of the Taylor Flat Formation are preserved only in the major grabens.

At the northwestern end of A-A′ (Figs. 14.19, 14.22), upper-slope and shelf carbonates above the Pekisko Formation grade basinward into spiculite and cherty slope carbonates of the Prophet Formation. Overlying sandstone-dominant deltaic and marine-shelf to shoreline lithofacies of the Mattson Formation grade basinward into prodelta shale of the Golata and upper Besa River formations.

Cross Section B-B*

Cross section B-B* (Fig. 14.23) illustrates the Banff, Rundle and Besa River assemblages in the Interior Platform of northeastern British Columbia and northwestern Alberta. Figure 14.31f represents a borehole section (b-86-H; 94-I-13) within B-B* and shows the relations between the gamma-ray logs used in B-B* and rock types. Figure 14.15 shows environmental data for a similar succession that lies to the northwest.

In cross section B-B*, the hinge zone of the Prophet Trough is displayed as a prominent positive belt that resembles a forebulge. The hinge is defined by erosional thinning beneath the Exshaw Formation and thickness trends within the Banff, Pekisko and Shunda formations. The Banff and Shunda thin over the hinge, whereas the grainstone-dominant Pekisko thickens. Thickness trends within the Banff Formation indicate that a northwest-trending topographic low, herein called the Petitot Depression, lay east of the hinge.

Cross section B-B* shows southwestward truncation of the Famennian Kotcho Formation beneath the Exshaw Formation and northeastward truncation of the Lower Carboniferous beneath the Cretaceous Fort St. John Group.

In the Banff Formation, proximal to distal ramp carbonates of members B and G and shelf to slope siltstone, sandstone, and silty limestone of member D pass basinward into basinal shale of member A and the Besa River assemblage (Fig. 14.23). Westward offlapping of shallow-shelf to slope strata produced prominent Banff clinoforms (Chatellier, 1988). Overlying ooid and skeletal grainstones of the Pekisko Formation grade basinward into slope spiculite and chert of an unnamed formation. Eastern occurrences of the Shunda (b-86-H; 94-I-13, and eastward) include protected- to restricted-shelf carbonates. Shelf-margin to middle- and upper-slope carbonates of the western Shunda pass into basinal shale of the Clausen Formation and overlying chert-rich slope deposits of the Prophet Formation.

Cross Section C-C*

Southwest-striking section C-C* (Figs. 14.24, 14.25) shows the Banff, Rundle, and Mattson assemblages in the Peace River Embayment region. The relations between rock types and the mechanical logs used are shown by Figure 14.31d, which represents a borehole (11-14-81-25W5) along C-C*. It is also illustrated by Figure 14.31e, which represents a section (11-18-79-16W6) 40 km north of a-10-A; 93-P-10 along C-C*. Figure 14.14 shows environmental data for a similar succession lying toward the southwest.

Cross section C-C* crosses the northeast-trending structural and depositional axis of the Peace River Embayment. In the northeast, thick slope- to outer-shelf carbonates predominate in the Banff Formation and lower Rundle Group, indicating that Carboniferous paleoshorelines and the northeastern limit of the embayment lay well eastward of the erosional edge of the Banff Formation.

Some of the numerous normal faults in the Peace River region (Figs. 14.5, 14.6, 14.14) are shown in C-C*. Block faulting took place throughout the middle to late Paleozoic, but there appear to have been three main episodes, as suggested by the thickness changes occurring across normal faults. The first phase commenced during the middle to late Famennian and continued into the early Tournaisian, when the lower Banff Formation was deposited. A second period, which climaxed during the late Serpukhovian to earliest Bashkirian, started during deposition of the uppermost Debolt. A third occurred during the latest Carboniferous, after deposition of the Ksituan member, and continued through the Early Permian.

At the northeastern end of C-C*, the Big Valley Member of the Wabamun is truncated beneath the Exshaw Formation (Fig. 14.24), but the Big Valley/Exshaw contact is highly variable in aspect and is at least locally conformable in the Peace River Embayment. Because of pre-Banff erosion, the Exshaw is absent along the southwestern portion of C-C* and in part of the Rocky Mountains farther southwestward (Richards, 1989b; Figs. 14.13, 14.14).

In the Banff Formation along C-C* (Fig. 14.24), shallow-shelf ramp carbonates of upper member B pass basinward (southwestward) into distal ramp carbonates of lower member B, which in turn grade basinward into basinal shale and marlstone of member A. Southwestward offlapping of shallow-shelf to distal-ramp deposits formed the Banff clinoforms. Overlying shale, marlstone and argillaceous carbonates of slope and basin origin in the lower Shunda Formation (members A to D) pass southwestward into slope to shelf-margin carbonates of the Pekisko Formation. The latter facies change records uplift of Sukunka Uplift and concomitant subsidence along the axis of the Peace River Embayment. An anhydrite-dominated unit in the upper Debolt Formation of central Peace River Embayment passes southwestward into shelf carbonates.

Of the several Paleozoic unconformities shown on the lower slice of C-C* (Fig. 14.24), the break below the Kiskatinaw Formation is the most significant. Erosion surfaces (not shown) also occur in the uppermost Debolt Formation. These resulted from ravinement during the early late Viséan (foraminiferal zone 14) transgression that culminated with deposition of the lower Golata. In the northeast, the base of the Golata Formation may be locally erosional. The lower panel of C-C* also shows abrupt northeastward truncation of units within the Rundle Group and the Banff Formation beneath the sub-Cretaceous subaerial unconformity.

Upper C-C* (Fig. 14.25) illustrates marked local changes in the thicknesses of units in the Stoddart Group and overlying Belloy Formation. Most of these thickness variations resulted from deposition across growth faults (Barclay et al., 1990) and differential post-depositional erosion accompanied by block faulting. This cross section also shows northeastward erosional truncation of the Stoddart Group below the Belloy Formation. In the southwest, the Ksituan member thickens abruptly at the Murray River Graben west of the prominent northeasterly striking horst herein called the Pouce Coupe High. Over the axis of the Sukunka Uplift, which lies southwest of the line of cross section, the Stoddart Group is truncated southwestward beneath Permian and Triassic strata (Fig. 15.4).

Cross Section D-D*

Cross section D-D* (Fig. 14.26) illustrates the Banff and Rundle assemblages preserved in the western Interior Platform and in the eastern foothills of west-central Alberta. The upper Turner Valley Formation and overlying Mount Head Formation, widely preserved farther west, were eroded. Figure 14.31c, which represents a borehole section (7-23-46-17W5) near the western end of D-D*, reveals the relations between the gamma-ray logs used in the cross section and rock types. Figure 14.13 provides environmental data for a similar succession preserved north of D-D*.

The eastern flank of the Sukunka Uplift, indicated on Figure 14.26 by westward thinning of the Exshaw and Banff formations, is displayed as a broad, positive region along the southwestern side of the cratonic platform. Thickness trends within the Banff Formation demonstrate that a northwestward-trending topographic low, herein called the Drayton Valley Depression, lay along the northeastern side of the uplift.

Cross section D-D* shows eastward truncation of the Exshaw Formation below the Banff Formation. Higher in the succession, unconformities resulting from transgressive ravinement and possible subaerial erosion occur at the bases of the Pekisko and Turner Valley formations. Eastward truncation of the Lower Carboniferous beneath sub-Jurassic and sub-Cretaceous subaerial unconformities is prominently displayed on D-D*.

Members B, C, and D of the Banff Formation are well developed in the region represented by cross section D-D*. In this region, the Pekisko is divisible into three members (Fig. 14.31c), but along D-D* only the contact between the upper anhydrite-dominated member and the underlying units is illustrated. The overlying Shunda Formation is dominated by the argillaceous deposits of member F. Member E, which is widely preserved elsewhere in the Shunda (Figs. 14.19, 14.24, 14.29), is not developed.

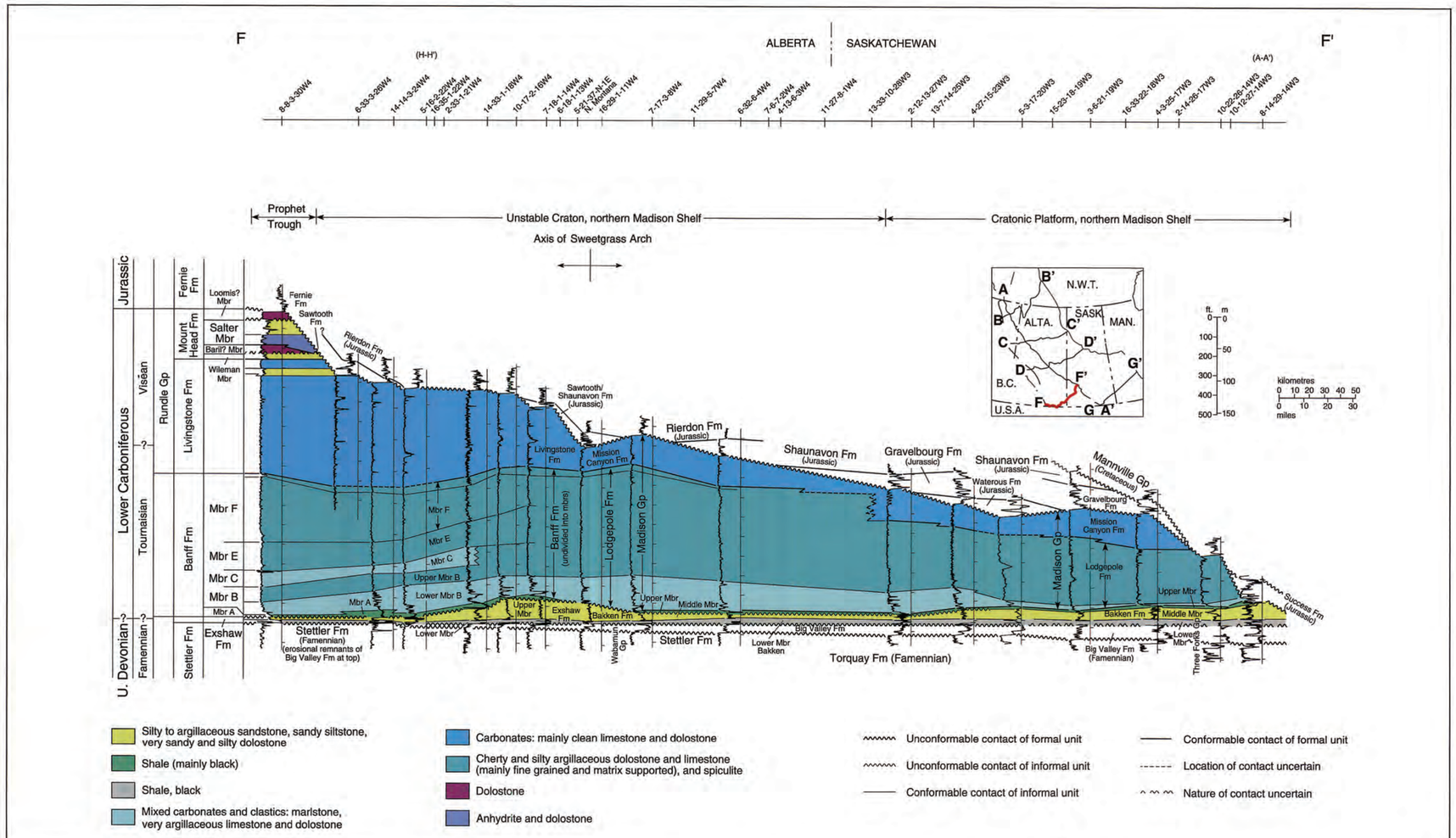


Figure 14.27 Cross section F-F′, showing uppermost Devonian and Lower Carboniferous (Banff and Rundle assemblages) deposited on northern Madison Shelf, southwestern Saskatchewan and southern Alberta.

Cross Section F-F′

Cross section F-F′ (Fig. 14.27) shows the Banff assemblage and lower to middle parts of the Rundle assemblage of southernmost Alberta and southeastern Saskatchewan. The upper Rundle assemblage and the overlying Mattson assemblage, which are widely exposed in the Rocky Mountains to the west, were eroded from even the extreme western part of the section.

Along cross section F-F′, the boundary between the Famennian Big Valley Formation and overlying Exshaw and Bakken formations is probably a minor unconformity, as indicated by southwestward truncation of the Big Valley and units within it. Slightly higher in the succession (Fig. 14.27), the upper boundaries of the Exshaw and middle member of the Bakken are probably unconformities, because both units vary greatly in thickness and are abruptly overlain by transgressive black shale. The Lower Carboniferous thins gradually northeastward to zero beneath the sub-Jurassic subaerial unconformity.

Along F-F′, the boundary between the Banff and Rundle assemblages is gradational and lies between chert-rich skeletal lime wackestone and mudstone of the Banff and Lodgepole formations and the overlying cherty, skeletal grainstone and packstone of the Mission Canyon and Livingstone formations. Immediately below the contact, the gamma-ray logs show a slight downward increase in radioactivity. Dolomitization and chertification obliterated allochems and primary fabrics near the boundary and in most of the Rundle assemblage. The Lodgepole, comprising basin and distal ramp to slope deposits, thins northeastward as it grades into overlying upper-slope to shelf-margin deposits of the Mission Canyon Formation.

