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Introduction

The Upper Givetian to Lower Frasnian Beaverhill Lake Group (Fig. 11.1 and 11.2) covers a major part of the Western Canada Sedimentary Basin, attaining a maximum thickness of approximately 240 m (Fig. 11.3). This stratigraphic interval is bounded below by the post-Elk Point unconformity (Fig. 11.2) and above, conformably to disconformably, by the Woodbend Group. The succession can be subdivided into two stratigraphic phases: a transgressive "reefal" phase (Fig. 11.4), dominated by restricted- to open-marine carbonates of the Slave Point and Swan Hills formations (Fig. 11.2), and a regressive "basin-fill" phase (Fig. 11.5), dominated by shales and argillaceous carbonates of the Waterways Formation (Fig. 11.2). Selected reference wells (Fig. 11.6) illustrate the regional stratigraphy and lithological character of the strata that comprise the Beaverhill Lake Group and its Manitoba Group correlatives in Saskatchewan and Manitoba.

The banks and reefs of the transgressive phase are host to significant hydrocarbon reserves, and remain a focus of exploration activity, with recent discoveries at the Caroline Field (Tp 34, R 4 W6M) in southern Alberta and at Hamburg (Tp 96, R 11 W6M) in northern Alberta (Fig. 11.3).

Previous Work

The previous atlas (Committee on the Slave Point and Beaverhill Lake formations, 1964) set out the regional distribution of Beaverhill Lake and equivalent strata. The subsurface stratigraphy has since become much better known because of the increased drilling activity associated with this economically important depositional sequence.

The sequence stratigraphy of the Beaverhill Lake Group is discussed by Moore (1989) for Western Canada and by Stoakes (1988) for west-central Alberta. The biostratigraphy is outlined by Braun et al. (1988) and Braun and Mathison (1986). Fischbuch (1968) presents a detailed geological description and stratigraphic framework for the Swan Hills Reef Complex, and individual reefs are discussed in Wendte and Stoakes (1982) and Kaufman and Meyers (1989). A depositional model for the Watt Mountain, Fort Vermilion and Swan Hills formations in the Swan Hills area of central Alberta is provided by Jansa and Fischbuch (1974). Craig (1987) provides a regional depositional model for the Slave Point fringing reef complex flanking the Peace River Arch. Individual reefs are described by Dunham et al. (1983), Gosselin et al. (1989) and Tooth and Davies (1989).

Beaverhill Lake strata, in conjunction with the Elk Point Group, are described for the northern region by Meijer Drees (1990), Williams (1981, 1984), Griffin (1967) and Norris (1965). The Clarke Lake Field is described in detail by Gray and Kassube (1963). Equivalent strata in Saskatchewan and Manitoba are dealt with by Lane (1964) and Dunn (1982 a,b). The stratigraphic significance of the Watt Mountain Formation and its relation to the Beaverhill Lake Group is discussed by Meijer Drees (1988) and Williams (1984). Braun and Mathison (1986) and Williams (1984) review the stratigraphic relation between the Dawson Bay Formation and the Beaverhill Lake Group.

Geological Framework and Synthesis

The post-Elk Point relative sea-level rise allowed seas to return to the intracratonic Elk Point Basin, transgressing the older basin margins. The marine incursion deposited open-marine carbonates that formed an extensive carbonate platform. Continued relative sea-level rise segregated the interior basin into several bank complexes and intraplatform "basins" (Fig. 11.1). A carbonate bank, the Hay River Bank, developed in the northern part of the basin with the seaward margin roughly coincident with the underlying Elk Point barrier, forming a continuous "barrier reef" known as the Presqu'île Barrier. Along the western margin of the basin a fringing reef complex developed flanking the Peace River Arch, and the Swan Hills Complex developed marginal to the West Alberta Ridge (Fig. 11.1).

Following the transgressive phase, westward- and northward-prograding shale-carbonate clinothem cycles of the regressive phase infilled the Waterways Basin and downlapped the reef complexes. These clinothems correlate with shallowing-upward carbonate-evaporite cycles that were stacked aggradationally in the Souris River Shelf (Fig. 11.1).

The basin is presumed to have extended farther eastward but is not preserved because of post-Devonian tectonics and erosion. The basin also extended farther south into Montana and North and South Dakota.

