Chapter 15 – Permian Strata of the Western Canada Sedimentary Basin

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Introduction

Overview

Permian strata of the Western Canada Sedimentary Basin consist mainly of phosphatic marine siliciclastics and silty to sandy carbonates. They occur only in a narrow belt throughout most of the eastern Cordillera and, locally, on the Interior Platform in the Peace River and Liard River areas, owing to localization of deposition and truncation beneath several sub-Mesozoic unconformities. These strata, representing the lower Absaroka Sequence of Sloss (1963), were deposited mainly on the western margin of the ancestral North American plate in the pericratonic Ishbel Trough (Fig. 15.1), which extended from the 49th parallel to the ancestral Aklavik Arch in the northern Yukon (Henderson, 1989; Henderson et al., *in press*). Permian sediments were also deposited in the Peace River Embayment, a downwarped and downfaulted region of the Interior Platform that opened westward into the Ishbel Trough during the Permian (Naqvi, 1972; Henderson, 1989). Permian strata are generally thin but laterally persistent in the Western Canada Sedimentary Basin. The thin nature of the succession resulted from a combination of depositional condensation and erosion beneath several intra-Permian unconformities and eastward truncation beneath sub-Triassic to sub-Cretaceous subaerial unconformities.

Previous Work

The stratigraphic succession and current formational nomenclature for the Permian System in the Western Canada Sedimentary Basin has been established and described in numerous studies, particularly those of Beales (1950), McGugan and Rapson (1961, 1963a, 1963b), McGugan and Rapson-McGugan (1976), MacRae and McGugan (1977), McGugan and Spratt (1981), Scott (1964), Norris (1965) and McGugan (1984) for the southern Canadian Rocky Mountains, and Halbertsma (1959), Laudon and Chronic (1949), Naqvi (1972), Sikabonyi and Rodgers (1959), Bamber et al. (1968), and Bamber and Macqueen (1979) for the Peace River Embayment and northeastern British Columbia (see also summaries by Henderson, McGugan, Richards, and Bamber, *in* Glass (ed.), 1990). Regional lithostratigraphic syntheses have been prepared by McGugan et al. (1964), Douglas et al. (1970), Henderson (1989), and Henderson et al. (*in press*). Important biostratigraphic reports include Jansonius (1962), McGugan (1963, 1983), McGugan and May (1965), Logan and McGugan (1968), McGugan et al. (1968), Nassichuk (1969), Ross and Bamber (1978), McGugan and Rapson (1979), MacRae and McGugan (1977), Bamber and Copeland (1970), Henderson and McGugan (1986), and Henderson and Orchard (1991).

Geological Framework

The major tectonic elements in the Western Canada Sedimentary Basin during deposition of Permian sediments were the Ishbel Trough, the Peace River Embayment and the Interior Cratonic Platform (Fig. 15.1). The Ishbel Trough, named by Henderson et al. (*in press*; see also Henderson, 1989), developed on the downwarped and downfaulted ancestral western margin of the North American plate and resulted mainly from extension. The location of the western margin of the Ishbel Trough is not well established, but the axis of the western rim may be locally preserved in the Kootenay or Cariboo terranes (Struik and Orchard, 1985; Struik, 1986). The Cariboo Terrane is part of the Proterozoic to upper Paleozoic Cassiar Terrane, which lacks Permian strata and may have been subaerially exposed during the Permian. A marginal basin to the west of the Cariboo Terrane (Barkerville Terrane within the Kootenay Terrane: Monger and Price, 1979; Monger and Berg, 1987) was characterized by Permian volcanic and sedimentary deposits (Sugar Limestone). Western marginal basin deposits are also present in the Slide Mountain Terrane west of the Kootenay Terrane (Struik and Orchard, 1985). The eastern margin of the Ishbel Trough was a broad hinge-zone along the western margin of the Cratonic Platform (Fig. 15.1) and coincided approximately with that of the Carboniferous Prophet Trough (see Richards et al., *this volume*, Chapter 14; Richards, 1989). In northeastern British Columbia and southwestern District of Mackenzie the hinge line coincided with the Bovie Lake Fault (Figs. 15.1, 15.10), but generally the position of the eastern trough margin cannot be defined because of eastward sub-Mesozoic truncation of Permian strata. In the Peace River area, Permian sediments were also deposited east of the Ishbel Trough, on the western Interior Cratonic Platform in the Peace River Embayment (Douglas et al., 1970), a deeply downwarped and downfaulted part of the cratonic platform in northeastern British Columbia and northwestern Alberta. The Peace River Embayment resulted from rejuvenation of a Carboniferous embayment that occupied approximately the same area but differed significantly in terms of tectonic character (Richards et al., *in press*; Richards, 1989; Barclay et al., 1990; and Richards et al., *this volume*, Chapter 14). The extent of the embayment was, in part, controlled by the position of structures like the Beatton High and the Sukunka Uplift (Fig. 15.1; Richards et al., *this volume*, Chapter 14).

Stratigraphy

Stratigraphic Nomenclature and Depositional History

In most places, the Permian succession unconformably overlies various Lower Carboniferous formations that contrast strikingly with the Permian in terms of their extensive carbonate development. Locally, the Permian unconformably overlies older Paleozoic rocks, as in the region of the Sukunka Uplift (Fig. 15.1), where it overlies Upper Devonian strata as a result of deep subaerial erosion accompanied by block faulting. The Permian also unconformably overlies Upper Carboniferous units, from which it is commonly difficult to distinguish. In the Peace River Embayment area some of these Upper Carboniferous rocks have been included within part of the Belloy Formation. These strata, herein referred to as the Ksituan Member of the Belloy Formation (see also Richards et al., *this volume*, Chapter 14, where they are referred to as the Ksituan Member of the Taylor Flat Formation), are, using lithostratigraphic criteria, commonly difficult to distinguish from both the underlying Lower Carboniferous Taylor Flat Formation or from the overlying younger Permian units of the Belloy Formation. The Upper Carboniferous units are discussed herein because they have been identified previously as Permian in age and because the Upper Carboniferous and Permian are both part of the lower Absaroka sequence.

Lower Triassic strata of the Spray River or Diaber groups generally unconformably overlie Permian rocks. More extensive erosion beneath various sub-Mesozoic unconformities may result in the unconformable contact of Permian strata with younger Mesozoic rocks (e.g., Figs. 15.4, 15.12). Belloy Formation sandstone in outliers also may be difficult to distinguish from overlying siliciclastic Mesozoic units.

The following discussion of stratigraphy is organized in terms of four transgressive-regressive sequences, depicted in Figure 15.2. The first sequence is Upper Carboniferous, but includes rocks traditionally correlated with various Permian formations. These rocks are also discussed in the previous chapter on the Carboniferous. The remaining three sequences belong to the Ishbel Group and are unquestionably Permian in age, on the basis of biostratigraphic information from various biotic groups (Henderson et al., *in press*). These sequences are discussed sequentially for all regions except the Liard Basin and Peace River Embayment areas, where the Kindle Formation and Permian sequences within the Belloy Formation are discussed as separate sections.

Sequence 1

In numerous outcrop sections along the eastern Rocky Mountain Front Ranges, from southeastern British Columbia to Banff, Alberta, this sequence is represented by the Tobermory and Kananaskis formations (sometimes included within the upper undifferentiated Spray Lakes Group). The Bashkirian Tobermory, consisting of shallow-shelf, bioturbated sandstone and minor dolostone, unconformably overlies the Bashkirian Storelk Formation or lower undifferentiated Spray Lakes Group (Tunnel Mountain or Misty formations). The transgressive deposits of the Tobermory Formation are conformably overlain by the Kananaskis Formation, which consists of shallow-marine, silty to sandy dolostone grading to dolomitic siltstone and sandstone with minor chert nodules, chert beds, brachiopods and fusulinaceans. These fauna form the basis for the Early Moscovian age designation of the base of the formation, and conodonts suggest that the top of the formation may be as young as Kasimovian (Higgins et al., 1991). In contrast, at the Telford Thrust Plate section in southeastern British Columbia, rocks correlative with sequence 1 have not previously been identified. Henderson and McGugan (1986) recognized Upper Bashkirian conodonts within the "Johnston Canyon" and lower Telford formations (Fig. 15.2), but suggested that these were reworked, on the basis of regional correlations that placed these rocks in the Permian Ishbel Group. Similar "anomalous" conodont faunas have recently been recovered from strata of a different tectonic setting in northeastern British Columbia (Chung and Henderson, 1992), lending support to the interpretation that these conodonts are not reworked, but are in situ, and that the rocks that they are found in are not Permian but Upper Carboniferous. These conodont studies are proving to be biostratigraphically invaluable, because Upper Carboniferous and Permian rocks in the region are otherwise sparsely fossiliferous. The "Johnston Canyon" Formation, herein informally referred to as the Bull River beds, is lithologically similar, but of markedly different age and separated from Artinskian strata correlative with the type Johnston Canyon Formation near Banff (sequence 3) by at least two unconformities. It is therefore inappropriately named. The Bull River beds consist of a transgressive succession of phosphatic, argillaceous siltstone and nodular to bedded, spicular chert of slope to basinal origin, with a basal conglomerate of chert and phosphatic pebbles. The Bull River beds are conformably overlain by Carboniferous strata of the lower Telford Formation, which coarsens upward from silty carbonates and mixed skeletal wackestone deposited on the slope, to outer-shelf sandy carbonates with abundant brachiopods and pelmatozoan fragments. The sub-Permian unconformity that apparently occurs within the Telford Formation has not been studied and cannot be precisely located, but the Upper Bashkirian to Lower Moscovian conodont faunas suggest that perhaps the lower 140 m of the Telford belong to sequence 1 (Fig. 15.3). The Bull River beds and lower Telford Formation should be included within the Carboniferous Spray Lakes Group.