Cross Section G-G*

Cross section G-G* (Fig. 14.28) shows components of the Banff, Rundle and Mattson assemblages that were deposited in central to eastern Williston Basin. Figure 14.31a, representing a borehole section (6-3-1-19W2) along G-G*, reveals the relations between the gamma-ray logs used in G-G* and rock types. Figure 14.10 illustrates environmental data and Figure 14.7 the seismic expression of the succession.

Black to variegated shale and overlying sandstone of the Bakken Formation unconformably overlie the Famennian Torquay Formation because the Big Valley Formation, which commonly occurs between these two units (Fig. 14.20), was truncated west of the area represented by cross section G-G*. Most units within the illustrated succession (Fig. 14.28) are truncated northeastward below the regional sub-Triassic subaerial unconformity; a few (basal Lodgepole) are truncated beneath the sub-Jurassic unconformity.

Prominent southwestward-dipping clinoforms, resulting from basinward progradation of transgressive/regressive sequences, are present in the Lodgepole Formation along the line of cross section (Fig. 14.28). The Lodgepole of southeastern Manitoba comprises several members that include shallow-marine carbonates (Fig. 14.2; McCabe, 1959), but these units are not differentiated on the cross section.

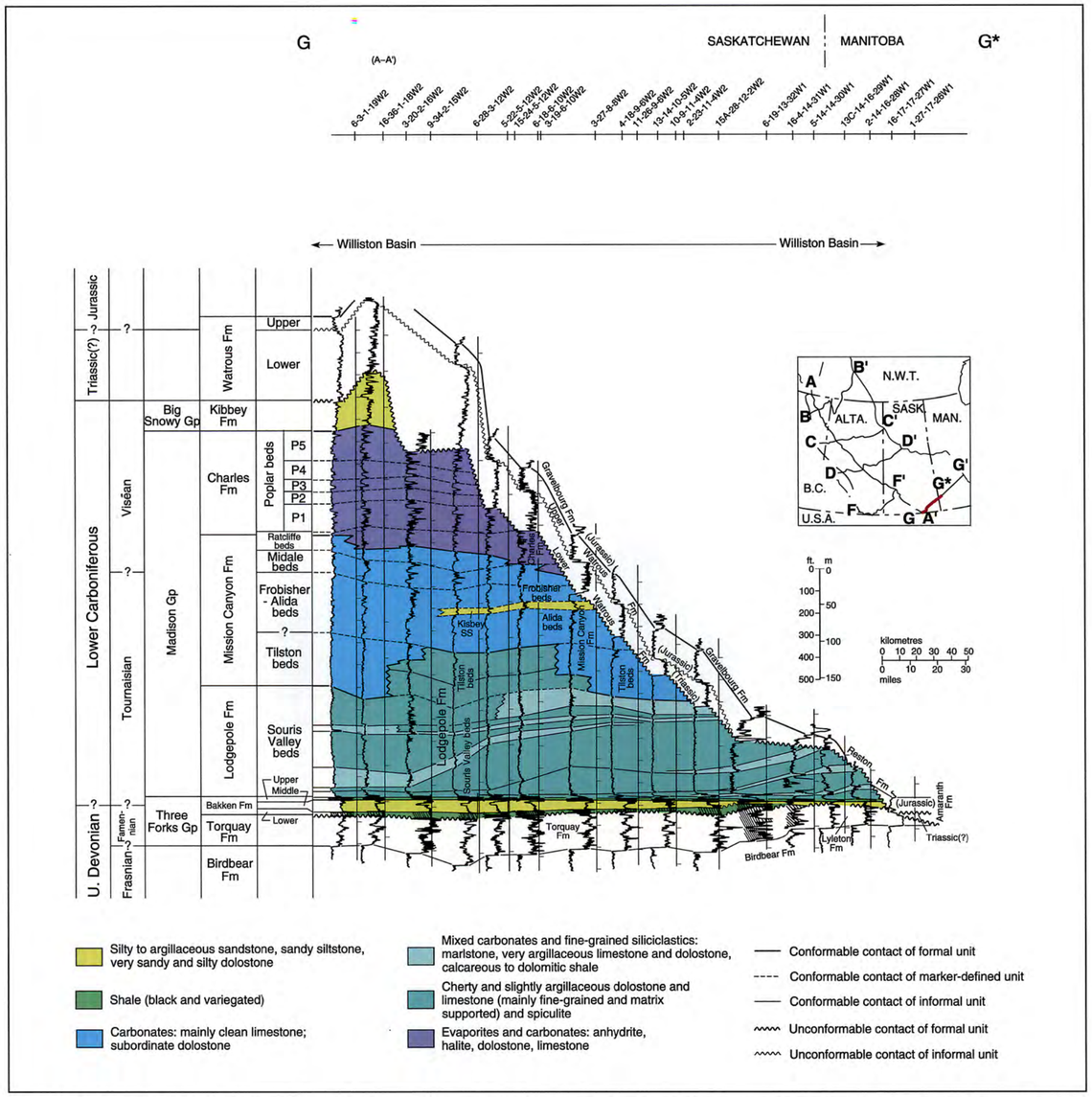


Figure 14.28 Cross section G-G*, showing uppermost Devonian and Lower Carboniferous (Banff, Rundle and Mattson assemblages) deposited in eastern and central Williston Basin, southwestern Manitoba and southeastern Saskatchewan. Figure 14.31a illustrates reference logs.

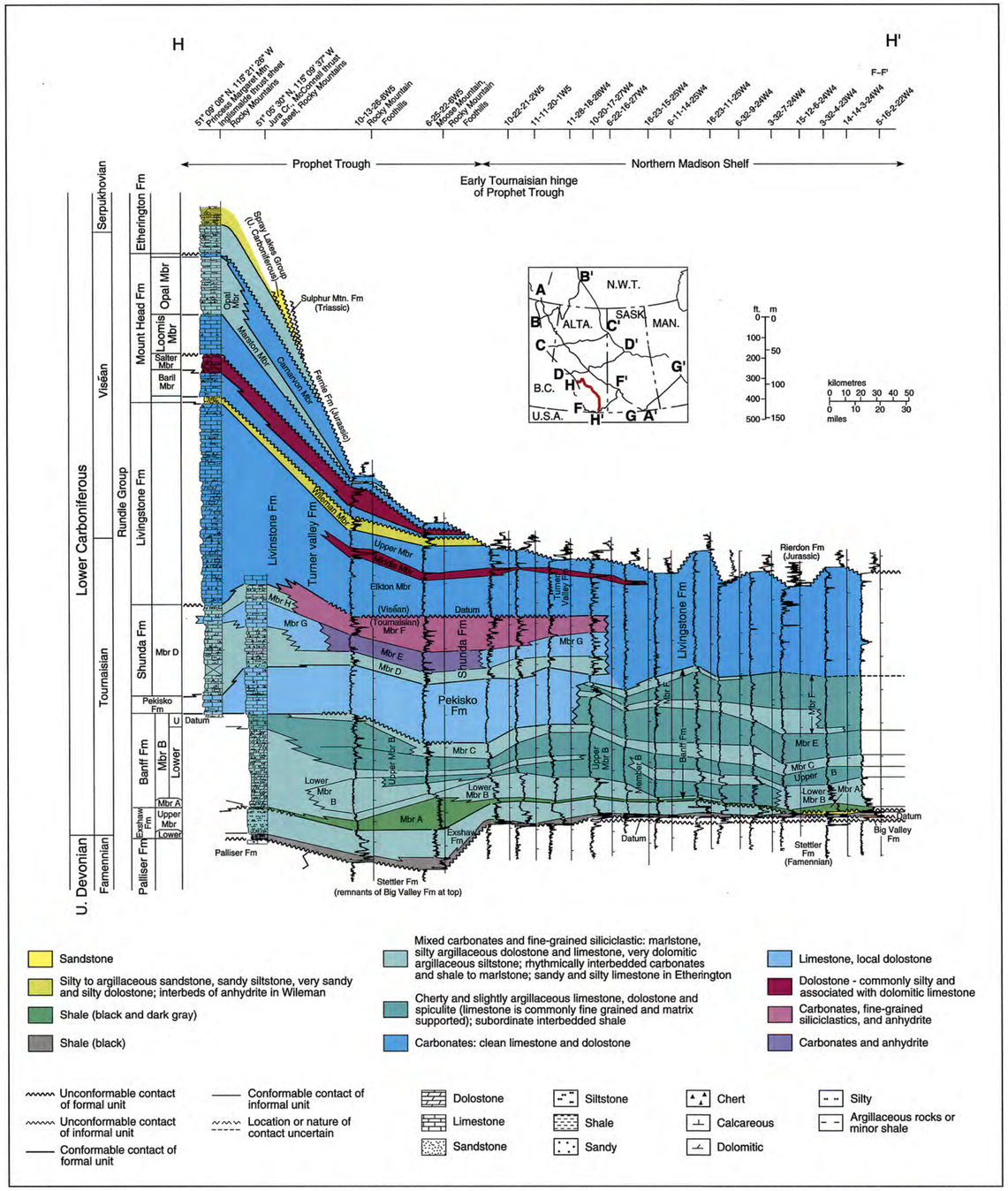


Figure 14.29 Cross section H-H', showing uppermost Devonian and Lower Carboniferous (Banff, Rundle and Mattson assemblages) deposited in eastern Prophet Trough and on the northern Madison Shelf, southwestern Alberta. Figure 14.31b provides reference logs.

In Saskatchewan, spicule lime packstone to mudstone of basin and slope origin in the Lodgepole Formation are overlain by upper-slope to shelf-margin skeletal lime grainstone and packstone of the lower Mission Canyon Formation. In the zone between wells at 3-27-8-8W2 and 9-34-2-15W2 (Fig. 14.28), upper-slope to shelf-margin grainstone of the lower Mission Canyon gives way to deeper water spicule-rich Lodgepole facies, thereby indicating that the margin of the carbonate platform was deeply embayed toward its northern paleoshoreline. Protected- and restricted-shelf carbonates (dolostone, lime wackestone to packstone, algal boundstone) and evaporites (anhydrite and hypersaline dolostone) of the lower Charles Formation grade southwestward into the protected-shelf to shelf-margin skeletal, oolitic, and peloidal carbonates of the upper Mission Canyon Formation.

Cross Section H-H′

Cross section H-H′ (Fig. 14.29) extends from the Inglismalde thrust sheet in the eastern Front Ranges to the Interior Plains of southernmost Alberta. The Mattson assemblage is thick and well developed in the northwest, but only its basal part is shown because its overlying deposits (about 90 m thick) have not been measured in detail. Figure 14.31b, representing a borehole section at 6-25-22-6W5 along H-H′, reveals the relations between the gamma-ray logs used and rock types. Figure 14.12 shows environmental data.

On cross section H-H′, the eastern, early Tournaisian hinge zone of the Prophet Trough is indicated by northwestward (basinward) thickening of the Exshaw and Banff formations between boreholes at 10-22-21-2W5 and 6-25-22-6W5. From the late Tournaisian through the Late Carboniferous, the hinge zone probably lay slightly farther westward, as suggested by lithofacies and thickness changes between 10-13-26-8W5 and the Front Ranges.

In the region represented by H-H′, a minor unconformity occurs at the base of the Exshaw Formation (Macqueen and Sandberg, 1970; Richards et al., 1991), and several minor unconformities lie within the Carboniferous succession. Between the Front Ranges and foothills, marked southeastward erosional thinning of the Spray Lakes Group and Etherington Formation is evident below the sub-Triassic and sub-Jurassic subaerial unconformities.

The northwestern part of cross section H-H′ shows westward-dipping transgressive/regressive sequences of the Banff Formation. The clinoforms, also recognized by Chatellier (1988), developed as proximal- to distal-ramp carbonates of member B that prograded westward over argillaceous to silty carbonates and shale of lower distal ramp and basin origin. In the region representing the Madison Shelf, H-H′ shows shelf-margin to upper-slope grainstone of the Pekisko Formation grading southward (toward Central Montana Trough) into the Banff Formation. The southern Banff contains southward-dipping clinoforms and comprises chert-rich distal-ramp and slope carbonates.

Higher in cross section H-H′, fenestral cryptalgal boundstone, anhydrite, and associated restricted-shelf carbonates of member E of the Shunda pass northwestward into cherty slope carbonates of member D through protected-shelf to shelf-margin grainstone of member G. Toward the same direction, restricted-shelf carbonates, anhydrite, and siliclastics of member F grade into member H of the Shunda and overlying shelf-margin grainstone of the lower Livingstone Formation. Protected-shelf to inner shelf-margin carbonates of the Turner Valley Formation overlie the Shunda and pass basinward into grainstone of the middle and upper Livingstone. The northwestern limit of the Turner Valley coincides with the underlying Shunda/Livingstone transition.