Tectonic History

The Peace River Arch and West Alberta Ridge (Fig. 11.1) were paleotopographic high features that strongly influenced the Beaverhill Lake stratigraphy and depositional (facies) pattern. Their origin predates the Middle Devonian (O'Connell et al., 1990) and, except for minor tectonic activity associated with the Peace River Arch, they remained relatively inactive during Late Givetian-Early Frasnian time.

Normal block faulting (post-Elk Point, pre-Beaverhill Lake) was a result of possible readjustment of the Peace River Arch. The evidence includes local erosion of the Elk Point surface (Utikuma area, Tp 82, R 10 W5M), local dissolution of Elk Point salts (Kidney area, Tp 91, R 6 W5M) and the presence of coarse, arkosic, clastic sediment. Arkosic clastic debris was shed off the arch during the post-Elk Point hiatus, as a result of tectonic uplift and erosion. The sediment was reworked and deposited as a fluvial-deltaic complex (Gilwood Member; Fig. 11.2) during the ensuing relative sea-level rise. Arkosic, clastic sediment is also present within the Waterways Formation in the Girouxville area (Tp 78, R 21 W5M) along the southern flank of the arch, indicating a later tectonic pulse.

Givetian-Frasnian tectonic activity associated with the West Alberta Ridge and Tathlina High (an Elk Point paleotopographic feature in southern N.W.T.) is not documented or strongly exhibited, but may exist, as the tectonic history of these two features is thought to be similar to that of the Peace River Arch.