In northeastern British Columbia, some rocks that were previously assigned to the Permian Kindle Formation (Peck Creek section; Figure 10.13 of Henderson, 1989) are now included in the silty carbonates of the Taylor Flat Formation (Higgins et al., 1991) and dated as Early Bashkirian to Late Moscovian on the basis of conodonts (Fig. 15.2).

In the subsurface of the Peace River Embayment, some rocks that were previously correlated with the lower carbonate member of the Permian Belloy Formation are now recognized to be Late Bashkirian to Early Moscovian in age on the basis of conodonts recovered from core (Chung and Henderson, 1992; Chung, *pers. comm.*, 1992). These strata are now informally referred to as the Ksituan Member of the Belloy Formation (Figs. 15.2, 15.4, and 15.5) and are discussed in more detail in Chapter 14 (*this volume*, Fig. 14.25) as the Ksituan Member of the Taylor Flat Formation. The nomenclatural problem suggests that these rocks should be referred to a new formation. In any case, carbonate rocks are preferentially preserved within downfaulted blocks within the Peace River Embayment and may be as thick as 100 m. They are presumably older than the lower carbonate member of the type Belloy, which is herein correlated with sequence 2. Clean quartzose sandstones at the base of a thick lower Belloy, which form a potential hydrocarbon play in certain parts of the embayment, may be correlatable with the aeolian sandstones of the Storelk Formation (Stewart and Walker, 1980) or the overlying Tobermory Formation; there is need for more research on these units.

Sequence 2

In the eastern Front Ranges, from southeastern British Columbia to about 54°N, rocks of this sequence are absent, suggesting that the area was a topographic high during at least Early Permian (Asselian and Sakmarian) time. In this region, Lower Permian (Artinskian) strata generally rest unconformably on the Upper Carboniferous (Moscovian to Kasimovian) Kananaskis Formation.

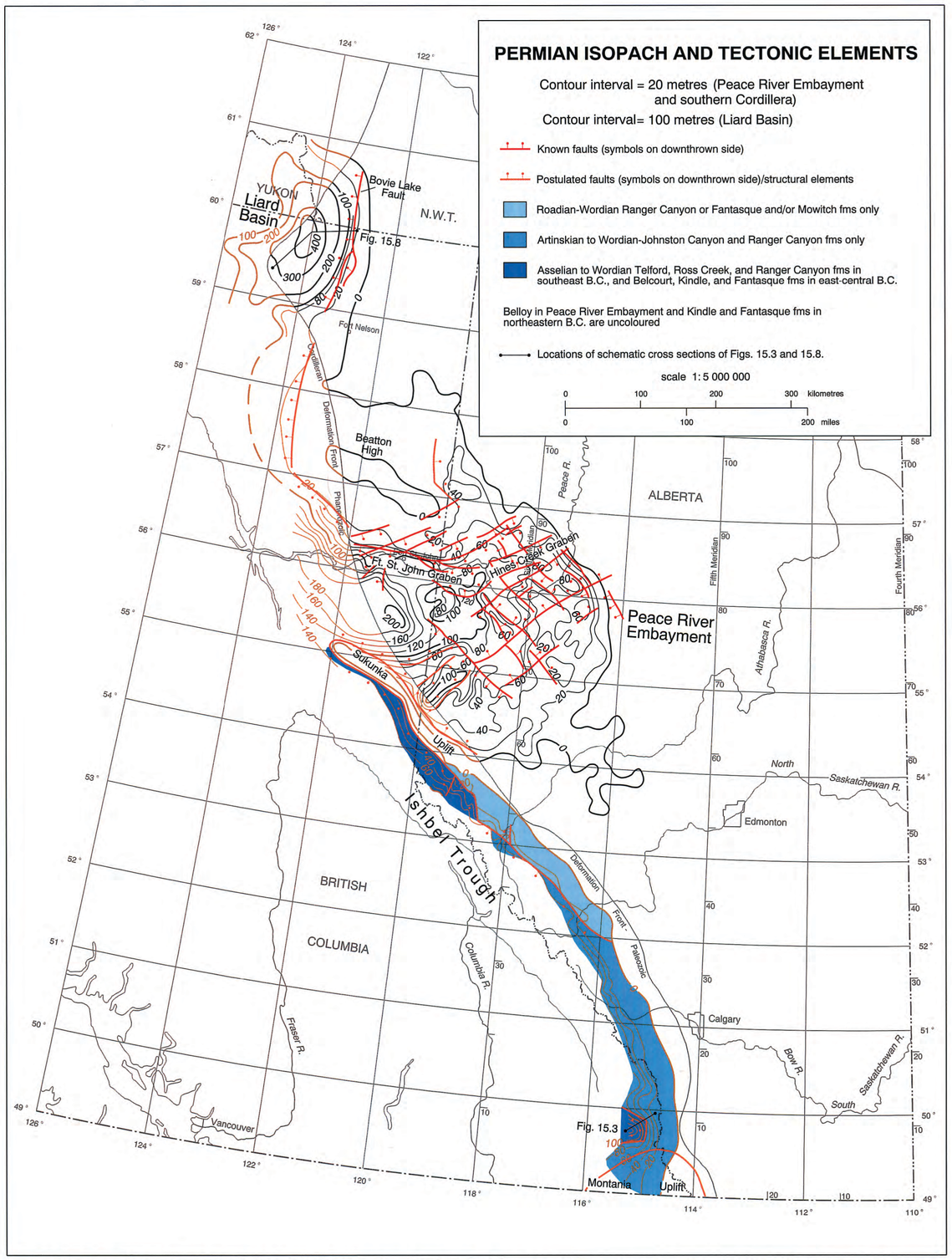


Figure 15.1 Map of Western Canada illustrating the location of various tectonic elements, including numerous faults affecting distribution of Upper Carboniferous and Permian units, as well as the lines of schematic cross sections depicted in Figures 15.3 and 15.8. Distribution of known faults was compiled by Richards, Halbertsma, and Barclay from seismic and lithostratigraphic data. The Peace River Embayment occupies a portion of the Interior Cratonic Platform.

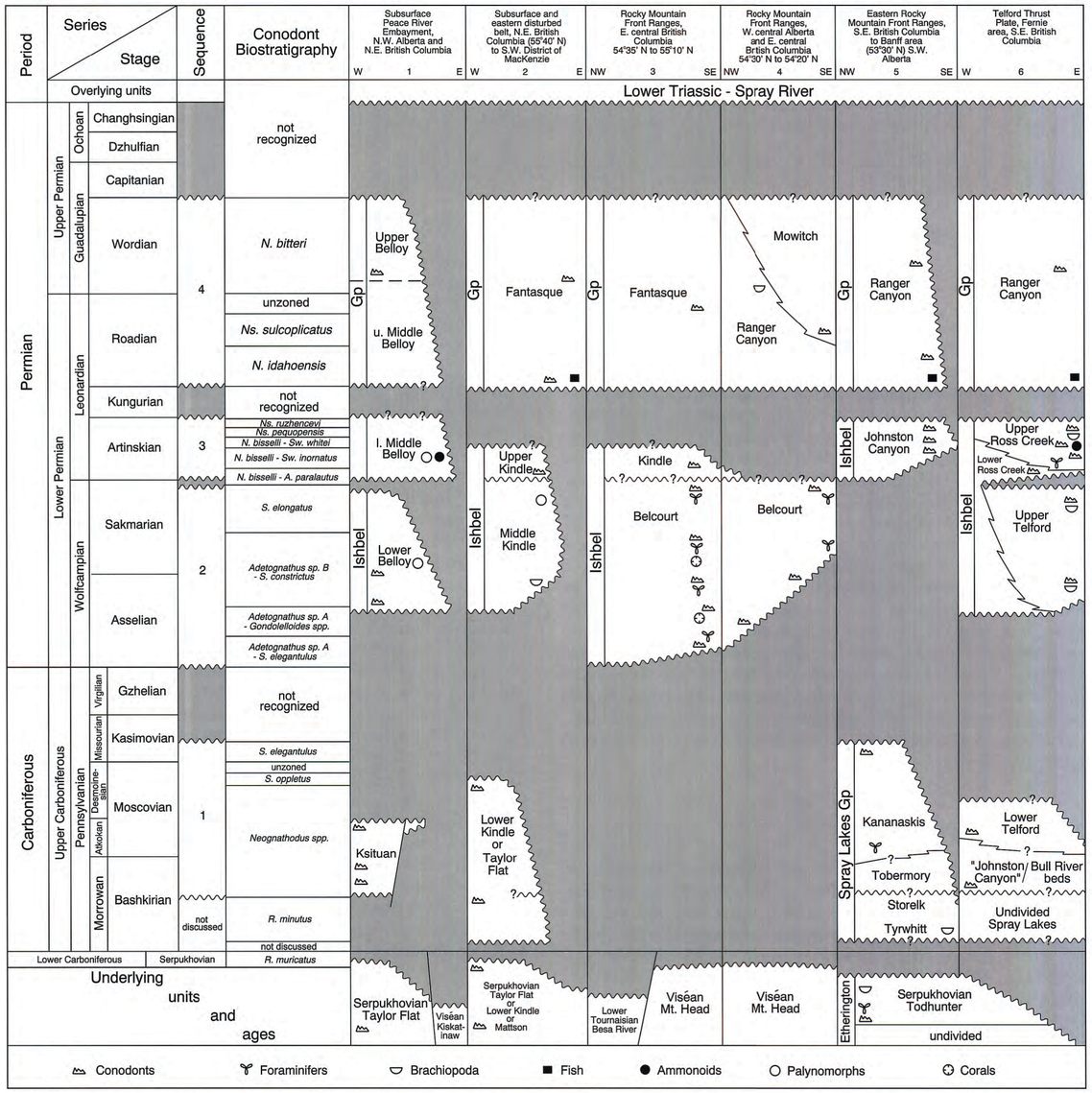


Figure 15.2 Correlation chart illustrating standard chronostratigraphic units, positions of four sequences discussed in the text, conodont biozonal scheme, and Upper Carboniferous and Permian lithostratigraphic units from southeastern British Columbia to the southwestern District of Mackenzie. Question marks indicate that the position or nature of contact is uncertain (modified from Henderson, 1989). *R.*, *Rhachistognathus*; *S.*, *Streptognathodus*; *N.*, *Neogondolella*; *Ns.*, *Neostreptognathodus*.