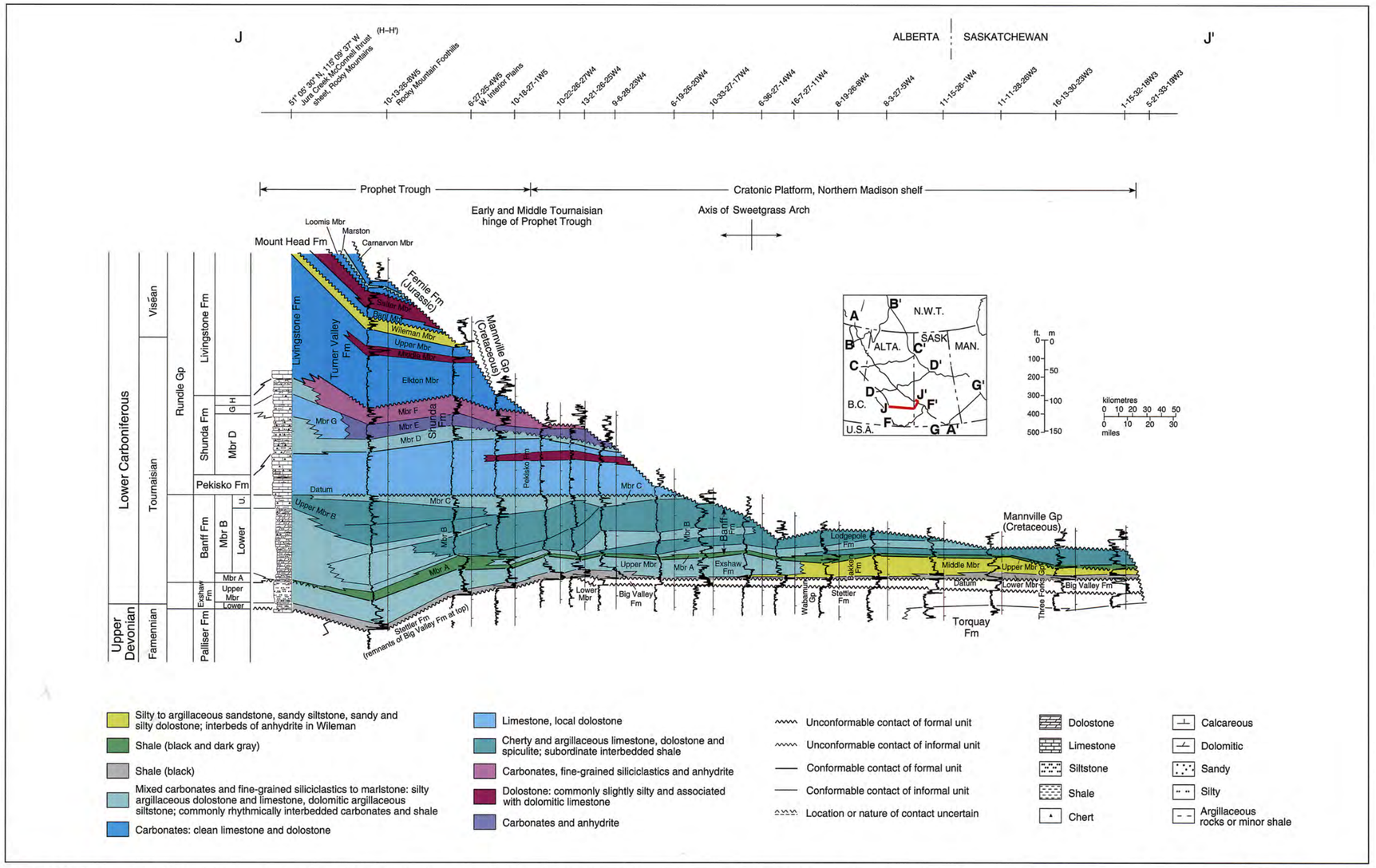


Figure 14.30 Cross section J-J′, showing uppermost Devonian and Lower Carboniferous (Banff and Rundle assemblages) deposited in eastern Prophet Trough and on the cratonic platform (northern Madison Shelf), southern Alberta and eastern Saskatchewan. Figure 14.31b shows reference logs.

Near the top of the succession, restricted-marine carbonates and shale of the Marston Member and lower to middle Carnarvon Member grade northwestward into wackestone and overlying grainstone of the lower to middle Opal Member.

Cross Section J-J′

Cross section J-J′ (Fig. 14.30) extends from the McConnell thrust sheet in the Rocky Mountains to the Interior Plains of eastern Saskatchewan. Figure 14.31b, representing a borehole (6-25-22-6W5) near the western end of the cross section, shows the relations between the gamma-ray logs used and rock types. Figure 14.12 provides environmental data.

On cross section J-J′, the early Tournaisian hinge zone of the Prophet Trough is indicated by westward thickening of the Exshaw and Banff formations between wells at 13-21-26-25W4 and 10-13-26-8W5. From the late Tournaisian through the Late Carboniferous, the hinge was probably slightly farther westward, as indicated by thickness and lithofacies changes between 10-13-26-8W5 and the McConnell thrust sheet.

A minor submarine unconformity occurs at the base of the Exshaw Formation along the line of cross section J-J′, whereas a significant subaerial hiatus (not shown) underlies 2 to 4 m of strata in the upper Palliser Formation that correlate with the Big Valley Formation (Richards et al. 1991). Numerous minor unconformities are present within the succession. In the foothills, prominent eastward erosional thinning of the Mount Head Formation is evident below the sub-Jurassic subaerial unconformity. On the Interior Platform, the Lower Carboniferous is progressively truncated eastward below the sub-Cretaceous unconformity.

Cross section J-J′ shows siltstone and argillaceous slope to outer-shelf carbonates of the upper Exshaw Formation grading eastward into shallow-marine shelf sandstone of the middle Bakken Formation. Westward-dipping clinoforms developed as overlying proximal-ramp carbonates of the Banff Formation prograded westward over shale and dolostone of distal ramp and basin origin. Higher in the succession, most of the restricted-shelf carbonates, anhydrite, and terrigenous clastics in members E and F of the Shunda Formation on the northern Madison Shelf pass basinward into protected-shelf

to shelf-margin grainstone of Shunda member G and shelf-margin grainstone of the lower Livingstone Formation. Overlying protected-shelf to inner shelf-margin carbonates of the Turner Valley Formation pass basinward into shelf-margin grainstone of the middle and upper Livingstone Formation.

Reference Logs

Logs for Williston Basin, Saskatchewan

Figure 14.31a, showing logs for a borehole at 6-3-1-19W2 along cross section G-G* (Fig. 14.28), represents the Carboniferous succession of central Williston Basin. Highly radioactive black shale of the lower Bakken Formation unconformably overlies the continental to restricted-marine Torquay Formation and is overlain by shallow-marine siltstone and sandstone of the middle Bakken. Highly radioactive, black shale also constitutes the upper Bakken.

Conformably overlying basin and slope deposits of the Lodgepole Formation (Fig. 14.31a) are cherty, argillaceous, and dolomitic spicule lime mudstone to packstone. Upper-slope to shelf-margin pelmatozoan lime grainstone of the lower Mission Canyon Formation abruptly overlies the fine-grained upper Lodgepole. At the latter major lithological change, the gamma-ray log records only a slight upward decrease in radioactivity and the resistivity and bulk-density logs indicate a corresponding increase in porosity. Toward the top of the Mission Canyon, the carbonates become finer grained and the relative abundance of ooids, calcareous algae and restricted-marine lithofacies increases.

As shown on Figure 14.31a, the base of the lowest anhydrite bed in the Madison Group marks the boundary between the Mission Canyon Formation and overlying Charles Formation. The latter formation is dominated by evaporites and carbonates of restricted-shelf aspect. The contact coincides with a marked upward increase in bulk density and decrease in porosity.

Anhydritic, red to greenish gray siltstone, sandstone, shale and minor dolostone of the partly continental Kibbey Formation gradationally overlie the Charles (Fig. 14.31a). A slight upward increase in radioactivity and a decrease in bulk density and interval travel time occurs across the contact.

Logs for Southwestern Alberta

Figure 14.31b, illustrating logs for a borehole at 6-25-22-6W5 within cross section H-H′ (Fig. 14.29), represents the Carboniferous of the southwestern Interior Platform and eastern Rocky Mountain Fold and Thrust Belt. Highly radioactive black shale and overlying slope to outer-shelf siltstone of the Exshaw Formation unconformably overlie thin, transgressive carbonates of the Big Valley Formation. The overlying Banff Formation, dominated by basin and slope deposits (Fig. 14.12), is a shallowing- and coarsening-upward sequence of shale grading upward into grainstone through marlstone and skeletal lime wackestone.

Higher in the section (Fig. 14.31b), pelmatozoan and ooid lime grainstone and cherty packstone of the Pekisko Formation abruptly overlie the Banff Formation and are gradationally overlain by the dominantly argillaceous carbonates, shale, siltstone, and anhydrite of the Shunda Formation. The Shunda, in turn, is unconformably overlain by peloid-skeletal lime grainstone and subordinate dolostone of the Turner Valley, which becomes finer grained and more dolomitic upward.