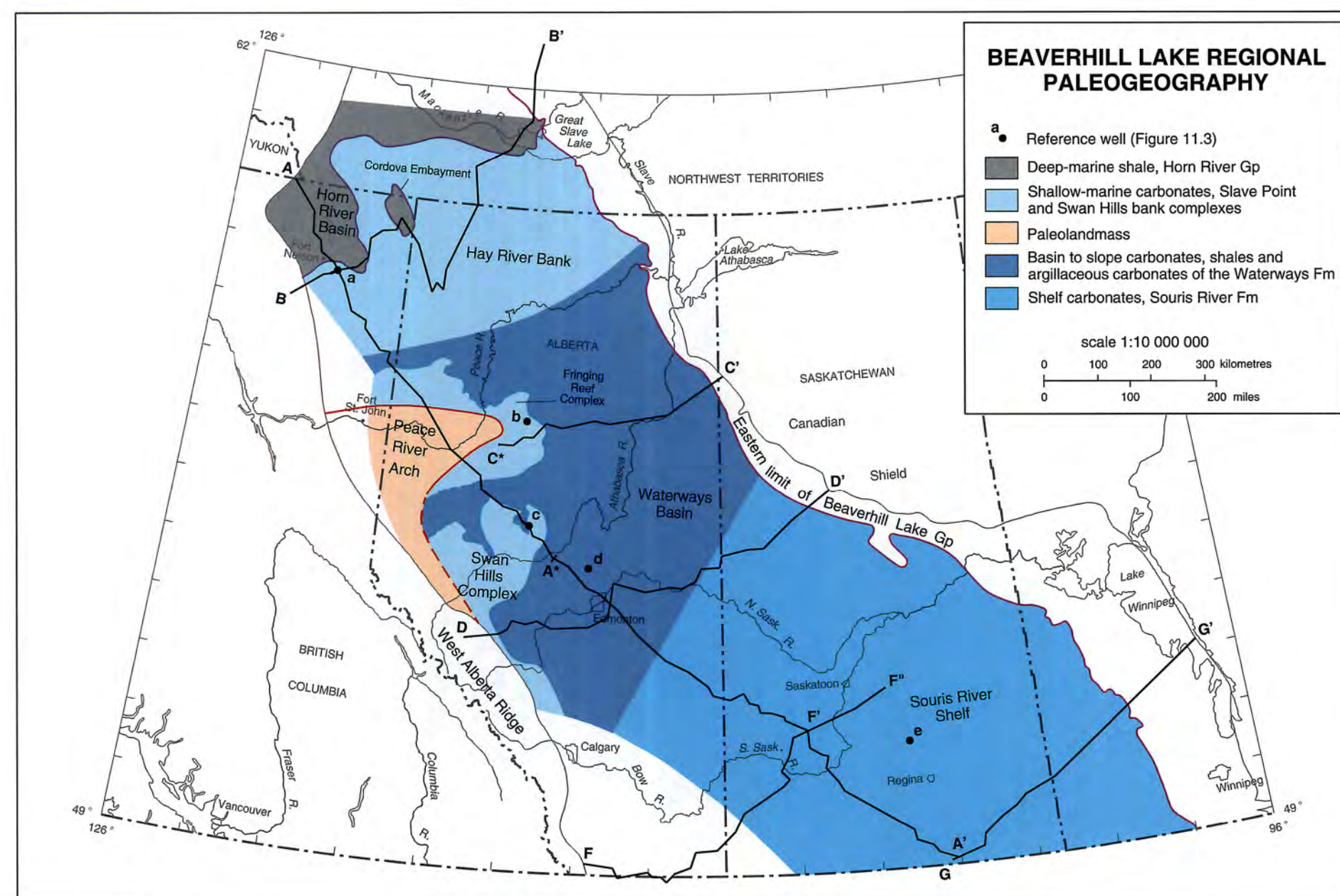


Figure 11.1 Index and regional paleogeography map, identifying six paleogeographic areas, the location of the master and discretionary cross sections and the reference wells.

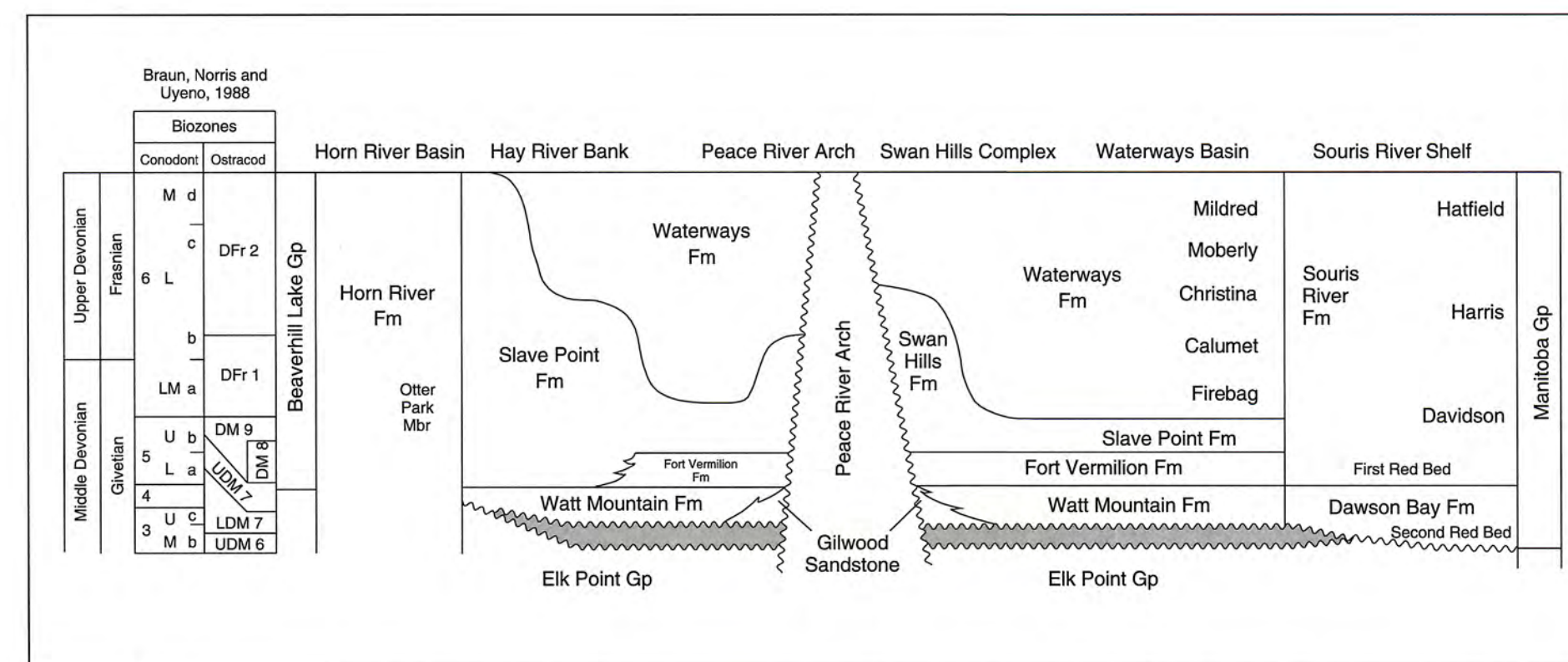


Figure 11.2 Table of formations for each of the six defined paleogeographic areas, presented in a northwest to southeast orientation. The biostratigraphic zonation of Braun et al. (1988) is illustrated.