In the Telford Thrust Plate outcrop sections of southeastern British Columbia, approximately the uppermost 100 m of the Telford Formation are presently correlated with sequence 2 (Figs. 15.2, 15.3). Conodonts recovered from the mostly outer shelf, silty to sandy carbonates suggest correlation with the Upper Asselian to Sakmarian. Brachiopod wackestone and medium- to coarse-grained, calcareous sandstone with *Zoophycos* and phosphatic material are also present in the upper Telford Formation.

In the Rocky Mountain Front Ranges of west-central Alberta and east-central British Columbia, carbonates of the Belcourt Formation (Fig. 15.4) are assigned to sequence 2 largely on the basis of conodonts, small foraminifers, and fusulinaceans. A widespread conglomerate (up to 6 m thick), containing pebble- to boulder-size material derived from Lower Carboniferous limestone and chert, forms the base of the Belcourt. In the northwestern part of the area, the conglomerate is overlain by relatively thick (44-138 m) Asselian to Lower Artinskian carbonates, consisting mainly of silty, mixed-skeletal wackestone and packstone, and finely crystalline dolostone. An eastern facies, which contains the type section of the Belcourt Formation (Forbes and McGugan, 1959), includes shallow-neritic, oolitic and skeletal dolostone grading eastward into thin (3-10 m), planar bedded, microcrystalline dolostone characteristic of intertidal to supratidal environments. Another conglomeratic horizon, high in the Belcourt, may represent the disconformable boundary between sequences 2 and 3 (Fig. 15.4).

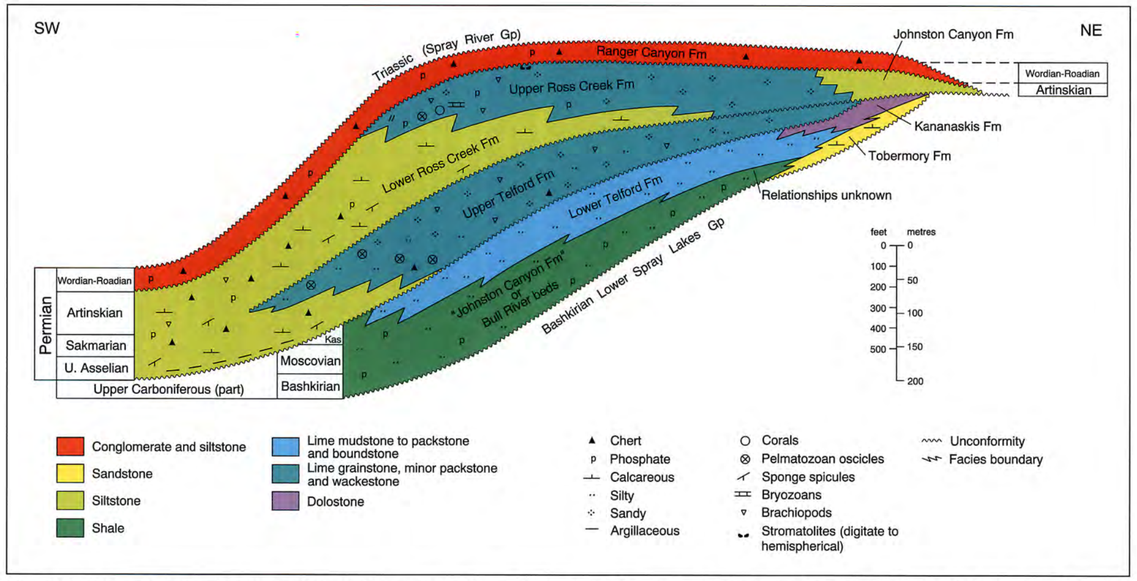


Figure 15.3 Schematic stratigraphic cross section of the Permian Ishbel Group, southern Rocky Mountains, southeast British Columbia. See Figure 15.1 for location. Modified from Henderson (1989). Kas, Kasimovian.

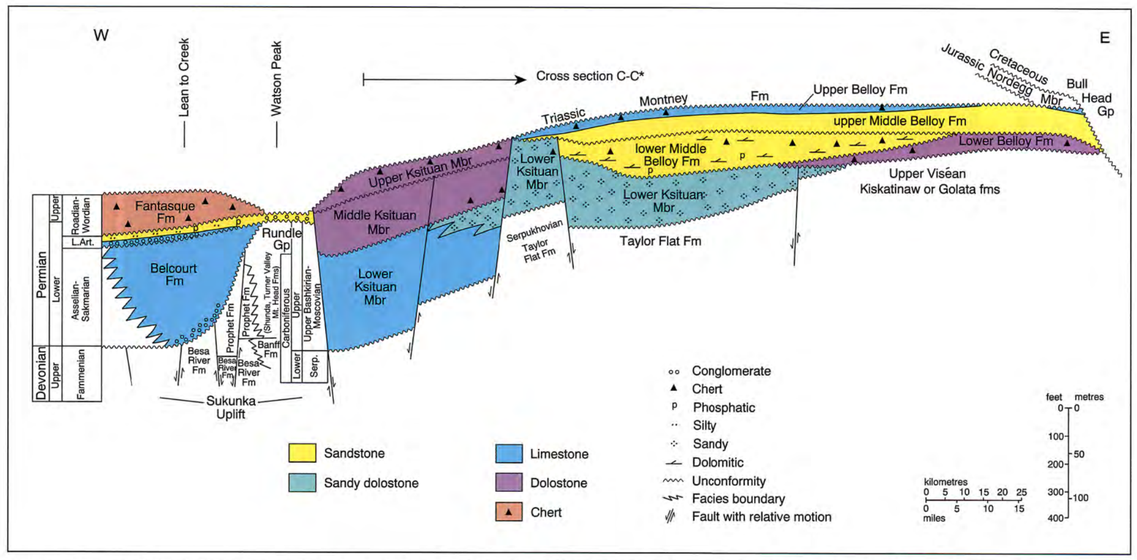


Figure 15.4 Schematic stratigraphic cross section of the Upper Carboniferous Ksituan Member and the Permian Ishbel Group, east-central British Columbia and the Peace River Embayment. Serp., Serpukhovian; L. Art., Lower Artinskian.

In the subsurface of the Peace River Embayment, rocks of the lower Belloy Formation, and in the subsurface of the Liard Basin area rocks of part of the Kindle Formation are correlative with sequence 2, but are discussed separately.

Sequence 3

In the southern Rocky Mountains of southeastern British Columbia and southwestern Alberta, rocks correlated with sequence 3 are assigned to the Johnston Canyon Formation, which is characterized by black, spicular chert, platy, phosphatic siltstone and minor pelmatozoan wackestone. Rhythmic bedding, abundant phosphorite, and the absence of shallow-marine sedimentary structures suggest slope or basinal depositional environments (Henderson et al., *in press*). However an alternative interpretation of a starved shelf appears more likely. In the Banff region at the type section (Fig. 15.2), the Johnston Canyon Formation consists of 45 m of rhythmically bedded, resistant, locally nodular, phosphatic and dolomitic siltstone and recessive, shaly siltstone that unconformably overlies the Upper Carboniferous Spray Lakes Group. The phosphatic nature of this unit, its thinness, and the lack of sequence 2 strata all point to a starved shelf setting in a trough characterized by slow subsidence rates, or to deposition in a topographically high region.

In the Telford Thrust Plate, southeastern British Columbia, these strata are assigned to the Ross Creek Formation (Figs. 15.2, 15.3), which averages about 150 m in thickness (McGugan and Rapson, 1963a). The lower Ross Creek Formation consists of phosphatic and calcareous siltstone and minor black, spicular chert, with a thin basal conglomeratic unit locally present. The regressive upper Ross Creek sediments, which prograded basinward (southwestward) over the lower, transgressive facies, include Middle and Upper Artinskian silty and sandy carbonate, phosphatic siltstone and sandstone with abundant thin-shelled brachiopods, suggesting deposition in an outer shelf environment. Stromatolites at the top suggest deposition in a lagoonal to supratidal setting.

In the Rocky Mountain Front Ranges of east-central British Columbia to northeastern British Columbia, rocks of sequence 3 occur only locally as a thin (up to 10 m) phosphatic siltstone of earliest Artinskian age that are correlative with the upper part of the "Kindle" Formation (Fig. 15.2). Locally, rocks of the uppermost Belcourt Formation may include correlatives of sequence 3.

In the subsurface of the Peace River Embayment rocks of the lower middle Belloy Formation are correlative with sequence 3, discussed separately below.

Sequence 4

Strata of sequence 4 transgressed over an intra-Permian disconformity and are remarkably consistent in lithology and thickness from southeastern British Columbia to the southern Mackenzie Fold Belt (Fig. 15.2). In the southern Rocky Mountains (south of Jasper) the strata comprise a relatively thin but widespread succession of blue-grey chert, silicified sandstone and phosphatic siltstone deposited in a slope setting and referred to the Ranger Canyon Formation (Fig. 15.2). A unit of very thin, but laterally persistent, phosphatic chert-pebble conglomerate, locally containing the elasmobranch fish *Helicoprion*, occurs at the base. In the type area near Banff, the thickness of the Ranger Canyon ranges from less than 1 m to 45 m, but is generally about 10 m (McGugan and Rapson, 1963a). To the north, in the Pine Pass area, the Interior Platform and the southern Mackenzie Fold Belt, a thin but widespread unit (Fantasque Formation) closely resembles and is correlative with the Ranger Canyon Formation (Fig. 15.2). The Fantasque Formation consists mainly of outer shelf to slope and basinal deposits, comprising rhythmically bedded, spicular chert, shale, and siltstone with a thin, basal lag deposit of phosphate nodules and chert pebbles to boulders.