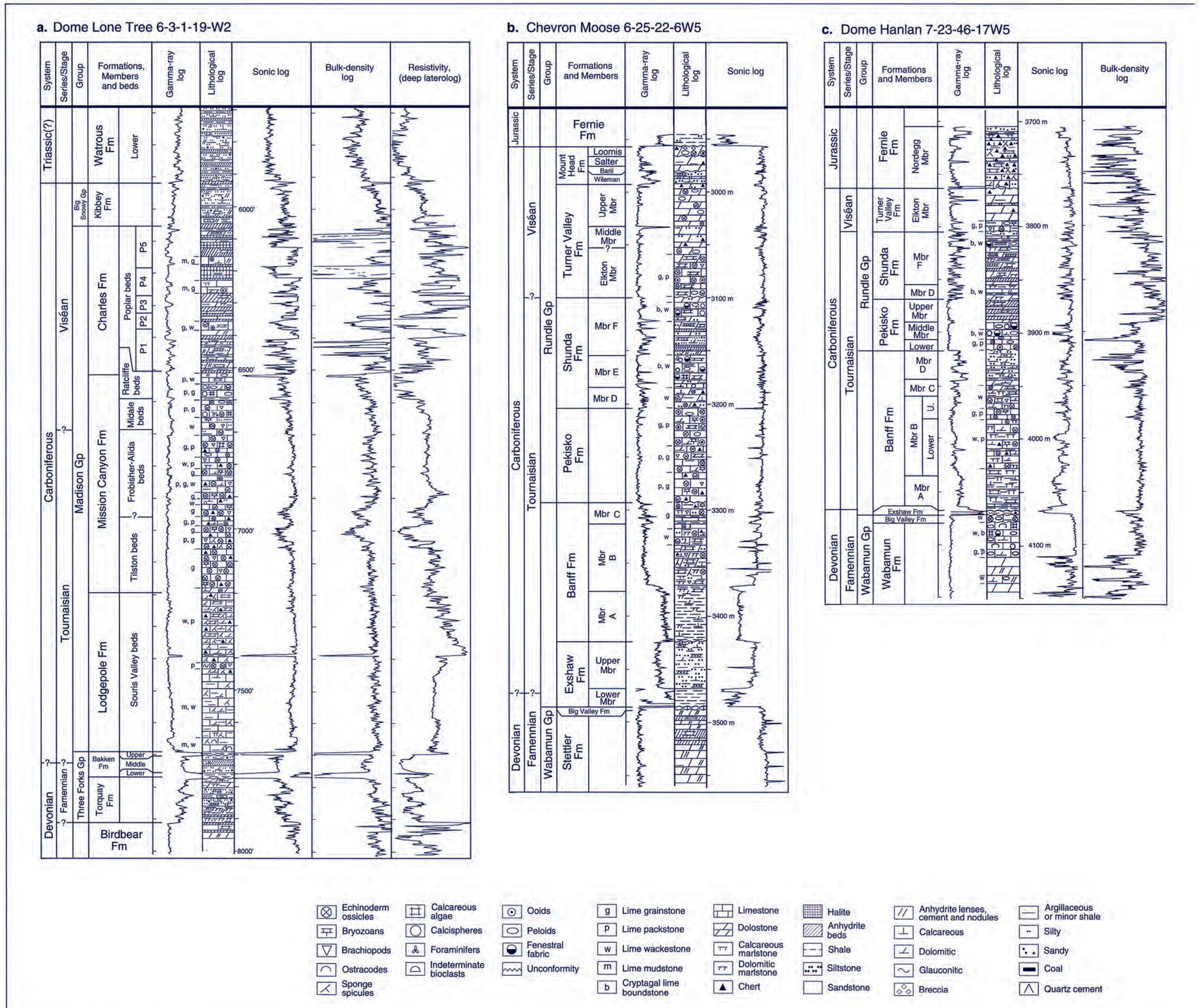
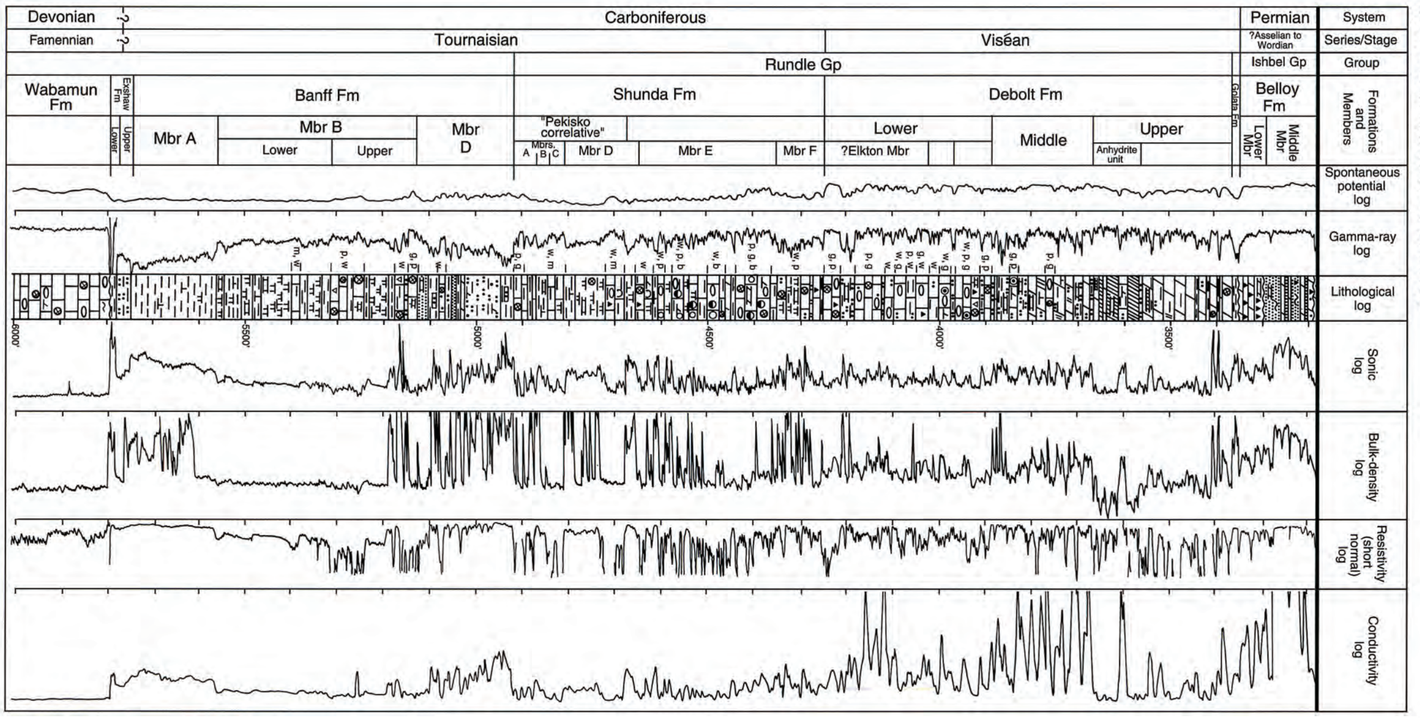
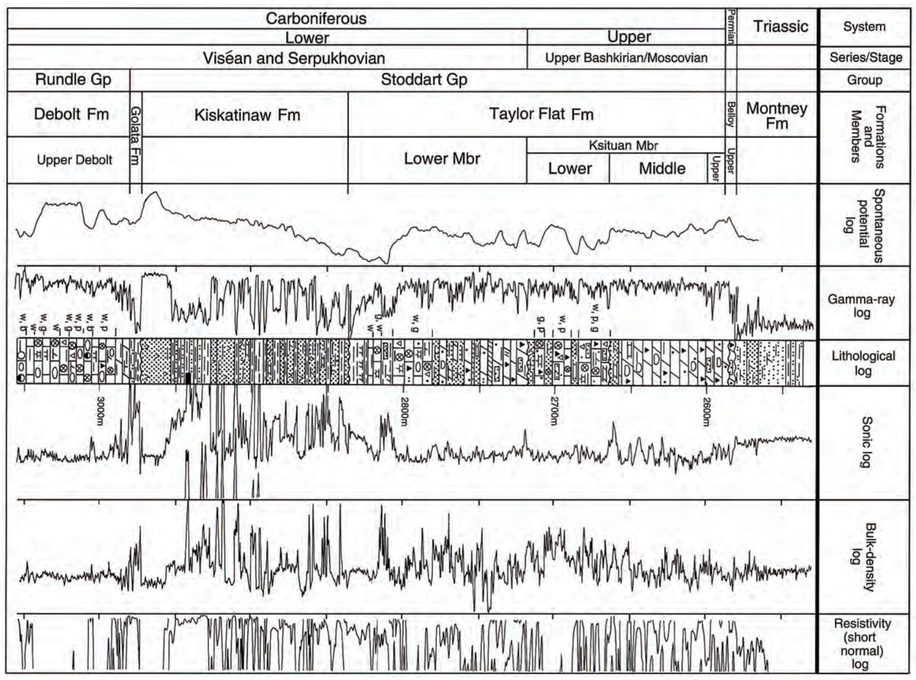


Figure 14.31 Representative borehole sections showing relations between mechanical logs and rock types in: **a.** central Williston Basin, south-central Saskatchewan (locality lies on cross section G-G*); **b.** Rocky Mountain Foothills near Moose Mountain, southwestern Alberta (locality lies near the western end of cross section J-J′, along section H-H′); **c.** easternmost Rocky Mountain Foothills, west-central Alberta (locality lies near western end of cross section D-D*); **d.** Peace River Embayment, northwestern Alberta (locality lies on cross section C-C*); **e.** western Peace River Embayment, northeastern British Columbia (locality lies near southwestern end of cross section C-C*); and **f.** western cratonic platform, northeastern British Columbia (locality lies on cross section B-B*). Vertical scale for all wells is Atlas standard (1:3000).

d. CS et al. Griffen 11-14-81-25W5



e. Focus et al Sunrise 11-18-79-16W6



f. BVX Redwater Yoyo b-86-H;94-I-13

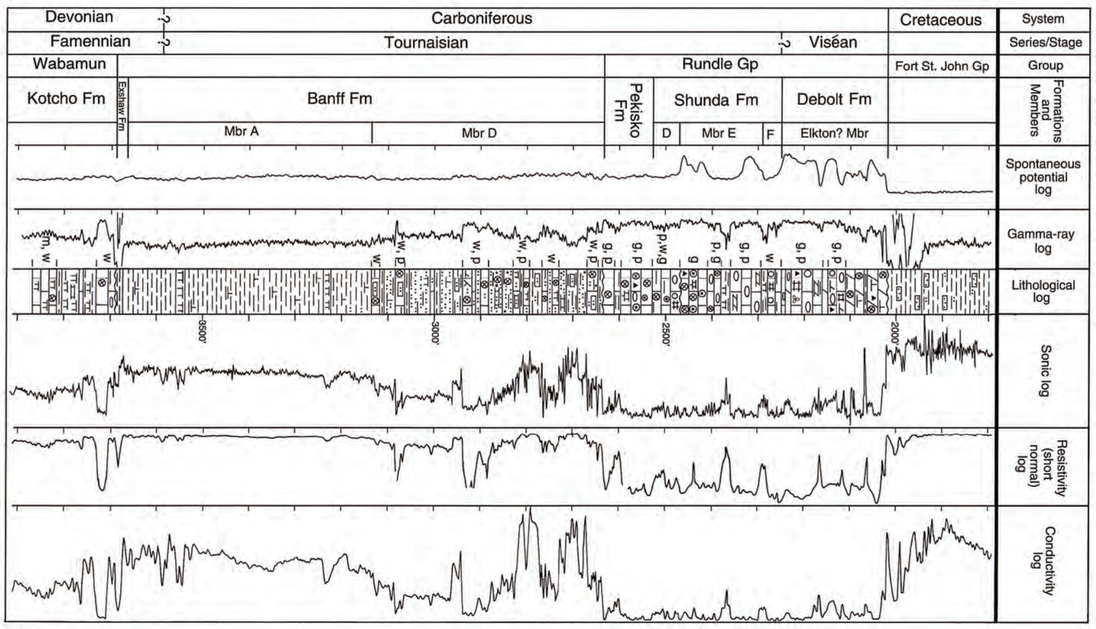


Figure 14.31. *Continued*

The sharp contact between the Turner Valley Formation and overlying Wileman Member of the Mount Head Formation (Fig. 14.31b) coincides with a marked increase in radioactivity and marks a change from clean dolostone to restricted-shelf siltstone and argillaceous dolostone. The overlying Baril, Salter and Loomis members of the Mount Head are poorly developed.

Logs for West-central Alberta

Figure 14.31c provides reference logs for a borehole at 7-23-46-17W5 (near 6-3-46-17W5 in cross section D-D*, Fig. 14.26), and represents the Carboniferous succession in the plains and foothills of west-central Alberta. The section resembles that shown in Figure 14.31b, but it lacks the Mount Head Formation and differs significantly in the upper Banff Formation and the Pekisko Formation.

Member D of the Banff Formation is well developed in the section (Fig. 14.31c) and is dominated by sandy siltstone of restricted-shelf origin. This member can be differentiated from underlying carbonate-dominated members of the Banff by its higher radiaoactivity.

The overlying Pekisko Formation comprises three members (Fig. 14.31c) and has its typical blocky gamma-ray/sonic signature. However, the Pekisko comprises mainly restricted-shelf carbonates and anhydrite instead of the skeletal and ooid lime grainstone that characterize it elsewhere (Figs. 14.31b, f). The upper Pekisko member is differentiated from adjacent units by using the bulk-density log. Samples must be used to pick the boundary between the grainstone-dominant lower member and the middle member, which includes algal wackestone and cryptalgal boundstone.

Figure 14.31c indicates that the Shunda Formation is dominated by restricted-marine lithofacies (anhydrite, argillaceous dolostone and shale) of member F. The Shunda is distinguished from the underlying Pekisko Formation and overlying Turner Valley Formation by its more highly serrated gamma-ray signature. The Turner Valley contains argillaceous units, but it is mainly dolomitized grainstone and packstone of protected-shelf origin.

Logs for Peace River Embayment

Figure 14.31d comprises logs for a borehole section at 11-14-81-25W5. The well is located along cross section C-C* (Figs. 14.24, 14.25), and it represents the Carboniferous in the axial region of northeastern Peace River Embayment. Highly radioactive black shale of the Exshaw Formation marks the base of the succession, and the upper boundary is defined by the subaerial unconformity between the Golata Formation and overlying Belloy Formation.

In the section shown (Fig. 14.31d), the Banff Formation is dominated by member B, which overlies basinal shale of member A and is overlain by shallow-marine siltstone and sandstone of member D. Member B is a coarsening- and shallowing-upward succession of distal-ramp marlstone and argillaceous limestone grading upward into relatively clean skeletal wackestone and packstone of proximal ramp origin.

The grainstone-dominated Pekisko Formation, which is widely developed along the southern and northern margins of the embayment is not developed at 11-14-81-25W5 (Fig. 14.31d). At this locality, the Pekisko has graded into argillaceous limestone and marlstone that are of basin to slope origin and preserved in the lower Shunda Formation (members A to D). Overlying member E of the Shunda is a shallowing-upward package of proximal-ramp carbonates that includes fenestral cryptalgal boundstone. Argillaceous proximal-ramp carbonates of Shunda member F record deepening.

The Debolt Formation at 11-14-81-25W5 (Fig. 14.31d) comprises three main units (lower, middle and upper Debolt) differentiated principally by using the ratio of clean carbonates to shale and argillaceous carbonates. Both the lower and upper Debolt are dominated by clean platform carbonates of protected- and restricted-shelf origin, dolomitized in the upper Debolt. The middle Debolt is dominated by argillaceous ramp carbonates and shale deposited on a restricted shelf. The middle Debolt is abruptly overlain by the anhydrite-rich lower unit of the upper Debolt, which is differentiated by using the bulk-density log.

Figure 14.31e represents the Carboniferous Stoddart Group of central Peace River Embayment. The figure comprises logs for a borehole section at 11-18-79-16W6 in British Columbia that lies 40 km north of a-10-A; 93-P-10 along C-C* (Fig. 14.25). The Golata Formation, dominated by marine shale, is preserved as an erosional remnant below the sub-Kiskatinaw unconformity. The sandstone-dominant Kiskatinaw Formation shows sharp-based channel fills (partly estuarine) and coarsening-upward sequences.