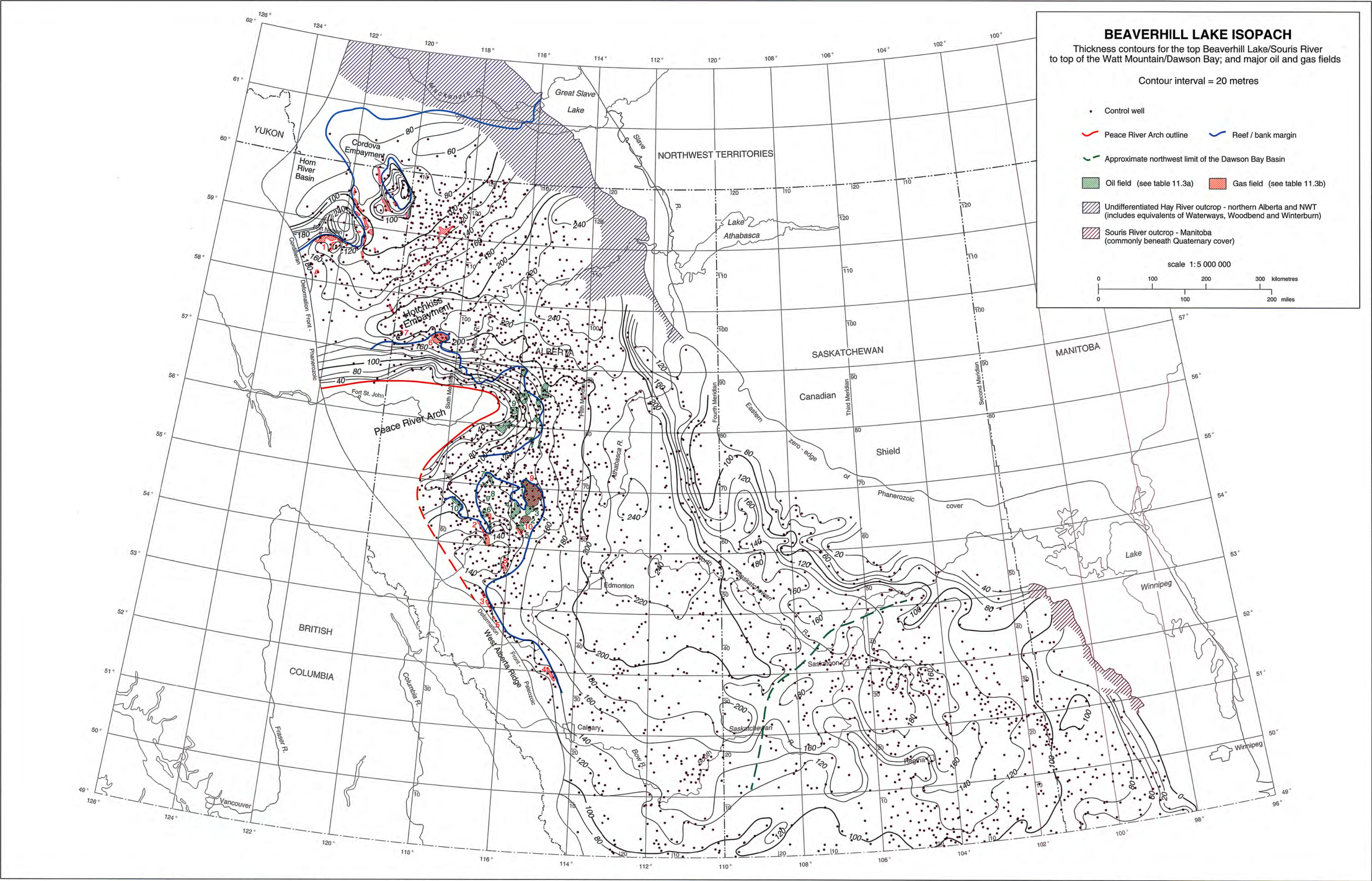


Figure 11.3 Beaverhill Lake isopach map. The isopach interval does not include the Watt Mountain Formation because of database limitations; however, the Watt Mountain is less than 20 m thick and does not significantly affect this map. Neither does it include the Dawson Bay Formation, which is mapped separately (Fig. 11.14). The Beaverhill Lake Group attains a maximum thickness of 240 m in east-central and northeastern Alberta, within the Waterways Basin, an intra-platform basin. The strata thin eastward as a result of erosion. The group also thins westward as it onlaps the emergent Peace River Arch and West Alberta Ridge. The bank margin of the transgressive sequence is outlined. A depositional thickening, the Hotchkiss Embayment, separates the Peace River Arch Fringing Reef Complex from the Hay River Bank. Isopach thickening within the basinal area west of the Hay River Bank margin, and within the Cordova Embayment, occurs as a result of an inability to differentiate between Beaverhill Lake and older basinal strata. Hydrocarbon accumulations occur along the bank margins and within the bank complexes.