In easternmost outcrops of east-central British Columbia and west-central Alberta, the Fantasque and Ranger Canyon formations grade laterally, cratonward, into siliciclastics of the Mowitch Formation (Fig. 15.2; McGugan et al., 1964). In the Jasper area the Mowitch, which conformably overlies and possibly interfingers basinward with the Ranger Canyon (McGugan, 1984), consists of medium-bedded, brown, shallow-marine, bioturbated to cross-bedded quartzose sandstone. Data from conodont, brachiopod, and elasmobranch fish occurrences indicate that the Ranger Canyon and Fantasque are Roadian and Wordian in age. Significant stratigraphic condensation has been postulated for this thin interval (MacRae and McGugan, 1977) because of the considerable time span that it represents.

A period of regression and erosion followed the transgressive phase of sequence 4, accounting for the Cordilleran-wide sub-Triassic disconformity.

In the subsurface of the Peace River Embayment, rocks of the upper middle Belloy and upper Belloy Formation, correlative with sequence 4, are discussed separately.

Reference Logs

Three separate reference well logs are provided for the Belloy Formation of the Peace River Embayment (Figs. 15.5, 15.6, and 15.7) to show variations in thickness and preservation of internal units. Lithological details for each are discussed in both preceeding and succeeding sections. A reference well is also provided for the Kindle and Fantasque formations of northeastern British Columbia (Fig. 15.9). These strata, in the Liard Basin region, are discussed below.

Kindle Formation, Northeastern British Columbia (Sequences 1 to 3)

In the northern Rocky Mountains of northeastern British Columbia and the southwestern District of Mackenzie, rocks correlative with sequences 1 to 3 have been assigned to the Kindle Formation, but marked correlation and nomenclatural problems are apparent. The Kindle consists of basinal to neritic siliciclastics and silty carbonates, which rest disconformably on Lower Carboniferous strata (Fig. 15.8). In the northwestern part of the outcrop belt at its type section, the Kindle is Serpukhovian (Lower Carboniferous) and should be correlated with the Taylor Flat or Mattson (Fig. 15.2). In the subsurface (Figs. 15.9, 15.10) the "Kindle" correlates with sequences 1 to 3 and comprises basinal to slope siltstone, shale, and subordinate silty carbonates, with a maximum thickness of 250 m. Palynological assemblages contain abundant reworked Viséan material (Utting, *pers. comm.* 1992). The formation becomes phosphatic, glauconitic, and highly calcareous southeastward in the outcrop belt, where it comprises siltstone units with subordinate calcareous sandstone and shale deposited in slope to neritic shelf environments. An increase in the proportion of calcareous sandstone toward the top of the formation (sequences 2 and 3) suggests shallowing. Sandstone also increases to the east where slope deposits pass laterally into an eastern progradational, slope to shallow-neritic facies on the western interior platform in northeastern British Columbia. There the Kindle reaches a maximum thickness of 133 m and thins abruptly southeastward to its subcrop edge.

Permian Belloy Formation (Sequences 2-4)

The Belloy Formation consists of interbedded siliciclastics and carbonates. It can be subdivided into a broad, eastern, shallow-marine sandstone/dolostone assemblage and a more local, western, deeper marine limestone/siltstone assemblage (Naqvi, 1972; Henderson, 1989; Burton et al., 1990). The eastern facies assemblage generally lies outside and along the margins of the Fort St. John Graben (Sikabonyi and Rodgers, 1959; Barclay et al., 1990) and is dominated by cherty sandstones and dolostones, with subordinate limestone and shale. Sandstones are most common near the embayment margins and generally pass laterally into less porous dolostones.

Naqvi (1972) interpreted the Belloy Formation as representing deposition within a tectonically stable, shallow-marine shelf setting characterized by limited clastic input and an active chemical environment. Burton et al. (1990) assigned the eastern facies assemblage to tidally influenced shoreline environments, and Henderson (1989) noted their similarity to the Belcourt and Kindle formations in outcrops to the west. Correlations suggest that the sandstones represent shoreline-related facies developed along the basin margins (Fig. 15.15) and that the dolostones represent proximal shallow-marine facies. Thicker deposits of the western facies siltstones and limestones within the western part of the Fort St. John Graben, which was termed the Hudson Hope Low depocen-

tre by Barclay et al. (1990), are interpreted as deeper, outer shelf to slope sediments (Fig. 15.16). At least part, if not most of these thicker western facies are correlative with the Upper Carboniferous Ksituan Member.

A three-part Belloy subdivision, first recognized at the type section (Halbertsma, 1959), can be locally applied in the eastern assemblage, although regional correlations are problematical, as first noted by Naqvi (1972). Correlation of these members into the western facies assemblage is even more problematical. A different subdivision of the Belloy Formation into two members separated by a mid-Belloy Formation angular unconformity was suggested by Campbell et al. (1989), wherein a carbonate lower member was interpreted as conformable with the Taylor Flat Formation. This carbonate member is clearly represented by the Ksituan Member described earlier, and is older than any of the Belloy units described by Halbertsma (1959). The Upper Belloy of Campbell et al. (1989) was described as a sandstone and carbonate unit and is correlative with the Permian Belloy described herein. In addition, outcrop studies throughout the region point clearly to the presence of two intra-Permian unconformities. The three-fold subdivision of the Permian Belloy reflects this complexity.

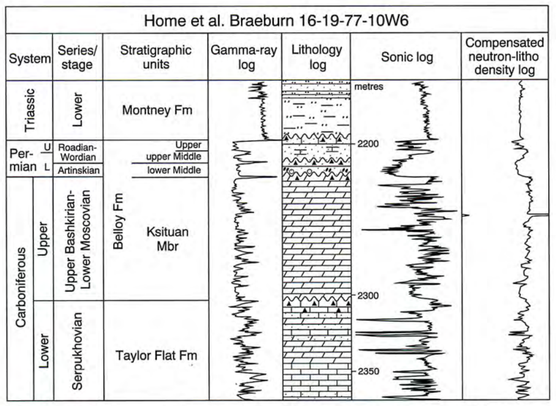


Figure 15.5 Reference well section for the Upper Carboniferous Ksituan Member and Permian Belloy Formation, central Peace River Embayment (16-19-77-10 W6).

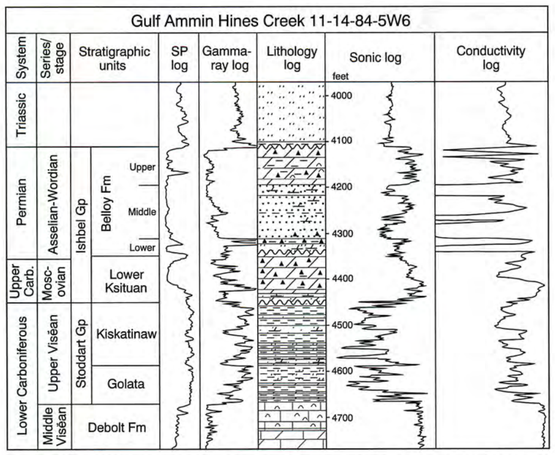


Figure 15.6 Reference well section for the Belloy Formation, northeastern Peace River Embayment (11-14-84-5 W6), in the Hines Creek Graben.

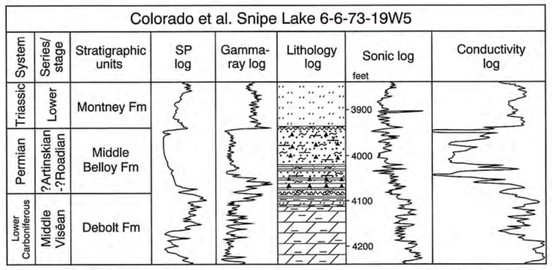


Figure 15.7 Reference well section for the Belloy Formation, southeastern Peace River Embayment (6-6-73-19 W5).

Halbertsma's (1959) lower carbonate member (above and separate from the Ksituan Member), or Lower Belloy member, consists of very fine-grained, glauconitic, quartz arenite, siltstone, and sandy, cherty, dolomitic limestone, correlative with sequence 2. Asselian to Sakmarian or Wolfcampian dates are provided by conodonts, palynomorphs (Jansonius, 1962), and small foraminifers (Bamber and Mamet, 1978). This carbonate member is laterally discontinuous.

Halbertsma's (1959) middle sandstone member, or Middle Belloy, consists of at least two medium-grained, coarsening-upward, quartz arenite units (containing glauconite and phosphate), and lesser interbedded carbonate and chert that appear to be correlative with sequences 3 and 4. A phosphatic conglomerate is locally developed at the base of the sandstone sequence. In some wells, the middle sandstone unit can be subdivided into two units (herein referred to as the lower Middle and upper Middle Belloy). A chert horizon that separates the two units is interpreted as a silcrete, where the influx of silica is related to subaerial exposure. An ammonoid assemblage found in a thin sandstone unit near the northern subcrop edge, dated as Lower Artinskian by Nassichuk (1969), supports the correlation of at least part of the middle sandstone member to sequence 3.

There is no age control as yet on the upper sandstone unit of the Middle Belloy, but well log cross section correlations suggest that it is genetically linked to the upper carbonate member and that together they comprise sequence 4. Sandstones of the upper Middle Belloy appear to truncate the lower Middle Belloy in eastern regions of the Peace River Embayment. In the south part of the Peace River Embayment the upper Middle Belloy passes directly into the Mowitch of the Front Ranges. The upper carbonate member or Upper Belloy consists of dolomitic limestone, dolostone, glauconitic sandstone, and bedded chert. This unit is correlative with sequence 4 on the basis of Wordian conodonts recovered from core samples in the type Belloy (Chung, *pers. comm.* 1992). Chert at the top of the unit probably represents a silcrete that developed below the sub-Triassic unconformity; the unit appears to have been truncated locally below the unconformity. Collectively, the upper Middle and Upper Belloy correlate with the Mowitch and Fantasque formations in the outcrop belt (Fig. 15.4).