In the section (Fig. 14.31e), ramp carbonates and subordinate siliciclastics of the cyclic, transgressive/regressive lower member of the Taylor Flat Formation unconformably overlie the Kiskatinaw. The base of the Taylor Flat is placed at the base of a unit comprising shale grading upward into carbonates. The lower Taylor Flat is, in turn, unconformably overlain by transgressive sandstone and ramp carbonates of the Ksituan member. An upward change fom restricted-marine carbonates and minor anhydrite to fossiliferous open-marine limestone and sandstone coincides with the contact between the lower Taylor Flat and the Ksituan. Cherty dolostone and subordinate sandstone of the middle Ksituan unconformably overlie the sandstone- and limestone-dominant lower Ksituan and are, in turn, unconformably overlain by dolostone of the upper Ksituan. The lower and upper Ksituan have more highly serrated gamma-ray signatures than the middle Ksituan, and the SP log shows a leftward shift at the base and top of the latter.

Logs for Northeastern British Columbia

Figure 14.31f shows logs for a borehole section at b-86-H; 94-I-13. This locality, which is included in cross section B-B* (Fig. 14.23), represents the Banff and Rundle assemblages deposited on the northwestern part of the cratonic platform. Highly radioactive black shale of the Exshaw Formation constitutes the base of the package, but the Devonian/Carboniferous boundary lies within the lower Banff, as indicated by data from the southwestern District of Mackenzie (Richards, 1989a).

The Banff Formation in the section (Fig. 14.31f) is a coarsening- and shallowing-upward sequence dominated by basinal shale of member A and overlying slope to outer-shelf sandy siltstone, shale, and silty limestone of member D. Upper-slope to shelf-margin packstone and grainstone of the Pekisko Formation unconformably overlie the Banff. The overlying Shunda Formation, a transgressive/regressive succession overall, comprises two members of shale and argillaceous limestone (D and F) separated by a relatively clean middle member of shelf-margin to protected-shelf limestone (E). Grainstone and packstone of protected-shelf origin in the lower Debolt Formation abruptly overlie the Shunda.

Maps

Map Units and Overview

The mainly Carboniferous stratigraphic interval embraced in this chapter (Fig. 14.32) is divided into four assemblages. Three of these – the Banff, Rundle and Mattson assemblages (Figs. 14.33, 14.34, 14.35) – are distributed over most of the basin and are mapped separately. Each of these three assemblages contain subdivisions that are recognizable over wide areas but cannot be readily mapped throughout the basin. The fourth assemblage, the Besa River assemblage in the west, is included in the isopach map of the total Caboniferous (Fig. 14.32) but is not mapped separately.

The stratigraphic interval discussed in this chapter lies mainly in the Interior Plains and southern to central foothills, but part of the Front Range succession of west-central Alberta and east-central British Columbia is included. The isopach maps and structure map (Fig. 14.8) also include the broadly deformed and downfaulted succession in eastern Liard Basin, which lies mainly west of the Bovie Lake normal fault (Figs. 14.19, 14.22).

Data used to compile the maps are derived principally from wells drilled during exploration for hydrocarbons in the Interior Platform, but thickness data from 57 subsurface and 23 surface sections in the eastern Cordillera are used as well. During the Mesozoic and early Tertiary Columbian and Laramide orogenies, northeastward-directed overthrusting foreshortened the western part of the Carboniferous succession, displacing westernmost deposits to the greatest extent. The Cordilleran localities are palinspastically restored to their pre-orogenic positions using data provided by Shell Canada Limited.

In the south, isopach maps for the total Carboniferous (Fig. 14.32) and the Banff assemblage (Fig 14.33) include less than 10 m of Upper Famennian strata preserved in the Bakken and Exshaw formations. The Famennian component thickens northwestward from Peace River Embayment, and in the District of Mackenzie it comprises more than 220 m of Exshaw and Banff strata (Richards, 1989a).

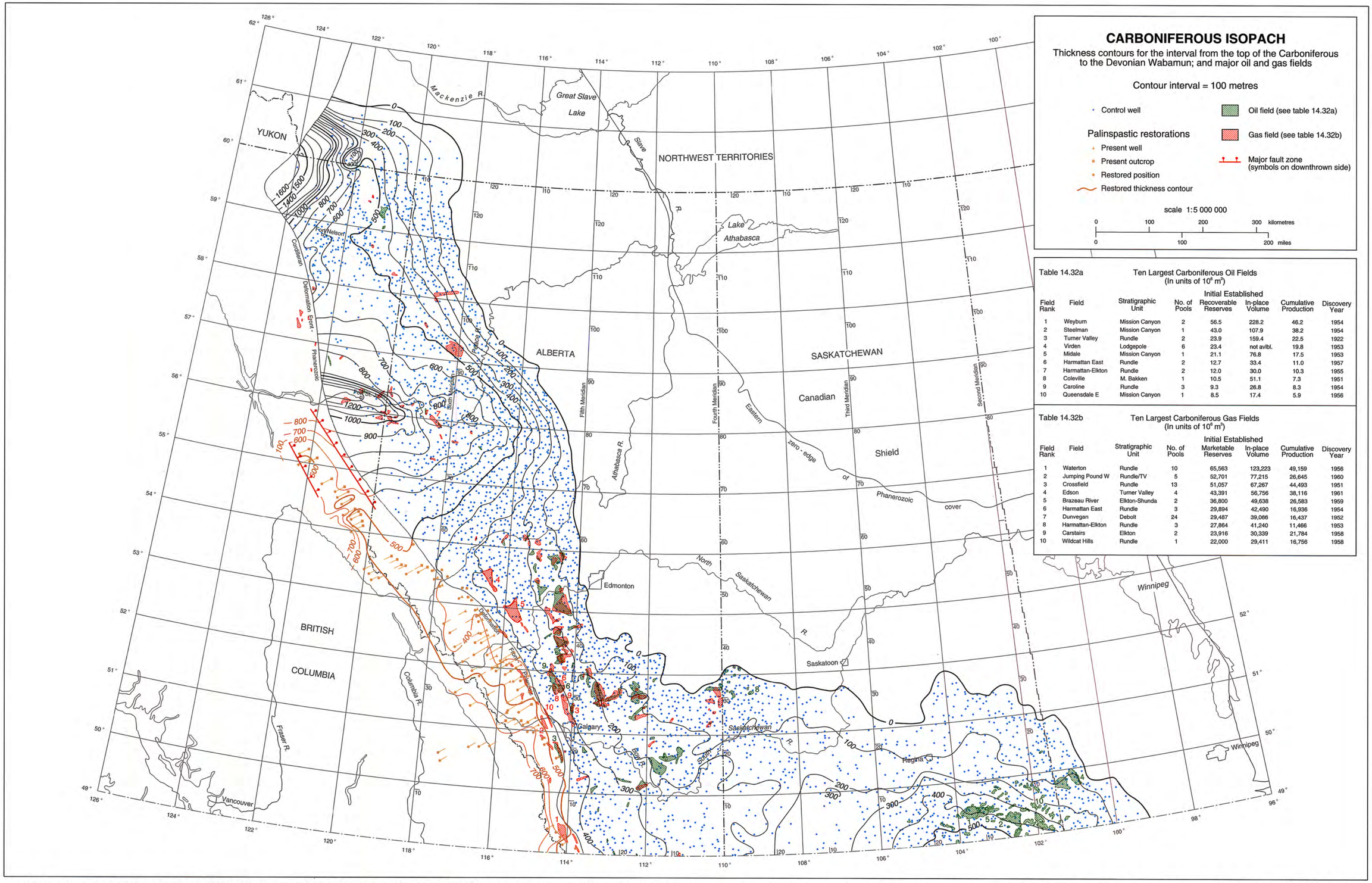
In the Hines Creek Graben (Fig. 14.5) and the southwestern Peace River Embayment, the total Carboniferous isopach map (Fig. 14.32) and the Mattson assemblage map (Fig. 14.33) are depicted as thinner than they should be (locally up to 180 m). This resulted from late recognition of the Upper Carboniferous age of the Ksituan member (formerly thought to be Permian) and its consequent exclusion from the isopach mapping. The Ksituan member is included in the Permian isopach (Fig. 15.1). Where overlain by Permian strata, the upper surface of the Carboniferous succession is a peneplain resulting from latest Carboniferous (post-Moscovian) and Early Permian erosion. In contrast, areas of the Carboniferous that are overlain by Jurassic and Cretaceous strata are commonly deeply incised by broad Mesozoic paleovalleys and channels (Figs. 14.32, 14.33), also noted by Macauley et al. (1964).

Total Carboniferous Isopach and Oil and Gas Fields

In the areas mapped (Fig. 14.32), the Carboniferous is thickest in the central Liard Basin of northeastern British Columbia and southwestern District of Mackenzie. There, more than 1600 m of strata are preserved. On the Interior Platform to the south, the thickest deposits lie in the axial region of the Peace River Embayment (1200 m or more). Farther south on the platform, central Williston Basin contains about 550 m of strata. In the Cordillera, the succession attains 700 m in the western Front Ranges of east-central British Columbia and in the western foothills of southern Alberta.

Below the Permian map unit and the sub-Mesozoic unconformities, the total Carboniferous interval (Fig. 14.32) generally thins gradually toward its northern and eastern erosional zero edges. Thinning is, however, moderately abrupt along the western, fault-controlled side of Peace River Embayment, from about 54°40′ to 57°30′N. Over one fault block on the southwestern side of the embayment, the Carboniferous thins abruptly below the Permian from over 500 m to less than 50 m. Similarly, the succession thins abruptly below Pleistocene deposits to about 66 m on the Celibeta High of southwestern District of Mackenzie (Fig. 14.32), due largely to rejuvenation of basement block faults after the Early Cretaceous (Williams, 1977). Below the sub-Cretaceous unconformity farther northwestward, the Carboniferous is strongly beveled northward along the southern flank of the broad, northeastward-striking La Martre Arch of Meijer Drees (1993).

In the southeast, the 500 m isopach of Figure 14.32 defines the central part of the Canadian component of Williston Basin, whereas the northeast-trending segment of the 300 m isopach marks the approximate western limit of that basin. In southeastern Alberta, the Carboniferous thins gradually toward the Mesozoic axis of the northeast-striking Sweetgrass Arch. Moderate westward thickening in the Cordillera southwest of Calgary defines the eastern limit of the Prophet Trough. The Peace River Embayment, lying between 53°50′ and 57°30′N, is indicated by progressive thickening toward the easterly-trending axis of the embayment, where 1300 m of section are attained. Pronounced southwestward thinning on the southwestern side of the embayment records the location of the Sukunka Uplift. Farther north, the Bovie Lake normal fault system (Figs. 14.8, 14.22), a site of recurrent tectonism in the Liard Basin, preserves an anomalously thick succession on its downthrown side, generalized in Figure 14.32 by prominent northwestward thickening in northeastern British Columbia.



CARBONIFEROUS ISOPACH

Thickness contours for the interval from the top of the Carboniferous to the Devonian Wabamun; and major oil and gas fields

Contour interval = 100 metres

- Control well
- Oil field (see table 14.32a)
- Gas field (see table 14.32b)

Palinspastic restorations

- Present well
- Present outcrop
- Restored position
- Restored thickness contour
- Major fault zone (symbols on downthrown side)

scale 1:5 000 000

0 100 200 300 kilometres

0 100 200 miles

Table 14.32a Ten Largest Carboniferous Oil Fields (In units of 10^6 m^3)

Field Rank	Field	Stratigraphic Unit	No. of Pools	Initial Established Recoverable Reserves	In-place Volume	Cumulative Production	Discovery Year
1	Weyburn	Mission Canyon	2	56.5	228.2	46.2	1954
2	Steelman	Mission Canyon	1	43.0	107.9	38.2	1954
3	Turner Valley	Rundle	2	23.9	159.4	22.5	1922
4	Virden	Lodgepole	6	23.4	not avlbl.	19.8	1953
5	Midale	Mission Canyon	1	21.1	76.8	17.5	1953
6	Harmattan East	Rundle	2	12.7	33.4	11.0	1957
7	Harmattan-Elkton	Rundle	2	12.0	30.0	10.3	1955
8	Coleville	M. Bakken	1	10.5	51.1	7.3	1951
9	Caroline	Rundle	3	9.3	26.8	8.3	1954
10	Queensdale E	Mission Canyon	1	8.5	17.4	5.9	1956

Table 14.32b Ten Largest Carboniferous Gas Fields (In units of 10^6 m^3)

Field Rank	Field	Stratigraphic Unit	No. of Pools	Initial Established Marketable Reserves	In-place Volume	Cumulative Production	Discovery Year
1	Waterton	Rundle	10	65,563	123,223	49,159	1956
2	Jumping Pound W	Rundle/TV	5	52,701	77,215	26,645	1960
3	Crossfield	Rundle	13	51,057	67,267	44,493	1951
4	Edson	Turner Valley	4	43,391	56,756	38,116	1961
5	Brazeau River	Elkton-Shunda	2	36,800	49,638	26,583	1959
6	Harmattan East	Rundle	3	29,894	42,490	16,936	1954
7	Dunvegan	Debolt	24	29,487	39,066	16,437	1952
8	Harmattan-Elkton	Rundle	3	27,864	41,240	11,466	1953
9	Carstairs	Elkton	2	23,916	30,339	21,784	1958
10	Wildcat Hills	Rundle	1	22,000	29,411	16,756	1958

Figure 14.32 Isopach and distribution map for the total Carboniferous succession of southern and central parts of the WCSB. Isopachs in Cordillera are contoured using data from palinspastically restored localities. Map also shows oil and gas fields in Carboniferous strata (reservoir data from Hay, *this volume*, Chapter 32; see also Tables 14.32a1, 2, 3, and Tables 14.32b1, 2, 3).