Table 11.3a

Oil Production from the Beaverhill Lake Group

The Beaverhill Lake Group has been a major source of oil production in western Canada since 1956, primarily from the Swan Hills reefs of central Alberta. Additional oil production occurs in the Slave Point of north-central Alberta and from scattered small pools in northwest Alberta. There is no Beaverhill Lake oil production in British Columbia or in Saskatchewan.

There are fifteen Beaverhill Lake oil fields with Initial Established Recoverable Oil Reserves of over 1×10^6 m³ (6 MMBbls). The ten largest Beaverhill Lake oil fields, listed in order of Initial Established Recoverable Oil Reserves, are shown in Table 1. Cumulative production data include to the end of 1990.

Table 1. Ten Largest Beaverhill Lake Oil Fields (in units of 10⁶m³)

No.	Field	Formation	No. of Pools	Initial Established Marketable Reserves	In-place Volume	Cumulative Production	Discovery Year
1	Swan Hills	Swan Hills	5	148.1	389.1	112.6	1957
2	Judy Creek	Swan Hills	4	75.7	169.4	64.3	1959
3	Swan Hills S	Swan Hills	1	67.5	134.8	56.2	1959
4	Virginia Hills	Swan Hills	4	28.3	46.5	22.2	1956
5	Canson Creek	N Swan Hills	1	27.5	60.2	23.2	1958
6	Kaybob	Beaverhill L.	2	20.1	45.6	17.0	1957
7	Stripe Lake	Beaverhill L.	2	12.4	31.2	9.0	1962
8	Goose River	Beaverhill L.	2	8.9	21.2	6.7	1963
9	Slave	Slave Point	16	3.5	13.1	1.5	1980
10	Ante Creek	Swan Hills	2	3.4	7.6	2.6	1962

Nine of these largest Beaverhill Lake oil fields occur in the Swan Hills Member reefs of central Alberta. Other major oil fields such as Slave, Red Earth, Gift, Evi and Sawm Lake are found in the Slave Point of north-central Alberta and result from drape over pre-Slave Point structures. Recent Beaverhill Lake oil discoveries have included Gift, Slave and Sawm Lake. All Beaverhill Lake oil fields contain light to medium gravity oil.

Total recoverable oil reserves in the Beaverhill Lake are estimated at 409×10^6 m³, of which 322×10^6 m³ have already been produced. Initial Established In-Place Volume of Beaverhill Lake oil reserves totals 1052×10^6 m³. There are 165 Beaverhill Lake oil pools, with average recoverable oil reserves of 2479×10^3 m³/pool. Table 2 lists the distribution of Beaverhill Lake oil reserves according to In-Place Pool Size.

Table 2. Size Distribution of Beaverhill Lake Oil Pools (in units of 10⁶m³)

In-Place Pool Size Class	No. of Pools	Recoverable Reserves	Cumulative Production
less than 0.1	29	0.17	0.06
0.1 to 1	101	3.41	10.6
1.0 to 10	23	15.81	9.58
10.0 to 100	9	148.82	115.15
over 100	3	240.86	196.70
Total	165	409.07×10^6 m ³	322.56×10^6 m ³

Table 11.3b

Gas Production from the Beaverhill Lake Group

Gas production from the Beaverhill Lake Group is primarily derived from three sources, namely reefs in northeastern British Columbia and northwestern Alberta, the foothills of south-central Alberta, and as solution gas in the Swan Hills oil fields in central Alberta.

There are 30 Beaverhill Lake gas fields with Initial Established Marketable Gas Reserves of over 1000 × 10⁶ m³ (35 BCF). The ten largest Beaverhill Lake gas fields, listed in order of Initial Established Marketable gas reserves, are shown in Table 1. Cumulative production data include figures released to the end of 1990.