Biostratigraphy

Permian strata of the eastern Cordillera have been dated using ammonoids, brachiopods, fusulinaceans and palynomorphs (Bamber and Copeland, 1970; Nassichuk, 1969; Jansonius, 1962). Zonal schemes have been proposed for brachiopods (northern Yukon Territory; Bamber and Waterhouse, 1971) and fusulinaceans (northeastern British Columbia; Ross and Bamber, 1978). However, the geographic separation of the fauna in these studies make interregional correlations difficult. Also, these faunas are largely restricted to shallow-shelf facies and are therefore difficult to relate to faunas in slope and basinal facies elsewhere. Recent conodont studies, coupled with ongoing research, provide dates for these slope to basinal sediments as well as shelf sediments in the Rocky Mountain Front Ranges, from southeastern British Columbia (Henderson and McGugan, 1986) to northeastern British Columbia and in the subsurface of the Peace River Embayment (Higgins et al., 1991; Chung, *pers. comm.* 1992). Presently, four Upper Carboniferous and twelve Permian conodont zones or informal faunal units are recognized in Western Canada (Fig. 15.2). Reference to some of these conodont zones and the named taxa can be found in Henderson and Orchard (1991), Higgins et al. (1991), and Henderson (1988). Correlation of these conodont zones has significantly refined and at times considerably revised previous regional stratigraphic correlations. This is important because Upper Carboniferous and Permian rocks are characterized by several unconformities, separating thin and discontinuous internal units.

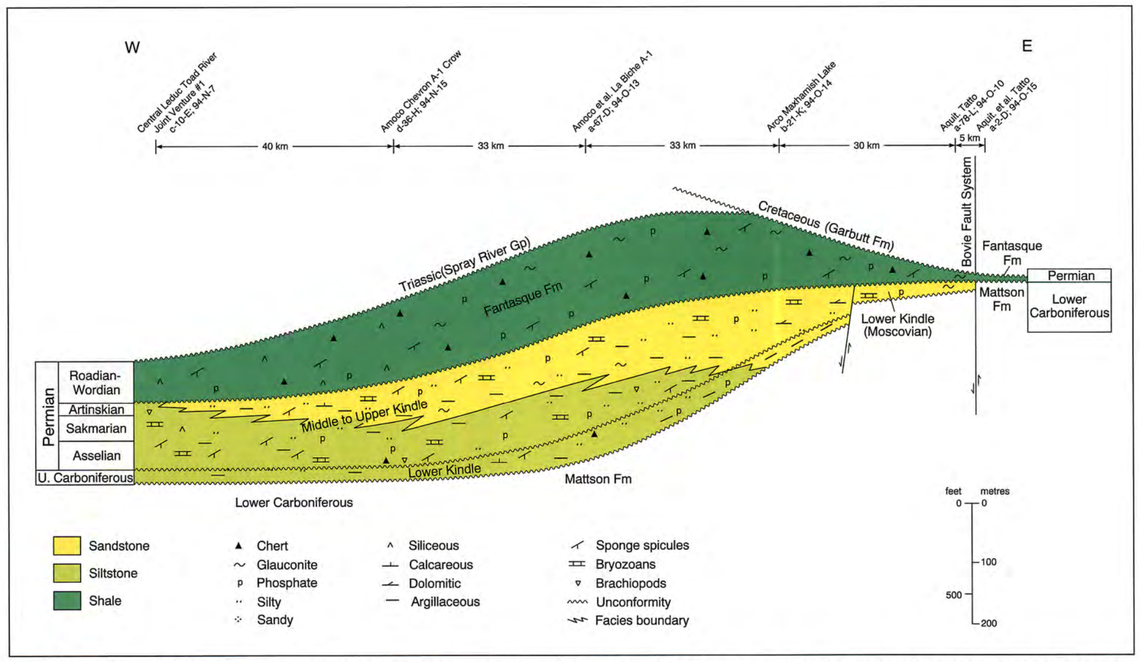


Figure 15.8 Schematic stratigraphic cross section of the Kindle and Fantasque formations, northeastern British Columbia. See Figure 15.1 for location. Modified from Henderson (1989).

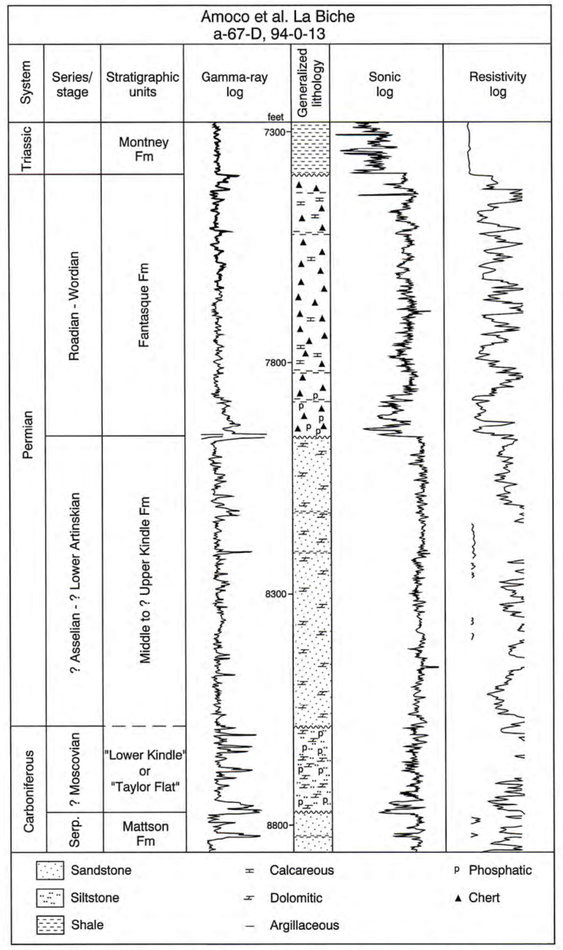


Figure 15.9 Reference well section for the Kindle and Fantasque formations, northeastern British Columbia (a-67-D, 94-O-13). Serp., Serpukhovian.

Regional Cross Sections

Cross section A-A*

Cross section A-A* (Fig. 15.10) shows the dramatic thickening of the Kindle and Fantasque formations west of the Bovie Lake normal fault in the subsurface of northeastern British Columbia. Part of this thickening can be attributed to preservation of Lower Permian units in downfaulted blocks (Fig. 15.8). In this region, the Bovie Lake fault represents the eastern boundary of the Ishbel Trough.

Cross Section A**-A***

Cross section A**-A*** (Fig. 15.11) is restricted to the eastern portion of the Peace River Embayment. Here the Belloy Formation is represented by the eastern facies assemblage dominated by cherty sandstones and dolostones, with subordinate limestone and shale. The Permian Belloy Formation forms a generally thin and flat-lying blanket of strata, indicating a relatively quiet tectonic setting, and unconformably overlies various Carboniferous stratigraphic units (see also Barclay et al., 1990). On A-A′, the Belloy is thickest in the area of the Hines Creek Graben, in part because of syndepositional differential subsidence. It tapers to its subcrop edge in both northwesterly and southeasterly directions as a result of erosion beneath the sub-Triassic unconformity, which locally removed the Upper Belloy. Erosion beneath intra-Permian unconformities also accounts for some thickness variation and lateral discontinuity of units. The greatest part of the thickness variation is related to preferential preservation of the Ksituan Member in the Hines Creek Graben, owing to downfaulting of this unit during the latest Carboniferous.

Cross Section C-C*

This cross section (Fig. 15.12) runs slightly oblique to and south of the axis of the Peace River Embayment, and shows a dramatic westward thickening of rocks correlated with the Belloy Formation. Most of this thickness variation is related to preservation of the Upper Carboniferous Ksituan Member of the Belloy Formation in downfaulted blocks in the southern Fort St. John Graben and on the eastern flank of the Sukunka Uplift (Figs. 15.1, 15.4), where the Ksituan reaches over 190 m in thickness. Otherwise the Permian part of the Belloy shows only minor thickening in a westward direction, ultimately thinning again above the Pouce Coupe High (*this volume*, Chapter 14). The close juxtaposition of bounding unconformities and three internal unconformities within the Belloy Formation make correlations very difficult. As a result, the interpretation offered in Figure 15.12 differs from that presented in Chapter 14 (*this volume*).

Structure

The structure at the top of the Permian (Fig. 15.13) is that of a surface tilted gently toward the west, with dips increasing toward the disturbed belt. Only very minor disruptions in this pattern are apparent. The subcrop edge is controlled by erosion beneath various sub-Mesozoic unconformities. Irregularities in the shape of the subcrop edge are related to the thinness of the Belloy and the artificial amalgamation of possible outliers with the main area of subsurface preservation. In particular, the irregular shape in the southeastern corner probably represents an isolated erosional remnant that accounts for the location of the Virginia Hills oil and gas field.