Table 14.32a1

Oil Production from the Banff/Bakken

Oil production from the Banff/Bakken occurs primarily at the unconformity edge in southwest Manitoba, western Saskatchewan and southeast Alberta. Included are fields producing from the Lodgepole Formation in Manitoba. Numerous other small Banff/Bakken oil fields are scattered throughout southern and central Alberta and Saskatchewan.

There are eleven Banff/Bakken oil fields with Initial Established Recoverable Oil Reserves of over 1 x 10^6 m^3 (6 MMBbls). The ten largest Banff/Bakken oil fields, listed in order of Initial Established Recoverable Reserves, are shown in Table 1. Cumulative production data for Alberta are updated to the end of 1990 and for Saskatchewan to the end of 1989.

Table 1. Ten Largest Banff/Bakken Oil Fields (in units of 10^6m^3).

No.	Field	Stratigraphic Unit	No. of Pools	Initial Established Recoverable Reserves	In-place Volume	Cumulative Production	Discovery Year
4	Virden	Lodgepole	6	23.4	not avlbl	19.8	1953
8	Coleville*	Bakken Sd	1	10.5	51.1	7.3	1951
	Cactus Lake	Bal Mnvl-Bakken	1	6.9	31.2	1.7	1974
	Daly	Lodgepole	22	5.7	not avlbl	4.6	1951
	Cherhill	Banff	9	5.1	37.0	2.3	1967
	Glenevis*	Banff	1	1.6	3.6	1.4	1951
	North Hoosier	Bakken Sd	1	1.6	11.7	1.2	1965
	Alexis*	Banff	1	1.1	7.6	0.5	1968
	Watts	Banff	18	1.1	9.9	0.5	1970
	Luseland*	Bakken Sd	1	1.1	15.9	0.3	1979

All of these fields occur at the unconformity edge. Virden and Daly fields are in southwest Manitoba, Coleville, Cactus Lake, North Hoosier and Luseland in western Saskatchewan and the last four in southern and central Alberta.

*Asterisks identify the heavy-oil pools.

Total recoverable oil reserves in the Banff/Bakken (excluding Manitoba) are estimated at 37.1 x 10^6m^3, of which 19.3 x 10^6m^3 have already been produced. Initial Established In-Place Volume of Banff/Bakken gas reserves (excluding Manitoba) totals 265.3 x 10^6m^3. There are 147 Banff/Bakken oil pools in Alberta and Saskatchewan in 56 fields, with an average 252 x 10^3m^3 recoverable oil reserves/pool. Table 2 lists the distribution of Banff/Bakken oil reserves (excluding Manitoba) according to In-Place Pool Size.

Table 2. Size Distribution of Banff/Bakken Oil Pools (in units of 10^6m^3).

In-Place Pool Size Class	No. of Pools	Recoverable Reserves	Cumulative Production
less than 0.1	35	0.14	0.05
0.1 to 1	83	1.97	0.64
1.0 to 10	22	11.92	6.90
10.0 to 100	7	23.03	11.66
over 100	-	-	-
Total	147	37.05 x 10^6m^3	19.25 x 10^6m^3

Table 14.32a2

Oil Production from the Shunda/Pekisko - Mission Canyon

Major oil production from the Shunda and Pekisko formations and their Frobisher/Alida/Tilston equivalents occurs in southeast Saskatchewan and southern and central Alberta. Most of this production is located in stratigraphic traps along the erosional unconformity.

There are 25 Shunda/Pekisko oil fields with Initial Established Recoverable Oil Reserves of over 1 x 10^6m^3 (6 MMBbls). Twenty of these major fields are in Saskatchewan. The ten largest Shunda/Pekisko oil fields, listed in order of Initial Established Recoverable Reserves, are shown in Table 1. Cumulative production data for Alberta are updated to the end of 1990 and for Saskatchewan to the end of 1989.

Table 1 - Ten Largest Shunda/Pekisko Oil Fields (in units of 10^6m^3)

No.	Field	Stratigraphic Unit	No. of Pools	Initial Established Marketable Reserves	In-place Volume	Cumulative Production	Discovery Year
10	Queensdale E	Frob-Alida	1	8.5	17.4	5.9	1956
	Twining	Rundle/LwrMnvl	4	7.3	145.1	4.9	1951
	Willmar	Frob-Alida	1	6.2	24.5	5.0	1957
	Rosebank	Alida	1	5.4	18.6	4.7	1955
	Hastings	Frobisher	1	5.0	30.3	4.5	1955
	Parkman	Tilstn-SourV	2	5.0	34.4	3.8	1958
	Ingoldsby	Frob-Alida	2	4.8	17.0	4.1	1955
	Sylvan Lake	Pekisko	12	4.5	18.5	3.1	1960
	Lost Horse Hill	Frob-Alida	1	3.7	16.1	3.0	1963
	Medicine River	Pekisko	13	3.5	21.5	2.4	1953

Seven of these ten largest Shunda/Pekisko oil fields occur in Frobisher/Alida/Tilston beds along the wedge edge in southeast Saskatchewan. The remaining three, Twining, Sylvan Lake and Medicine River, occur along the wedge edge in south-central Alberta. The most recent major Shunda oil discovery was in the Desan area of northeast B.C. in 1983. All Shunda/Pekisko oil fields contain light to medium gravity oil, with the exception of a few of the smaller Alberta fields .

Total recoverable oil reserves in the Shunda/Pekisko are estimated at 107.5 x 10^6m^3, of which 82.2 x 10^6m^3 have already been produced. Initial Established In-Place Volume of Shunda/Pekisko oil reserves totals 653.9 x 10^6m^3. There are a total of 209 Shunda/Pekisko oil pools, with an average 514 x 10^3m^3 recoverable oil reserves/pool. Table 2 lists the distribution of Shunda/Pekisko oil reserves according to In-Place Pool Size.

Table 2 - Size Distribution of Shunda/Pekisko Oil Pools (in units of 10^6m^3)

In-Place Pool Size Class	No. of Pools	Recoverable Reserves	Cumulative Production
less than 0.1	33	0.14	0.09
0.1 to 1	91	4.10	2.74
1.0 to 10	72	47.27	35.04
10.0 to 100	12	48.74	39.45
over 100	1	7.24	4.85
Total	209	107.48 x 10^6m^3	82.17 x 10^6m^3

Table 14.32a3

Oil Production from the Debolt/Elkton

Oil production from the Debolt/Elkton is primarily derived from the erosional unconformity in southeast Saskatchewan and south-central Alberta, as well as from the foothills disturbed belt in southern Alberta and northeast B.C. Scattered Debolt/Elkton oil production also occurs in southern Alberta, around the Peace River Arch and in northeast B.C. Included are fields producing from the Midale and Ratcliffe beds, Turner Valley and Debolt formations, and Stoddart Group.

There are 19 Debolt/Elkton oil fields (13 in Saskatchewan, 5 in Alberta and 1 in B.C.) with Initial Established Recoverable Oil Reserves of over 1 x 10^6 m^3 (6 MMBbls). The ten largest Debolt/Elkton oil fields, listed in order of Initial Established Recoverable Reserves, are shown in Table 1. Cumulative production data for Alberta and British Columbia are updated to the end of 1990 and for Saskatchewan to the end of 1989.

Table 1 - Ten Largest Debolt/Elkton Oil Fields (in units of 10^6m^3)

No.	Field	Stratigraphic Unit	No. of Pools	Initial Established Marketable Reserves	In-place Volume	Cumulative Production	Discovery Year
1	Weyburn	Midale	2	56.5	228.2	46.2	1954
2	Steelman	Midale	1	43.0	107.9	38.2	1954
3	Turner Valley	Rundle/TV	2	23.9	159.4	22.5	1922
5	Midale	Midale	1	21.1	76.8	17.5	1953
6	Harmattan East	Rundle/TV	2	12.7	33.4	11.0	1957
7	Harmattan-Elkn	Rundle/TV	2	12.0	30.0	10.3	1955
9	Caroline	Rundle/TV	3	9.3	26.8	8.3	1954
	Carnduff	Midale	1	5.2	15.2	4.6	1955
	Benson	Midale	1	3.5	19.9	2.4	1956
	Alameda	Midale	1	3.4	12.5	2.9	1956

Six of these fields occur along or immediately downdip of the unconformity developed on the Midale in southeast Saskatchewan. Caroline, Harmattan East and Harmattan-Elkton occur in stratigraphic traps at the Elkton wedge edge. The Turner Valley field is in a structural trap in the foothills disturbed belt. Almost all of the Debolt/Elkton oil fields contain light to medium gravity oil.

Total recoverable oil reserves in the Debolt/Elkton are estimated at 220 x 10^6m^3, of which 184 x 10^6m^3 (i.e. 84%) have already been produced. Initial Established In-Place Volume of Debolt/Elkton oil reserves totals 936 x 10^6m^3. There are 124 Debolt/Elkton oil pools, with average recoverable oil reserves of 1776 x 10^3m^3/pool. Table 2 lists the distribution of Debolt/Elkton oil reserves according to In-Place Pool Size.

Table 2 - Size Distribution of Debolt/Elkton Oil Pools (in units of 10^6m^3)

In-Place Pool Size Class	No. of Pools	Recoverable Reserves	Cumulative Production
less than 0.1	8	0.03	0.02
0.1 to 1	63	2.35	1.26
1.0 to 10	38	18.21	13.21
10.0 to 100	12	76.41	62.58
over 100	3	123.23	106.85
Total	124	220.24 x 10^6m^3	183.91 x 10^6m^3

Table 14.32b1

Gas Production from the Banff/Bakken

Gas production from the Banff/Bakken primarily occurs along the Banff wedge edge in south-central Alberta, and in the Bakken sandstone of eastern Alberta and western Saskatchewan. Local smaller Banff gas fields are also present in northwestern Alberta and northeastern British Columbia. There are three Banff/Bakken gas fields with Initial Established Marketable Gas Reserves of over 1000 x 10^6m^3 (35 BCF). These three largest Banff/Bakken gas fields, listed in order of Initial Established Marketable gas reserves, are shown in Table 1. Cumulative production data for Alberta are updated to the end of 1990 and for Saskatchewan to the end of 1989.

Table 1. Three Largest Banff/Bakken Gas Fields (in units of 10^6m^3).

No.	Field	Stratigraphic Unit	No. of Pools	Initial Established Marketable Reserves	In-place Volume	Cumulative Production	Discovery Year
	Cherhill	Banff	14	2,249	4,286	522	1966
	Esther	Banff/Bakken	14	1,443	1,892	951	1957
	Pembina	Banff	14	1,173	1,729	230	1960

The Cherhill and Pembina Banff gas fields occur as stratigraphic traps along the Banff wedge edge in central Alberta. The Esther field is located in eastern Alberta in the Bakken sandstone along the wedge edge.

Total recoverable gas reserves in the Banff/Bakken are comparatively small, and are estimated at 19.1 x 10^9m^3, of which 5.4 x 10^9m^3 have already been produced. Initial Established In-Place Volume of Banff/Bakken gas reserves totals 29.1 x 10^9m^3. There are 266 Banff/Bakken gas pools, with an average 72 x 10^6m^3 recoverable gas reserves/pool. Table 2 lists the distribution of Banff/Bakken gas reserves according to In-Place Pool Size.

Table 2. Size Distribution of Banff/Bakken Gas Pools (in units of 10^6m^3).

In-Place Pool Size Class	No. of Pools	Recoverable Reserves	Cumulative Production
1.0 to 10	25	86	21
10 to 100	158	4,385	826
100 to 1000	83	14,585	4,548
1000 to 10000	-	-	-
over 10000	-	-	-
Total	266	19,056 x 10^6m^3	5,395 x 10^6m^3

Table 14.32b2

Gas Production from the Shunda/Pekisko - Mission Canyon

Gas production from the Shunda and Pekisko formations is primarily derived from the Shunda and Pekisko wedge edges in southern and central Alberta, and to a lesser extent in northern Alberta and B.C. No Shunda/Pekisko gas production occurs in Saskatchewan or Manitoba other than solution gas.

There are thirteen Shunda or Pekisko gas fields with Initial Established Marketable Gas Reserves of over 1000 x 10^6m^3 (35 BCF). The ten largest Shunda/Pekisko gas fields, listed in order of Initial Established Marketable gas reserves, are shown in Table 1. Cumulative production data are updated to the end of 1990.