No.	Field	Formation	No. of Pools	Initial Established Marketable Reserves	In-place Volume	Cumulative Production	Discovery Year
1	Clarke Lake	Slave Point	3	42,442	62,433	40,530	1956
2	Kaybob South	Beaverhill L	3	36,589	104,754	18,798	1961
3	Hanlan	Beaverhill L	2	25,479	42,465	7,318	1974
4	Caroline	Beaverhill L	1	21,274	61,958	132	1986
5	Blackstone	Beaverhill L	1	13,600	22,666	2,463	1979
6	Cranberry	Slave Point	4	11,452	16,868	4,127	1974
7	Hamburg	Slave Point	4	11,227	13,932	1,380	1983
8	Rosevear	Beaverhill L	2	9,600	13,190	4,664	1971
9	Swan Hills	SHM solution	2	9,011	36,601	8,521	1957
10	Judy Creek	SHM solution	3	8,927	48,399	7,643	1959

The largest field, Clarke Lake, occurs along the Slave Point reef edge flanking the Horn River Basin in northeastern British Columbia. The next seven fields occur in stratigraphic traps at the up-dip edge of Swan Hills-Slave Point reefs. The most recent major discovery of Beaverhill Lake gas reserves was in the Caroline area in 1985.

Total recoverable gas reserves in the Beaverhill Lake are estimated at 262.4 × 10⁶ m³, of which 111.2 × 10⁶ m³ have already been produced. Initial Established In-Place Volume of Beaverhill Lake gas reserves totals 564.2 × 10⁶ m³. There are a total of 330 Beaverhill Lake gas pools, with an average 795 × 10³ m³ recoverable gas reserves/pool. Table 2 lists the distribution of Beaverhill Lake gas reserves according to In-Place Pool Size.

In-Place Pool Size Class	No. of Pools	Recoverable Reserves	Cumulative Production
1.0 to 10	78	328	3
10 to 100	136	2,292	74
100 to 1000	73	14,658	2,837
1000 to 10000	31	51,940	23,904
over 10000	12	193,215	84,406
Total	330	262,433 × 10 ⁶ m ³	111,224 × 10 ⁶ m ³

Several stages of post-Beaverhill Lake salt solution in southern Saskatchewan overprinted earlier dissolution events, creating complex stratigraphic and structural relations. The isopach map (Fig. 11.3) depicts the solution-influenced geometries in only a very generalized way. Post-Beaverhill Lake solution removal of Elk Point evaporites along the subcrop edge near the Alberta-Saskatchewan border is best reflected in the Beaverhill Lake structure map (Fig. 11.7).

Stratigraphy

Stratigraphic Nomenclature

The Geological Staff of Imperial Oil Ltd. (1950) originally defined the Beaverhill Lake Formation in the Edmonton area, in the Anglo-Canadian Beaverhill Lake No. 2, 11-11-50-17 W4M well. It was later equated to the Waterways Formation as defined by Crickmay (1957) in northeastern Alberta. Leavitt and Fischbuch (1968) raised the Beaverhill Lake to group status and defined the group to include the Fort Vermilion, Swan Hills and Waterways formations in the Swan Hills area of central Alberta (Fig. 11.2, Swan Hills Complex). The Givetian-Frasnian boundary, as defined by the base of the lower *asymmetricus* conodont Zone, occurs within the lower portion of the Waterways Formation (Braun et al., 1988). The reference wells (Fig. 11.6) illustrate the variation in regional stratigraphy and nomenclature across the basin.

Reefal carbonate complexes in the Swan Hills area are known as the Swan Hills Formation or as the Slave Point Formation fringing the Peace River Arch (Fig. 11.2). In northeastern British Columbia and southern Northwest Territories the Slave Point Formation comprises open-marine shelf carbonates that make up the upper portion of an extensive carbonate bank complex (Williams, 1981; Griffin, 1967; Norris, 1965). Fort Vermilion age-equivalent strata are those included within the Slave Point Formation.

The Otter Park Member of the Horn River Formation in north-eastern British Columbia (Griffin, 1967) and the Horn River Formation in southern Northwest Territories (Norris, 1965) consist of dark shales that are in part equivalent to the Slave Point Formation (Fig. 11.2). In the Norman Wells area of the Northwest Territories, Givetian platform carbonates are known as the Kee Scarp Reef of the Ramparts Formation and are the equivalent of the Slave Point Formation (Braun et al., 1988). The Flume Formation of the southern Canadian Rockies is considered equivalent to the upper part of the Swan Hills Formation.