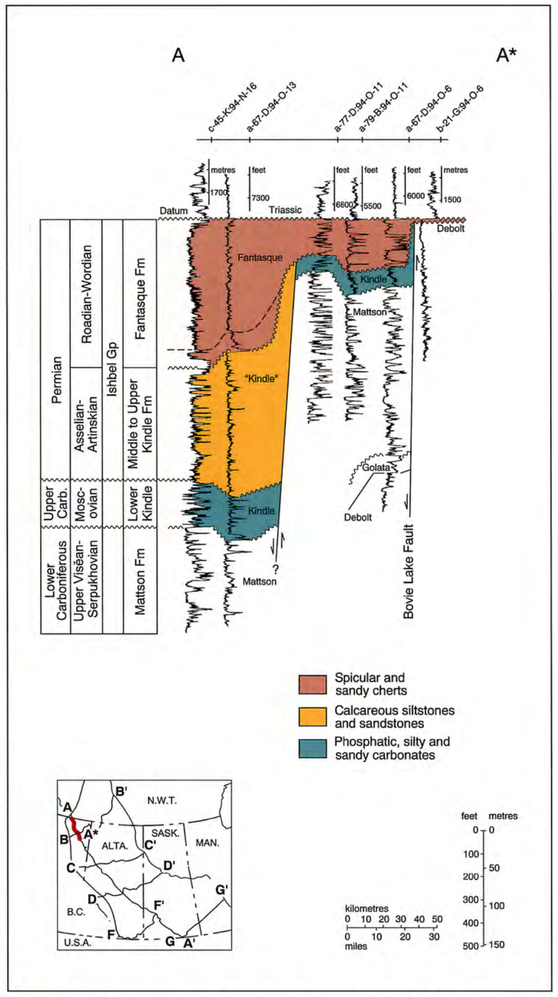


Figure 15.10 Cross section A-A*, highlighting Upper Carboniferous and Permian strata in the Liard Basin.

Thickness, Distribution and Lithology

Permian strata form a thin but laterally persistent succession throughout the Front Ranges of the Rocky Mountains and in the subsurface of the Peace River Embayment. The thickest succession in the southern Rocky Mountains occurs in the Telford Thrust Plate, where Permian strata (upper Telford, Ross Creek, and Ranger Canyon formations) are up to 250 m thick (Fig. 15.14). Upper Carboniferous strata that were previously correlated with the Permian ("Johnston Canyon" or Bull River beds and lower Telford formations) in this area total up to 200 m in thickness.

Elsewhere in the southern Rocky Mountains, Permian strata (Johnston Canyon and Ranger Canyon formations) range from a feather edge to about 55 m in thickness.

In east-central British Columbia to west-central Alberta, the Permian (Belcourt, upper Kindle, Fantasque, and Mowitch formations) ranges from a feather edge to about 185 m in thickness.

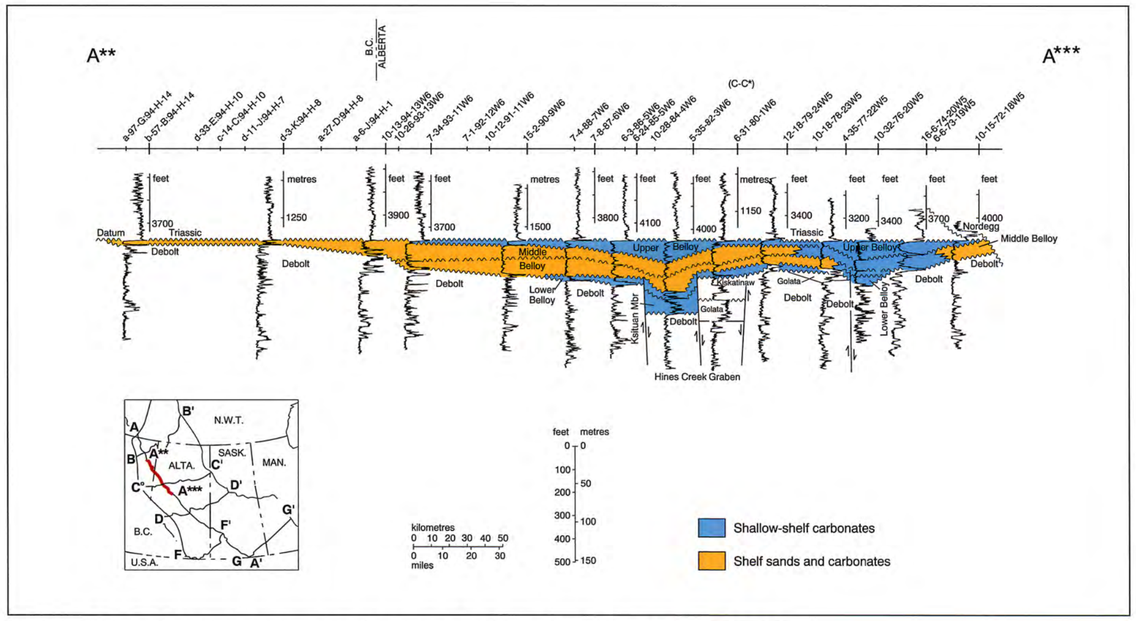


Figure 15.11 Cross section A**-A***, highlighting Upper Carboniferous and Permian strata in the Peace River Embayment.

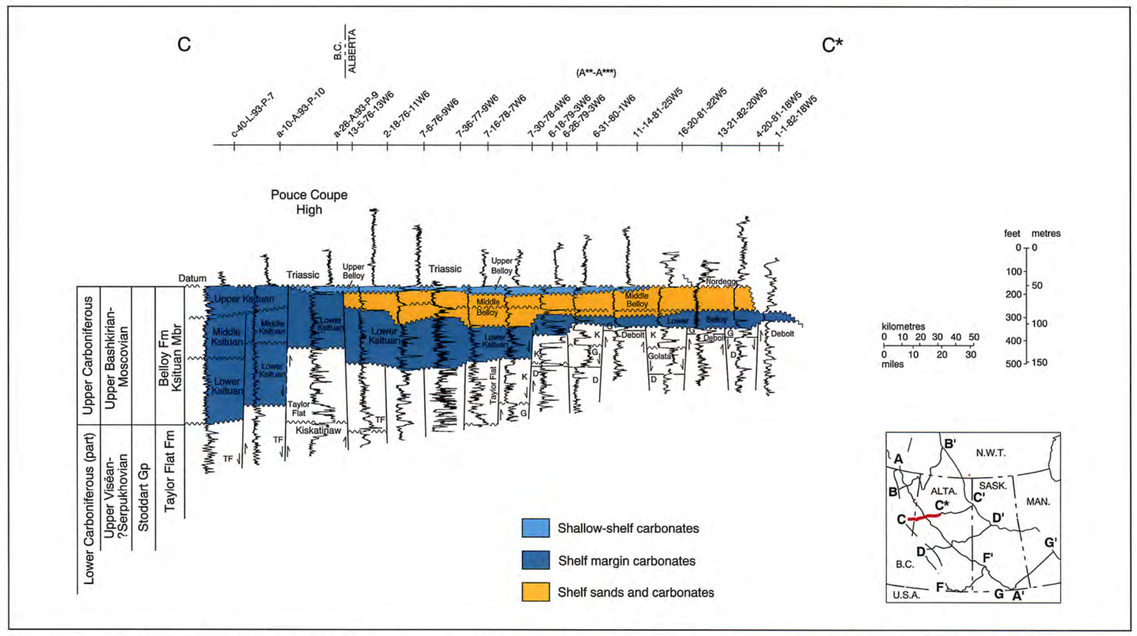


Figure 15.12 Cross section C-C*, highlighting Upper Carboniferous and Permian strata in the Peace River Embayment. For ages of Permian units refer to Figure 15.2.

In the outcrop belt and subsurface of northeastern British Columbia, in the Liard Basin area, the Kindle and Fantasque formations increase from a feather edge to as much as 425 m, in a northwestward direction. The Fantasque, up to 175 m thick, is definitely Permian, but it is uncertain how much of the underlying Kindle is Permian in age. In this region the Kindle also includes units that are dated as Serpukhovian to Moscovian, rendering analysis of isopachs almost meaningless until consistent age relations and well log picks can be made.

Throughout most of the Peace River Embayment, the Belloy Formation typically ranges from 10 to 100 m thick, but thickens to a maximum of 280 m in the Hudson Hope Low (Fig. 15.14; Barclay et al., 1990). Local thickness variations are in places related to fault-bounded structures, and the shapes of some graben complexes are only roughly outlined (Fig. 15.1) because the tectonic setting during the Permian was relatively quiet, with reduced rates of subsidence compared to the Carboniferous, when subsidence rates and tectonic activity were higher. However, many of the