Table 1 - Ten Largest Shunda/Pekisko Gas Fields (in units of 10^6m^3)

No.	Field	Stratigraphic Unit	No. of Pools	Initial Established Marketable Reserves	In-place Volume	Cumulative Production	Discovery Year
	Minnehik-Buck Lk	Pekisko	1	21,500	28,105	17,128	1952
	Sylvan Lake	Pekisko/Shunda	27	4,115	6,121	1,791	1952
	Medicine River	Pekisko	18	3,723	6,325	992	1959
	Three Hills Crk	Pekisko	3	3,539	5,511	2,198	1953
	Wilson Creek	Pekisko	4	3,509	5,067	675	1960
	Whitecourt	Pekisko	2	3,233	4,794	1,418	1963
	Hotchkiss	UpMnvl/Shunda	1	2,130	2,803	1,600	1975
	Markerville	Pekisko	1	1,840	2,555	270	1976
	Greencourt	Pekisko	4	1,704	3,275	1,554	1961
	Rowley	Pekisko	3	1,676	2,121	1,291	1960

Nine of these largest Shunda/Pekisko gas fields occur along the Pekisko wedge edge in south and central Alberta. The tenth, Hotchkiss, is a commingled Upper Mannville/Shunda gas field along the wedge edge in northern Alberta. Minor Shunda/Pekisko gas production is also present in northeast B.C. along the wedge edge and in structural traps near the Peace River Block.

Total recoverable gas reserves in the Shunda/Pekisko are estimated at 61.9 x 10^9m^3, of which 27.9 x 10^9m^3 have already been produced. Initial Established In-Place Volume of Shunda/Pekisko gas reserves totals 91.2 x 10^9m^3. There are a total of 242 Shunda/Pekisko gas pools, with an average 256 x 10^6m^3 recoverable gas reserves/pool. Table 2 lists the distribution of Shunda/Pekisko gas reserves according to In-Place Pool Size.

Table 2 - Size Distribution of Shunda/Pekisko Gas Pools (in units of 10^6m^3)

In-Place Pool Size Class	No. of Pools	Recoverable Reserves	Cumulative Production
1.0 to 10	15	50	14
10 to 100	125	3,466	313
100 to 1000	88	14,974	3,447
1000 to 10000	13	21,922	6,987
over 10000	1	21,500	17,128
Total	242	61,912 x 10^6m^3	27,889 x 10^6m^3

Table 14.32b3

Gas Production from the Debolt/Elkton

Gas production from the Debolt Formation and Elkton Member is concentrated along porous wedge edges from southern through to northern Alberta, as well as in northeast B.C. and in the foothills disturbed belt. Included are fields producing from the Turner Valley, Debolt, Livingstone and Mt. Head formations and the overlying Stoddart Group. There is no gas production from this zone in Saskatchewan.

There are 55 Debolt/Elkton gas fields with Initial Established Marketable Gas Reserves of over 1000 x 10^6m^3 (35 BCF). The ten largest Debolt/Elkton gas fields, listed in order of Initial Established Marketable gas reserves, are shown in Table 1. Cumulative production data for Alberta and British Columbia are updated to the end of 1990.

Table 1 - Ten Largest Debolt/Elkton Gas Fields (in units of 10^6m^3)

No.	Field	Stratigraphic Unit	No. of Pools	Initial Established Marketable Reserves	In-place Volume	Cumulative Production	Discovery Year
1	Waterton	Rundle/Livingstone	10	65,563	123,223	49,159	1956
2	Jumping Pound W	Rundle/TV	5	52,701	77,215	26,645	1960
3	Crossfield	Rundle/TV	13	51,057	67,267	44,493	1951
4	Edson	Elkton	4	43,391	56,756	38,116	1961
5	Brazeau River	Elkton-Shunda	2	36,800	49,638	26,583	1959
6	Harmattan East	Rundle/TV	3	29,894	42,490	16,936	1954
7	Dunvegan	Debolt	24	29,487	39,066	16,437	1952
8	Harmattan-Elktn	Rundle/TV	3	27,864	41,240	11,466	1953
9	Carstairs	Elkton	2	23,916	30,339	21,784	1958
10	Wildcat Hills	Rundle/Livingstone	1	22,000	29,411	16,756	1958

The Waterton, Jumping Pound West and Wildcat Hills gas fields occur in structural traps in the foothills disturbed belt of southern and central Alberta. The remaining seven are located at porous wedge edges within the Stoddart to Elkton interval.

Total recoverable gas reserves in the Debolt/Elkton are estimated at 499.0 x 10^9m^3, of which 233.0 x 10^9m^3 (i.e. 47%) have already been produced. Initial Established In-Place Volume of Debolt/Elkton gas reserves totals 956.8 x 10^9m^3. There are a total of 409 Debolt/Elkton gas pools, with an average 1220 x 10^6m^3 recoverable gas reserves/pool. Table 2 lists the distribution of Debolt/Elkton gas reserves according to In-Place Pool Size.

Table 2 - Size Distribution of Debolt/Elkton Gas Pools (in units of 10^6m^3)

In-Place Pool Size Class	No. of Pools	Recoverable Reserves	Cumulative Production
1.0 to 10	14	49	9
10 to 100	124	4,039	614
100 to 1000	190	41,819	8,620
1000 to 10000	62	95,535	25,016
over 10000	19	357,555	198,694
Total	409	498,996 x 10^6m^3	232,953 x 10^6m^3

Nearly all of the Carboniferous oil and gas reserves in the fields shown on Figure 14.32 are in Lower Carboniferous strata; moreover, most occur in the Rundle assemblage east of the Rocky Mountains. Dolomitized lime grainstone and packstone are the main reservoir rocks, but other carbonate rock types and sandstones contain oil and gas pools. Most of the reserves are in unconformity-related traps along the Carboniferous subcrop edges and in traps that are primarily structural (Podruski et al., 1988; Hay, *this volume*, Chapter 32).

The insert tables on the Figure 14.32 map enumerate the ten largest oil fields (Table 14.32a) and the ten largest gas fields (Table 14.32b). Further breakdowns of the oil and gas statistics, by stratigraphic subdivision, are set out in additional tables (Tables 14.32a1, a2 and a3 for oil and Tables 14.32b1, b2 and b3 for gas), as per Hay (*this volume*, Chapter 32).

The Lower Carboniferous succession is the principal oil exploration target in the Canadian part of Williston Basin, but is of lesser importance elsewhere. East of the Sweetgrass Arch, most oil pools are found in unconformity-related traps in the Williston Basin of Saskatchewan. Most of the recoverable oil reserves in the Carboniferous west of the arch are in southern Alberta, where the Pekisko and Turner Valley formations are the most important producing units.

Most of the proven gas reserves are in carbonates of the Rundle assemblage. The major fields are in southwestern to west-central Alberta, but other fields occur in northwestern Alberta and in northeastern British Columbia.

Map of Banff Assemblage

The maximum thickness shown on the distribution and isopach map of the Banff assemblage (Fig. 14.33) is in the Liard Basin. Western Peace River Embayment preserves a slightly thinner succession.

Cratonward of the erosional edge of the overlying Rundle assemblage, the Banff assemblage is gradually truncated northward in Williston Basin and on the adjacent Madison Shelf (Fig. 14.33). From the southern Rundle Shelf at 51°50'N in southeastern Alberta to the District of Mackenzie, much of the assemblage, particularly in the axial region of Peace River Embayment, is truncated markedly eastward because of Jurassic and Cretaceous erosion accompanied by regional tilting. Below the Permian on the Sukunka Uplift, the Banff assemblage is reduced to less than 50 m because of faulting accompanied by erosion. Similarly, over the Celibeta High in the District of Mackenzie, the Banff assemblage is eroded to about 66 m.

Where the Rundle assemblage is preserved, the map of the Banff assemblage (Fig. 14.33) shows thickness variations that resulted mainly from differential sedimentation rates and penecontemporaneous tectonism; therefore, tectonic features that the other isopach maps lack are evident. Isopachs in south-central Saskatchewan outline the Canadian component of central Williston Basin, and southward thickening trends on the cratonic platform to the west demonstrate that subsidence rates increased southward toward the Central Montana Trough. Farther westward, eastern Prophet Trough is locally represented by moderate rates of southwestward thickening in the southeastern Cordillera. In west-central Alberta, the Banff assemblage thickens gradually toward the easterly-striking axis of Peace River Embayment, where the greatest thicknesses attained are in the western Fort St. John Graben (Fig. 14.5). On the southwestern side of the embayment, gradual southwestward thinning reflects the location of the Sukunka Uplift. Subtle westward thinning in northwestern Peace River Embayment and on the Rundle Shelf farther northwestward represents the Beatton High and hinge zone of the Prophet Trough.

Lithology	Facies 1 N 13 mean	(std)	Facies 2 N 605 mean	(std)	Facies 3 N 494 mean	(std)	Facies 4 N 138 mean	(std)	Facies 5 N 185 mean	(std)	Total N 1435 mean	(std)
Sandstone	0.3	(0.7)	2.5	(2.6)	2.8	(2.5)	6.1	(7.4)	1.0	(2.0)	2.7	(3.5)
Siltstone	4.1	(3.6)	8.6	(5.9)	8.6	(4.3)	7.6	(5.9)	3.6	(3.4)	7.8	(5.4)
Shale	85.3	(5.3)	58.0	(11.5)	30.7	(10.2)	24.5	(11.8)	18.2	(7.4)	40.5	(19.5)
Marlstone	0.4	(0.9)	4.5	(6.2)	10.3	(9.4)	6.1	(7.8)	3.5	(4.5)	6.5	(8.0)
Limestone	9.3	(5.2)	24.4	(8.2)	38.1	(11.1)	38.7	(9.6)	58.4	(8.4)	34.7	(14.8)
Dolomite	0.3	(0.4)	1.3	(1.5)	7.2	(6.9)	4.5	(6.2)	7.9	(5.7)	4.5	(5.8)
Chert	0.2	(0.3)	0.6	(1.1)	2.2	(2.0)	12.4	(12.4)	7.3	(7.0)	3.2	(6.0)

BANFF/LODGEPOLE ISOPACH AND LITHOFACIES

Thickness contours for the interval from the top Banff/Lodgepole to Wabamun/Three Forks; and generalized lithology

Contour interval = 50 metres

- Control well
- Well with Canstrat coverage
- Major normal fault (symbols on downthrown side)

Palinspastic Restorations

- Present well
- Present outcrop
- Restored position
- Restored thickness contour

Banff/Lodgepole lithofacies

Facies 1
Shale, black to medium gray, calcareous; subordinate siltstone and silty lime wackestone to packstone in upper part.

Facies 2
Shale, black to medium gray, silty; with sandy siltstone to sandstone and silty, dense lime wackestone to grainstone in middle to upper part.

Facies 3
Limestone, medium to light olive gray; subordinate fine-grained sliciclastics , marlstone and dolostone; basal black shale and siltstone to sandstone unit; lower and middle parts of overlying succession are shale and marlstone grading upward into packstone and grainstone with good porosity locally; siltstone, sandstone and silty dolostone at top.

Facies 4
Limestone, cherty, medium to light olive gray, dense; subordinate fine-grained siliciclastics; minor dolostone; basal black shale and siltstone to sandstone unit; overlying succession is marlstone and wackestone grading upward into bedded chert, cherty lime packstone and grainstone.

Facies 5
Limestone, medium gray to cream, mainly dense, pale red in southeast; subordinate fine-grained siliciclastics, and dolostone; basal black to variegated shale and siltstone to sandstone unit; overlying succession is lime wackestone grading upward and eastward into lime packstone, grainstone, and dolostone, with local good porosity.

Bakken/Exshaw Subcrop
Siltstone, sandstone, and shale; subordinate limestone; sandstone and siltstone light olive gray to variegated, with poor to moderate porosity, underlain and overlain by black to variegated shale.

Lithology in thinner zones
- Dominated by Facies 1
- Dominated by Facies 2 and 3
- Dominated by Facies 3 and 5

scale 1:5 000 000

0 100 200 300 kilometres
0 100 200 miles

Figure 14.33 Distribution and isopach map of uppermost Devonian and Lower Carboniferous Banff assemblage (see Figure 14.2 for formations). Isopachs in the eastern Cordillera are contoured using thicknesses at palinspastically restored locations.

Map of Rundle Assemblage

The maximum thicknesses on the Rundle assemblage map (Fig. 14.34) occur in the Liard Basin and axial region of western Peace River Embayment; central Williston Basin preserves a moderate thickness of strata. Substantially greater thicknesses than those shown are attained in the southern Rocky Mountains. Prominent westward thickening occurs in eastern Liard Basin and in eastern Prophet Trough of southwest Alberta. Because much of the assemblage has been eroded, the paleogeography during deposition of this map unit is not well known.

Cratonward of the erosional edges of the overlying Mattson assemblage and the Permian succession, the Rundle assemblage is generally truncated progressively toward its eastern and northern edges (Fig. 14.34). Along the eastern nose of the Peace River Embayment, however, pronounced thinning takes place below Jurassic and Cretaceous formations. On the southwestern side of the embayment, southwestward erosional and depositional thinning reveals the presence of the Sukunka Uplift, on which the assemblage is locally truncated to zero below the sub-Permian unconformity. In the northwest, abrupt northward truncation occurs along the La Martre Arch, and over the Celibeta High the assemblage is totally removed.