The Waterways Formation in the northern part of the basin is subdivided into five lithostratigraphic members (Crickmay, 1957): Mildred, Moberly, Christina, Calmut (Calumet) and Firebag (e.g., Fig. 11.6d). Waterways stratigraphy is discussed in the Swan Hills area by Sheasby (1971) and north-central Alberta by Keith (1990). The Beaverhill Lake Group is known as the Manitoba Group in Saskatchewan and Manitoba and consists of the Dawson Bay and Souris River formations (Figs. 11.2 and 11.6).

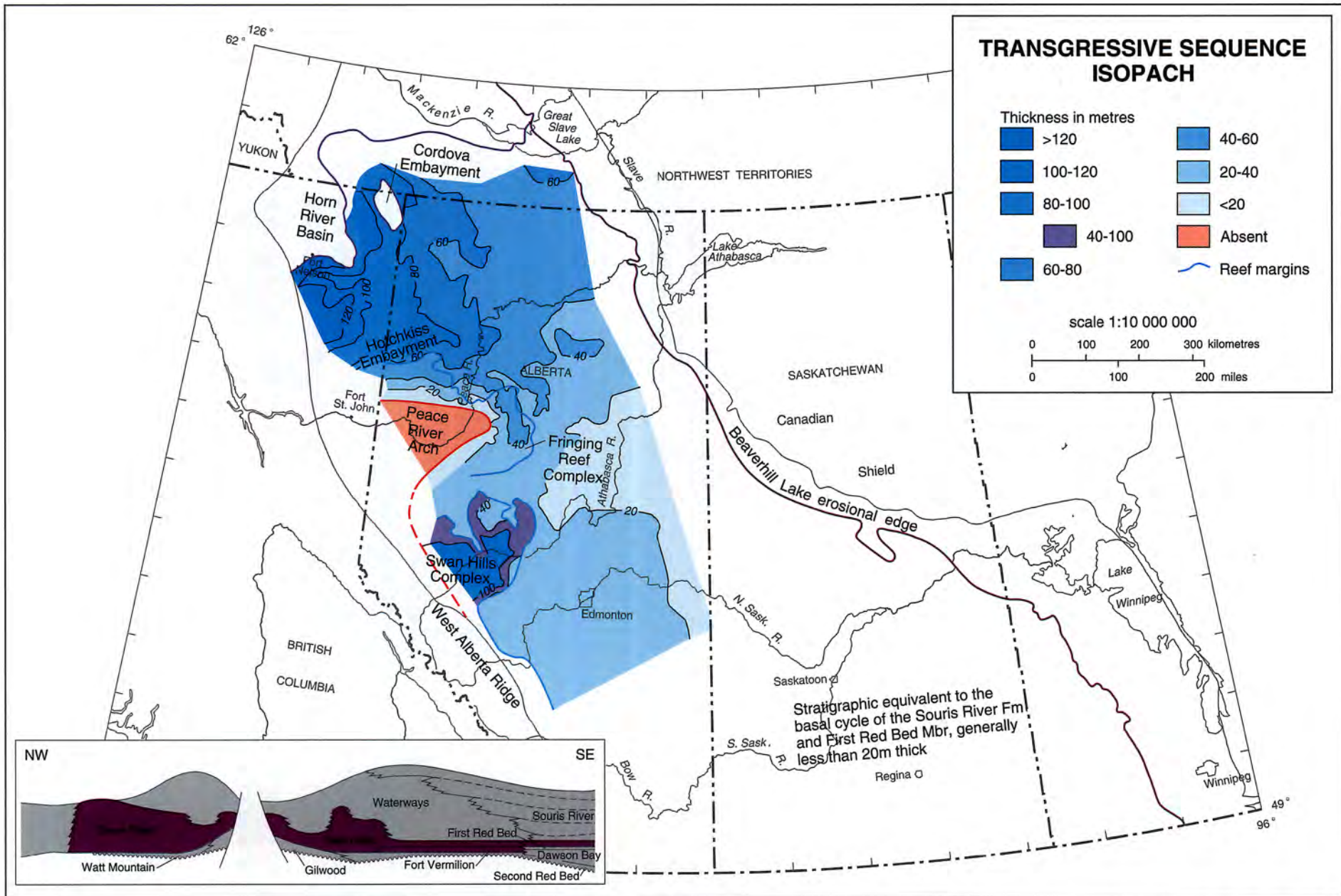


Figure 11.4 Transgressive phase isopach map. The transgressive phase exhibits general southeastward thinning from the bank margin of the Hay River Bank. Shallow-marine carbonates overlapped the emergent Peace River Arch. In the Swan Hills Complex the bank developed aggradationally and thickened to over 100 m. In southern Saskatchewan the transgressive phase thins to less than 20 m and forms the lower portion of the Souris River Formation (not shown). The Dawson Bay Formation and its equivalent, the Watt Mountain Formation, are not included because of database limitations in differentiating the Watt Mountain Formation (see also Figure 11.14).