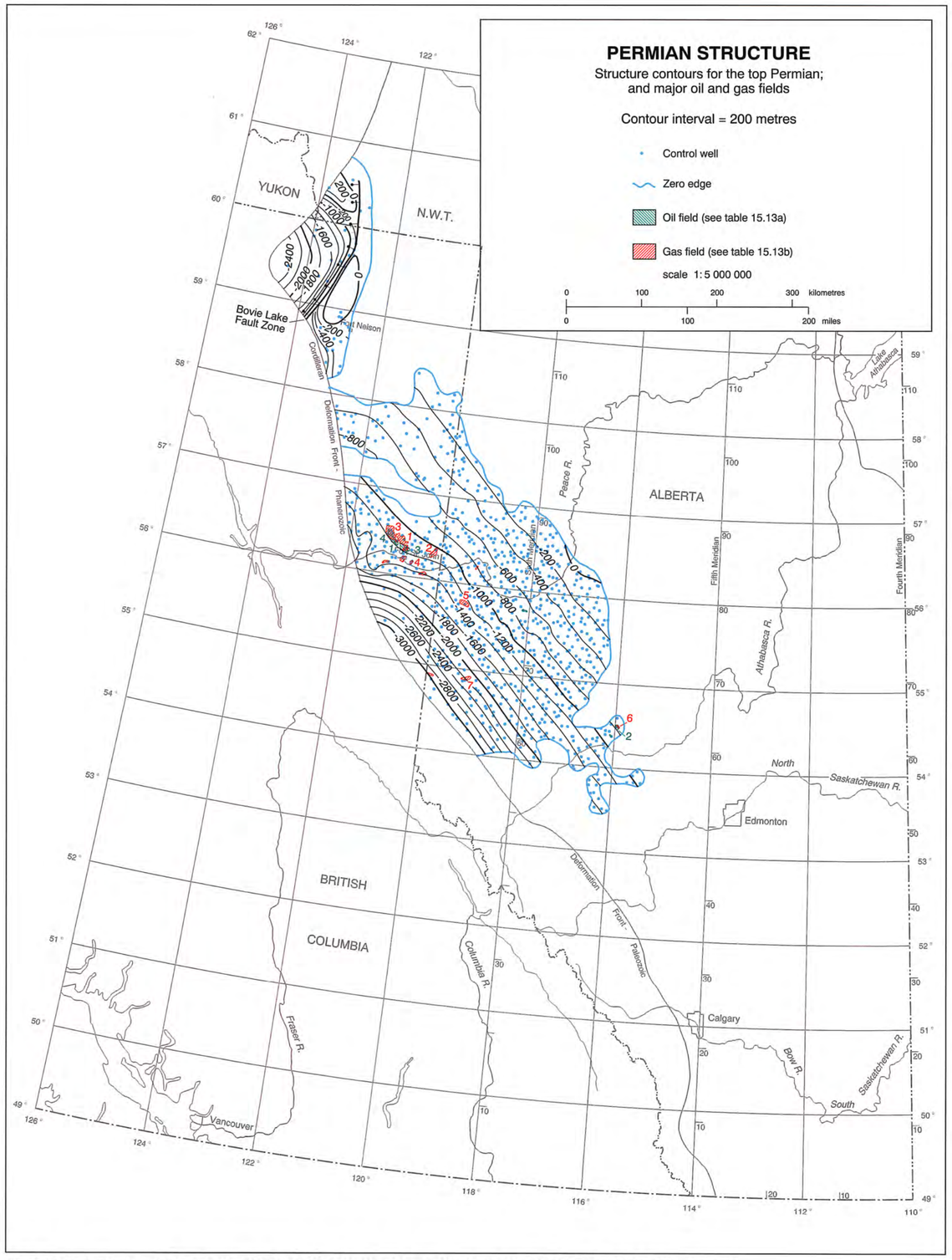


Figure 15.13 Structure contour map on top of the subsurface Permian. The map also shows prominent oil and gas fields in Permian strata.

Table 15.13a

Oil Production from the Permian

Oil production from the Permian is relatively minor in amount, and occurs primarily in the Peace River Block of northeast B.C. and scattered through west-central Alberta. There are only eleven Permian oil fields, and of these, only four have Initial Established Recoverable Oil Reserves of over 1 x 10^6m^3 (6 MMBbls). Data on these four largest Permian oil fields are shown in Table 1.

Cumulative production data for Alberta and British Columbia are updated to the end of 1990.

Table 1 - Largest Permian Oil Fields (in units of 10^6m^3)

No.	Field	Formation	No. of Pools	Initial Established Marketable Reserves	In-place Volume	Cumulative Production	Discovery Year
1	Eagle West	Belloy	1	7.3	23.5	4.9	1976
2	Virginia Hills	Belloy	2	3.8	10.3	3.2	1961
3	Eagle	Belloy-Kiskt	1	1.8	8.6	1.1	1972
4	Stoddart West	Belloy	3	1.3	8.6	1.0	1970

The Eagle West, Eagle and Stoddart West fields in B.C. are found in structural-stratigraphic traps related to facies changes adjacent to fault-bounded structures in the Peace River Embayment. The Virginia Hills field in Alberta occurs in a Belloy sandstone outlier south of the Peace River Embayment. All Permian oil production contains light to medium gravity oil.

Total recoverable oil reserves in the Permian are estimated at 14.7 x 10^6m^3, of which 10.4 x 10^6m^3 (i.e. 71%) have already been produced. Initial Established In-Place Volume of Permian oil reserves totals 55.5 x 10^6m^3. There are 22 Permian oil pools in 11 fields, with an average 668 x 10^3m^3 recoverable oil reserves/pool. Table 2 lists the distribution of Permian oil reserves according to In-Place Pool Size.

Table 2 - Size Distribution of Permian 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	9	0.43	0.19
1.0 to 10	3	3.15	2.07
10.0 to 100	2	11.08	8.14
over 100	-	-	-
Total	22	14.69 x 10^6m^3	10.42 x 10^6m^3

Table 15.13b

Gas Production from the Permian

Gas production from the Permian is primarily derived from the Belloy Formation in the Peace River Block area of northeast B.C., as well as from scattered Belloy fields in west-central Alberta.

There are seven Permian gas fields with Initial Established Marketable Gas Reserves of over 1000 x 10^6m^3 (35 BCF). These seven largest Permian 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 - Seven Largest Permian Gas Fields (in units of 10^6m^3)

No.	Field	Formation	No. of Pools	Initial Established Marketable Reserves	In-place Volume	Cumulative Production	Discovery Year
1	Stoddart	Belloy	2	8,252	9,170	7,208	1957
2	Boundary Lake	Belloy	9	4,027	4,474	8	1958
3	Stoddart West	Belloy	12	2,851	3,189	1,633	1962
4	Fort St John SE	Belloy	1	2,383	2,536	2,144	1952
5	Progress	Belloy	3	1,194	1,677	0	1980
6	Virginia Hills	Belloy	1	1,177	1,910	995	1961
7	Wapiti	Belloy	6	1,124	1,757	0	1956

The first four of these Permian gas fields occur in structural-stratigraphic traps in the Peace River Block of northeast B.C. and the last three in west-central Alberta.

Total recoverable gas reserves in the Permian are estimated at 73.0 x 10^9m^3, of which 20.2 x 10^9m^3 have already been produced. Initial Established In-Place Volume of Permian gas reserves totals 95.2 x 10^9m^3. There are a total of 218 Permian gas pools, with an average 334 x 10^6m^3 recoverable gas reserves/pool. Table 2 lists the distribution of Permian gas reserves according to In-Place Pool Size.

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

In-Place Pool Size Class	No. of Pools	Recoverable Reserves	Cumulative Production
1.0 to 10	4	15	10
10 to 100	67	2,481	502
100 to 1000	136	34,033	6,017
1000 to 10000	10	18,467	13,690
over 10000	1	18,000	0
Total	218	72,997 x 10^6m^3	20,220 x 10^6m^3

thickest sections of the Belloy in various graben complexes are related to preferential preservation of the Upper Carboniferous Ksituan Member. If the Ksituan Member were removed from the Belloy isopach, the Permian isopach map would reflect a less variable pattern. This indicates the blanket-like filling character of the younger Belloy units in the Peace River Embayment region. On cross sections (Figs. 15.10, 15.11, and 15.12), block faults that disrupt the Carboniferous Stoddart Group and Ksituan Member rarely appear to cause offset or differential synsedimentary subsidence of Permian Belloy Formation units.

Petroleum and Mineral Resources

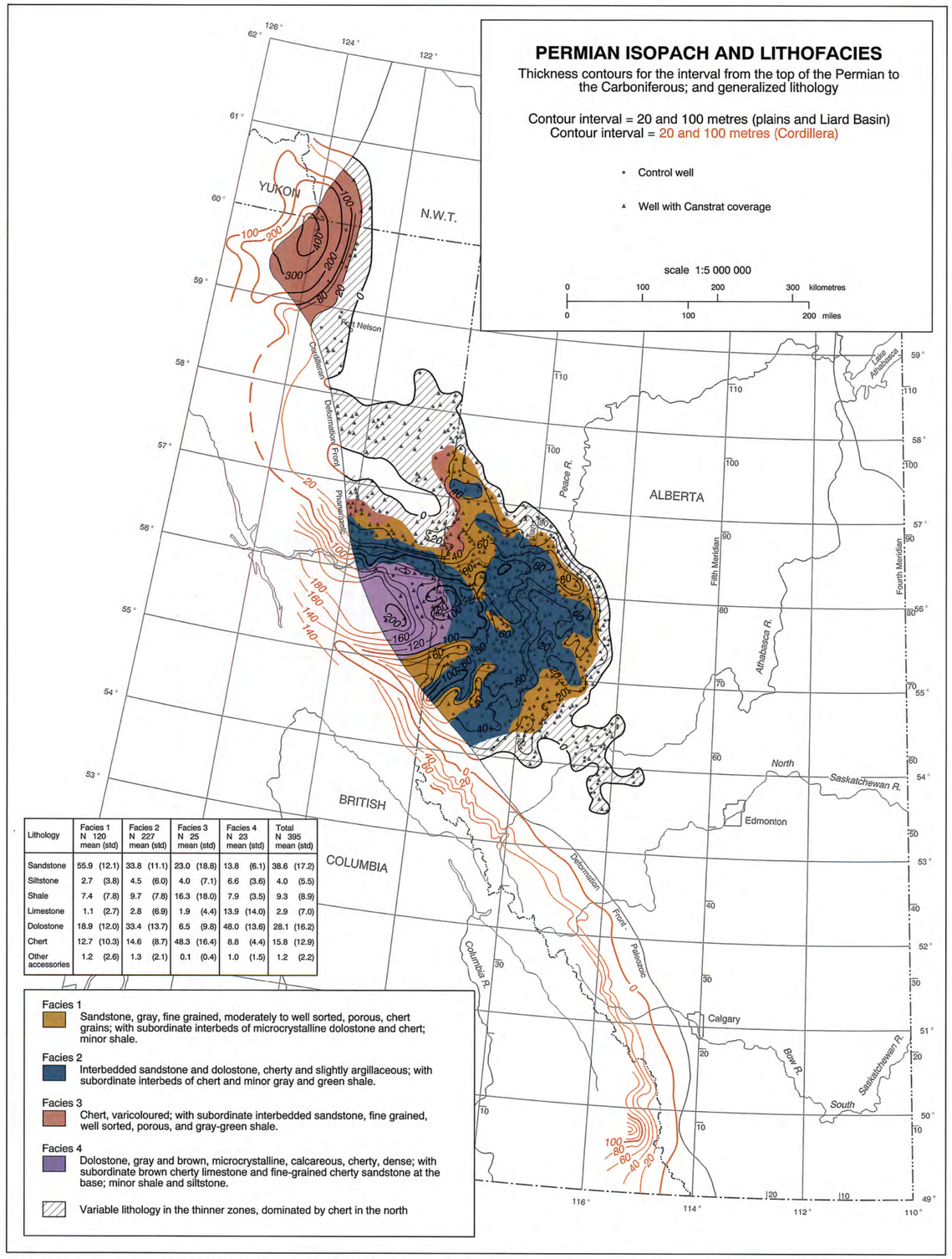
Oil and gas resources are generally restricted to structural, stratigraphic, and erosional edge traps that occur where rocks of the Belloy Formation are involved in fault-bounded structures in the Peace River Embayment. Proven conventional oil reserves are 55 million cubic metres, distributed in 11 fields with 22 pools (Fig. 15.13a), and account for 1.7 percent of the total for the Western Canada Sedimentary Basin (Podruski et al., 1988). Forty-seven gas fields with 218 pools include 30 billion cubic metres of marketable gas, representing 0.8 percent of Western Canada's gas reserves (Barclay et al., *in press*). The locations of major fields are indicated on Figure 15.13. The abundant phosphate in outcropping Permian rocks in the eastern Cordillera does not appear to be of immediate economic value.