Map of the Mattson Assemblage

The distribution and isopach map of the Mattson assemblage (Fig. 14.35) shows deposits that are widely separated and appear to occur in unrelated depocentres, but the assemblage is widely preserved in the Cordillera west of the area mapped (Figs. 14.1, 14.11). It is also widely developed in the Williston Basin and Antler Foreland Basin of the United States. The thickest succession occurs in the Liard Basin. A substantial thickness is also attained along the axis of western Peace River Embayment, which contains numerous anomalous thickness changes that resulted from block faulting (see Barclay et al., 1990) but cannot be shown at this scale. Along the eastern flank of the Sukunka Uplift, the assemblage is truncated southwestward below the Permian and Triassic.

Carboniferous Structure and Paleogeology Map

The top of the Carboniferous interval (Fig. 14.8) is a vast, broadly undulatory surface that dips southward from western Manitoba into southeastern Alberta and southwestward from southwest Alberta into District of Mackenzie. In the east, it is lowest in central Williston Basin. In the west, it is structurally low and (comparatively) steeply inclined along the western margin of the Interior Platform from southwestern Alberta into the Peace River region of northeastern British Columbia, but from the latter area northward it rises gradually along the disturbed belt front. The Sweetgrass Arch of the present day is displayed as a prominent, northeast-striking high in southeastern Alberta and southwestern Saskatchewan.

The structural patterns shown on the western part of Figure 14.8 resulted mainly from tilting of the craton during subsidence of compressional basins that lay in the foreland of the Columbian and Laramide orogens. Subsidence in Williston Basin and uplift of the Sweetgrass Arch occurred largely in response to intraplate compressional stresses present during the Jurassic to early Tertiary Columbian and Laramide orogenies. Uplift of the Celibeta fault block and the La Martre Arch in the District of Mackenzie elevated the upper surface of the Carboniferous above sea level in the northwest.

Tectonic History

Three principal phases of tectonism are recorded by the uppermost Devonian and Carboniferous succession. The first of these, which commenced during the latest Devonian and continued into the late Tournaisian and early Viséan, followed broad Famennian epeirogenic uplift that is recorded by the unconformity at the base of the Exshaw Formation in the northwest (Figs. 14.19, 14.23) and the subaerial unconformity below the Big Valley Formation in the south (Figs. 14.20, 14.29, 14.30). This phase of tectonism was dominated by episodes of marked regional subsidence. The latter resulted from intraplate compressive stress (Bond and Kominz, 1991) and to lesser extents from block faulting and tectonic loading during the Antler Orogeny of the western United States and the partly contemporaneous Cariboo Orogeny of eastern British Columbia (see Richards, 1988b; Poole and Sandberg, 1991; Smith et al., 1993).

During this initial phase, the major tectonic elements shown on Figure 14.1 became well established. Block faulting was not widespread, but took place in the Central Montana Trough (Fig. 14.4; Smith, 1977), Peace River Embayment (Fig. 14.19), and the Liard Basin. The major northeasterly striking normal faults in the trough and embayment formed at high angles to the southwestern margin of the continent and may therefore have resulted from intraplate shearing. Northwest-striking block faults probably resulted from flexural foreland deformation in the south and at least partly from back-arc extension in the northwest (Richards, 1989b). This initial compression-dominated phase of structural evolution was followed by a transitional period in the late Tournaisian and early Viséan characterized by moderate subsidence rates and basinward progradation of shallow-water carbonates.

The second phase of Carboniferous tectonism, which was dominated by extension in the Peace River Embayment region and northwestward, started during the early late Viséan and continued to the late Serpukhovian (Richards, 1989b). Profound subsidence, accompanied by widespread block faulting, took place in the Liard Basin and the axial region of western Peace River Embayment (Barclay et al., 1990). Substantial subsidence also took place in southern Prophet Trough. In the latter area, subsidence may have resulted from compressional stresses, given that extensional or transtensional structures other than the Central Montana Trough and the trough (Vulcan Low) north of the Montania block have not been documented. In addition, the Antler Orogeny in the United States continued through the Viséan (Poole and Sandberg, 1991) and would have influenced the region. The principal tectonic elements that developed during the previous tectonic phase were still well developed; Sukunka Uplift and the Liard Basin were particularly prominent.

The third phase of tectonism, which started in the late Serpukhovian and continued into the Permian, was characterized by moderate to slow subsidence rates, local block faulting, and episodes of broad epeirogenic uplift accompanied by deep subaerial erosion. At this time, regional stress patterns in the North American plate were greatly influenced by the collision of Euramerica with Gondwana (Ross, 1991). The dominantly slow subsidence rates are indicated by the presence of several subaerial unconformities and by the relatively thin, shallow-marine to continental nature of the deposits preserved in the Peace River Embayment and Prophet Trough (Figs. 14.11, 14.25). During the latest Early Carboniferous, Williston Basin was subjected to broad epeirogenic uplift accompanied by deep subaerial erosion (Maughan and Roberts, 1967; Sando et al., 1975). Broad, late Serpukhovian to Bashkirian uplift accompanied by subaerial erosion also produced the major unconformity below the Ksituan member in the Peace River Embayment and that below the Tyrwhitt and Tobermory formations of the Prophet Trough (Fig. 14.11). A final phase of epeirogenic uplift, accompanied by a major drop in sea level, produced the unconformity that separates Lower Permian from Upper Devonian to Moscovian strata throughout the basin.

Peace River Embayment and other major tectonic elements of the Early Carboniferous persisted during the third tectonic episode, but extensive sedimentation may not have taken place in the Canadian component of the Williston Basin. At this time in the western United States, numerous transtensional basins and transpressional uplifts developed in response to the sinistral intraplate shearing that gave rise to the ancestral Rocky Mountains during the Ouachita-Marathon Orogeny (Kluth and Coney, 1981; Budnick, 1986; Ross, 1991). The shearing influenced sedimentation and tectonism in Idaho and probably Williston Basin and southern Prophet Trough as well (Richards, 1989b; Gerhard et al., 1991).

Lithology	Facies 1 N 20 mean (std)	Facies 2 N 520 mean (std)	Facies 3 N 323 mean (std)	Facies 4 N 73 mean (std)	Facies 5 N 100 mean (std)	Total N 1036 mean (std)
Siltstone	0.4 (0.6)	1.0 (1.5)	2.4 (2.8)	3.2 (2.9)	2.6 (3.0)	1.7 (2.4)
Shale	33.7 (12.6)	20.8 (9.6)	12.3 (5.8)	7.5 (7.0)	4.5 (4.5)	15.9 (10.3)
Marlstone	5.6 (6.3)	3.6 (4.3)	2.9 (3.6)	1.7 (2.6)	0.3 (1.7)	2.9 (4.0)
Limestone	46.2 (10.0)	58.3 (10.5)	38.4 (12.5)	19.5 (11.5)	73.0 (12.3)	50.6 (18.0)
Dolomite	8.0 (5.8)	12.1 (7.3)	39.0 (11.3)	62.6 (15.4)	9.8 (9.9)	23.7 (19.1)
Anhydrite		0.4 (1.1)	2.6 (3.8)	2.1 (4.8)	0.4 (3.4)	1.2 (3.0)
Chert	6.2 (3.2)	3.4 (3.2)	1.7 (4.4)	2.4 (2.5)	8.4 (8.6)	3.4 (4.7)
Other accessories		0.4 (0.9)	0.7 (1.4)	0.9 (1.3)	0.9 (1.4)	0.6 (1.1)

RUNDLE/CHARLES ISOPACH AND LITHOFACIES

Thickness contours for the interval from top Rundle/Charles to Banff/Lodgepole top; and generalized lithology

Contour interval = 50 metres

- Control well
- Well with Canstrat coverage
- Major normal fault (symbols on downthrown side)

Palinspastic restorations

- Present well
- Present outcrop
- Restored position
- Restored thickness contour

Facies 1
Limestone, olive gray, cherty, with gray to black shale; basal shale, bedded chert and cherty wackestone grade upward into dense lime packstone and grainstone.

Facies 2
Limestone, olive gray; subordinate shale and dolostone; cyclic; grainstone and packstone of eastern sequences grade upward into argillaceous wackestone, cryptalgal boundstone and shale; western sequences commonly coarsen upward; lime grainstone and dolostone with good porosity increase upward and eastward.

Facies 3
Dolostone and limestone, medium gray to cream; subordinate gray to variegated shale; cyclic; basal grainstone and packstone of sequences have poor to excellent porosity and grade upward into dense argillaceous carbonates, shale, siltstone and anhydrite.

Facies 4
Dolostone, light olive gray; subordinate limestone decreases upward; minor fine-grained siliciclastics and anhydrite; cyclic; basal grainstone and packstone of sequences have poor to excellent porosity and grade upward into dense argillaceous carbonates, shale and anhydrite.

Facies 5
Limestone, gray to cream, cherty in southwest; minor dolostone and fine-grained siliciclastics; lime grainstone and packstone grade upward into argillaceous wackestone and cryptalgal boundstone; moderate to excellent porosity in dolostone and lime grainstone in southeast and northwest.

Charles Formation Subcrop
Dolostone and limestone, cream to variegated; subordinate fine-grained siliciclastics and evaporites increase upward; cyclic; basal grainstone to packstone of sequences have poor to excellent porosity and grade upward into argillaceous carbonates, shale and anhydrite; upper halite in southwest.

Lithology in thinner zones
- Dominated by Facies 5
- Dominated by Facies 4

scale 1:5 000 000

0 100 200 300 kilometres
0 100 200 miles

Figure 14.34 Distribution and isopach map of Lower Carboniferous Rundle assemblage (see Fig. 14.2 for formations). Isopachs in the eastern Cordillera are contoured using thicknesses at palinspastically restored locations.

Lithology	Facies 1 N 55 mean (std)	Facies 2 N 4 mean (std)	Facies 3 N 85 mean (std)	Facies 4 N 5 mean (std)	Facies 5 N 65 mean (std)	Total N 214 mean (std)
Sandstone	42.5 (9.6)	30.1 (3.9)	27.6 (6.8)	17.6 (3.8)	9.3 (9.8)	25.7 (15.1)
Siltstone	10.3 (7.4)	9.4 (3.7)	11.9 (5.4)	14.1 (5.3)	6.9 (7.5)	10.0 (6.9)
Shale	28.5 (8.5)	20.1 (7.2)	37.8 (8.7)	30.4 (9.0)	73.6 (14.4)	45.8 (21.7)
Limestone	1.0 (1.9)	0.3 (0.5)	5.6 (5.4)	24.5 (2.3)	1.9 (4.1)	3.6 (5.7)
Dolomite	9.0 (6.8)	30.1 (5.5)	10.9 (5.6)	7.3 (4.0)	6.5 (7.2)	9.3 (7.2)
Chert	7.7 (4.2)	8.6 (2.6)	5.2 (3.2)	4.2 (2.8)	1.3 (3.6)	4.7 (4.3)
Other accessories	1.1 (2.8)	1.4 (1.7)	1.2 (1.7)	1.9 (1.8)	0.5 (1.5)	1.0 (2.0)

STODDART/MATTSON/KIBBEY ISOPACH AND LITHOFACIES

Thickness contours for the interval from the top Stoddart/Mattson/Kibbey to Rundle/Charles; and generalized lithology. The Upper Carboniferous (Ksituan Mbr) of Peace River Embayment is not included in the isopach.

Contour interval = 50 metres

Contour interval = 100 metres in the Liard Basin and the Fort St. John Graben

- Control well
- Well with Canstrat coverage
- Major normal fault (symbols on downthrown side)

Palinspastic restorations

- Present well
- Present outcrop
- Restored position
- Restored thickness contour

Stoddart/Mattson/Kibbey

Facies 1
Sandstone, gray to pale red, siliceous, very fine to coarse grained; subordinate interbedded black to variegated shale and siltstone; in northwest, sandstone has poor to excellent porosity and overlies basal shale; at top, minor limestone and dolostone increase upward.

Facies 2
Sandstone and dolostone, gray to cream; subordinate shale; above basal shale lower part is fine grained, siliceous sandstone interbedded with shale; upper part is sandy dolostone interbedded with dolomitic siltstone to sandstone.

Facies 3
Shale and sandstone; subordinate siltstone and dolostone; shale is black to variegated, predominates at base; overlying shale is interbedded with fine-grained, siliceous sandstone that decreases upward; sandy siltstone and silty dolostone predominate at top.

Facies 4
Shale, limestone, sandstone and siltstone; shale gray to black, predominates at base; overlying shale interbedded with fine-grained sandstone, siltstone and silty limestone; sandstone dense and decreases upward.

Facies 5
Shale, dark gray to variegated; subordinate sandstone, siltstone and carbonates; lower shale-dominant unit has carbonate and siltstone beds; overlain by thin sandstone with poor to moderate porosity and shale interbeds.

scale 1:5 000 000

0 100 200 300 kilometres

0 100 200 miles

Figure 14.35 Distribution and isopach map of Lower Carboniferous strata in Mattson assemblage (see Fig. 14.2 for formations). Isopachs in eastern Cordillera are contoured using thicknesses at palinspastically restored locations.

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