Summary

Permian strata of the Western Canada Sedimentary Basin consist mainly of phosphatic marine siliciclastics and silty to sandy carbonates that are generally thin but laterally persistent throughout the region. They were deposited along the western margin of the ancestral North American plate in the Ishbel Trough and in the Peace River Embayment, a downwarped and downfaulted region of the Interior Platform that opened westward into the Ishbel Trough. The Permian succession can be subdivided into three transgressive-regressive sequences. An underlying fourth sequence is recognized in a new Upper Carboniferous unit designated the Ksituan Member of the Belloy Formation. These sequences generally represent retrogradational to progradational units separated by regional unconformities or their correlative conformities. The close juxtaposition of these various unconformities, owing to condensed sequences between them and erosion beneath them, make internal correlations very difficult. This is particularly evident from the subsurface cross sections (Figs. 15.10 - 15.12) but is also a problem in outcrop studies. Recent conodont research is proving invaluable in the refinement of some of these correlations. Increased resolution of the various units within the Belloy Formation could lead to the interpretation of previously unrecognized subtle stratigraphic traps and thus increase the resource potential of the Permian.

Acknowledgements

We wish to thank Atlas reviewers John Utting and Peter Aukes for their constructive and helpful comments. An earlier version of the manuscript was reviewed by Alan McGugan and his advise was very much appreciated. Some new correlations resulted from the M.Sc. research of Pauline Chung at the University of Calgary and her contributions are gratefully acknowledged. This Atlas chapter would not have been possible without the long hours dedicated by Grant Mossop and Irina Shetsen to database management and map generation, to coordination and communications by Mika Madunicky, and by the rest of the Atlas team to drafting and printing. This chapter was partly funded by a Natural Sciences and Engineering Research Council of Canada research grant to Charles Henderson.



Lithology	Facies 1 N 120 mean (std)	Facies 2 N 227 mean (std)	Facies 3 N 25 mean (std)	Facies 4 N 23 mean (std)	Total N 395 mean (std)
Sandstone	55.9 (12.1)	33.8 (11.1)	23.0 (18.8)	13.8 (6.1)	38.6 (17.2)
Siltstone	2.7 (3.8)	4.5 (6.0)	4.0 (7.1)	6.6 (3.6)	4.0 (5.5)
Shale	7.4 (7.8)	9.7 (7.8)	16.3 (18.0)	7.9 (3.5)	9.3 (8.9)
Limestone	1.1 (2.7)	2.8 (6.9)	1.9 (4.4)	13.9 (14.0)	2.9 (7.0)
Dolostone	18.9 (12.0)	33.4 (13.7)	6.5 (9.8)	48.0 (13.6)	28.1 (16.2)
Chert	12.7 (10.3)	14.6 (8.7)	48.3 (16.4)	8.8 (4.4)	15.8 (12.9)
Other accessories	1.2 (2.6)	1.3 (2.1)	0.1 (0.4)	1.0 (1.5)	1.2 (2.2)

Figure 15.14 Isopach and generalized facies distribution map for the total Permian succession (may include Upper Carboniferous units in the Peace River Embayment and Liard Basin).

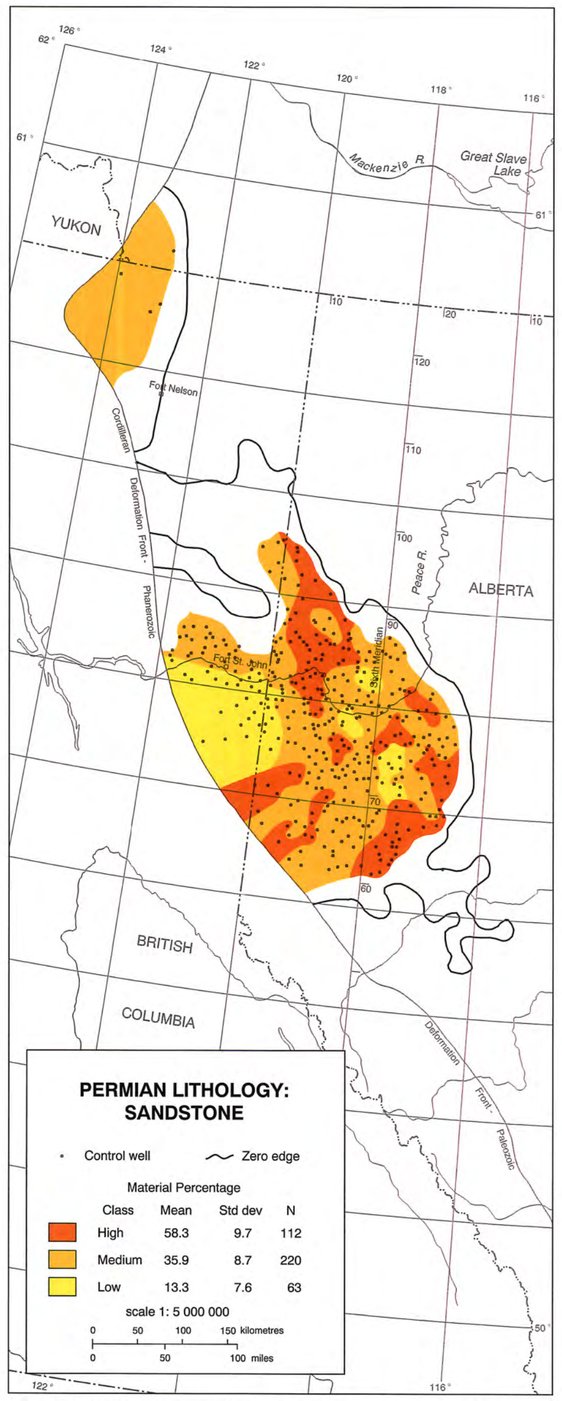


Figure 15.15 Distribution of Permian sandstone. Regions shown as "High" sandstone are concentrated around the margin of the Peace River Embayment.

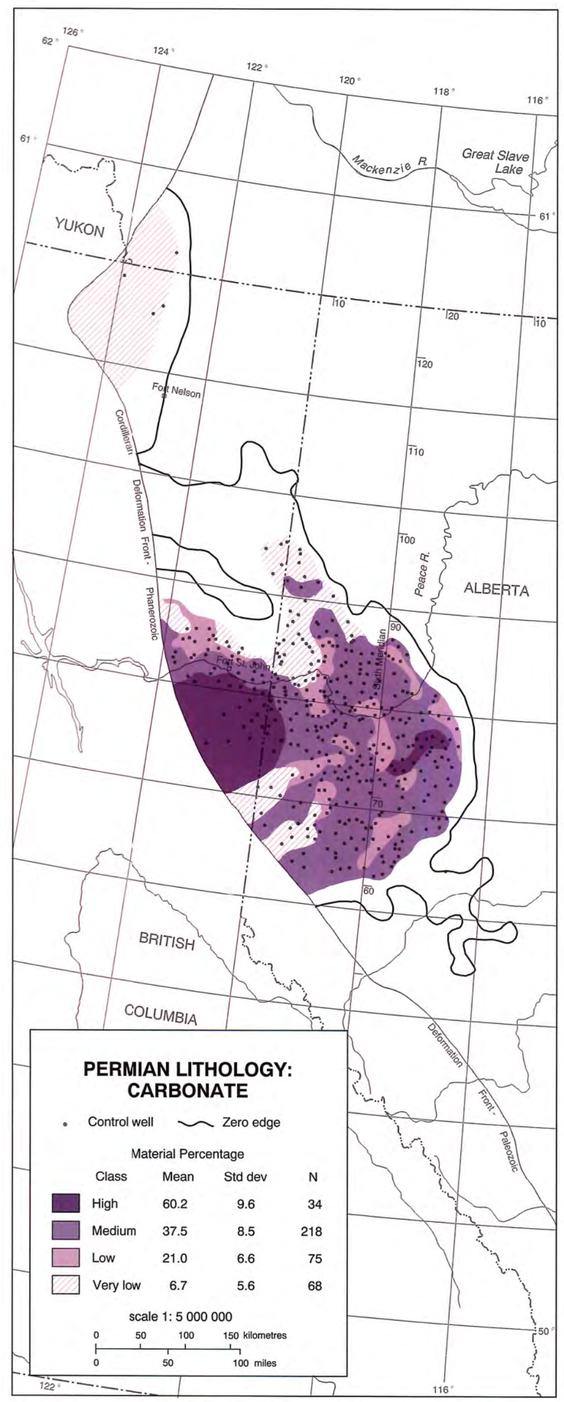


Figure 15.16 Distribution of Permian (and subjacent Upper Carboniferous) carbonate. Regions shown as "High" carbonate are so located because they include a large proportion of the Ksituan Member within the Belloy Formation, especially for the western portion of the map.

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