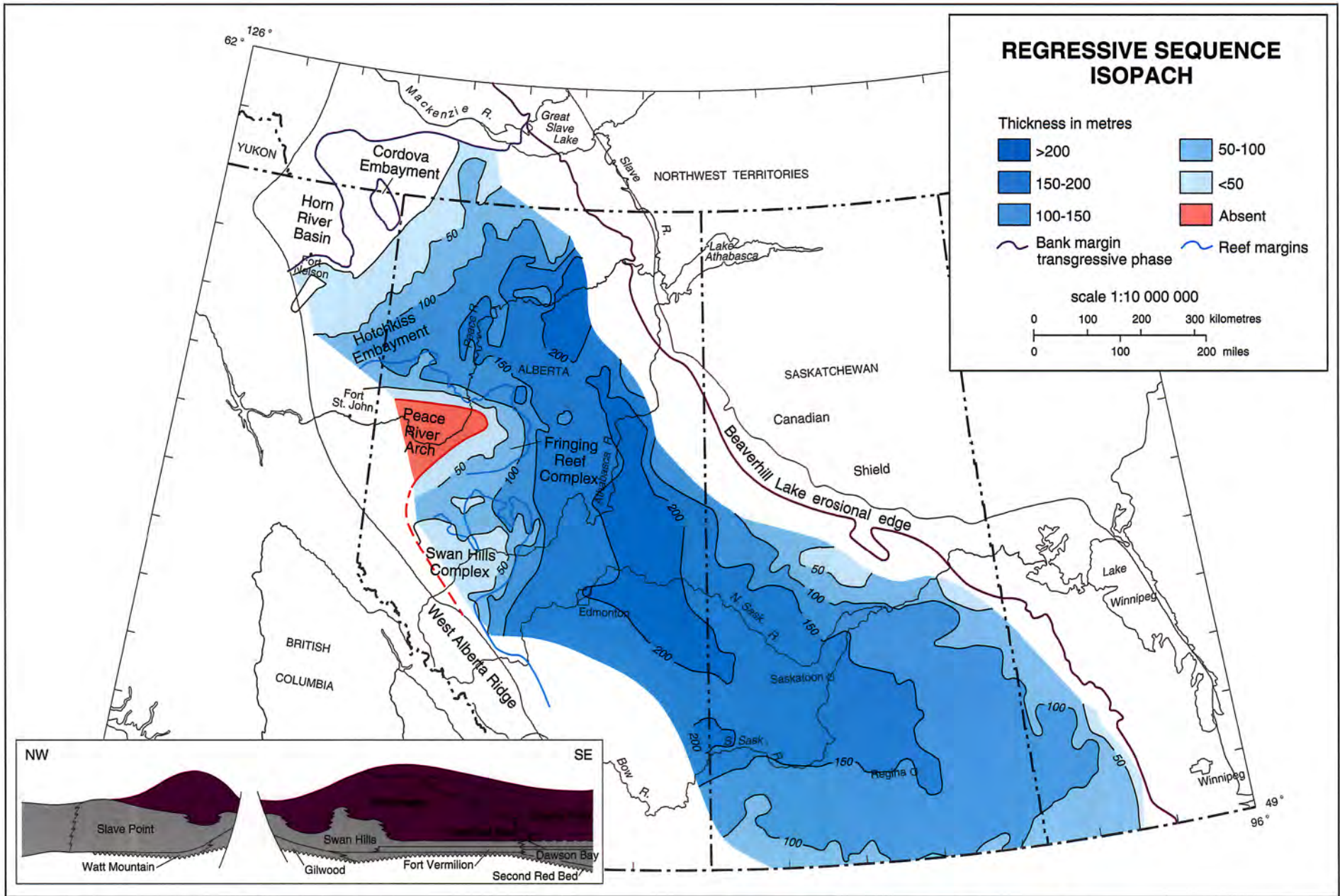


Figure 11.5 Regressive phase isopach map. The regressive phase attains a thickness of more than 200 m in east-central and northeastern Alberta, representing the depocentre of the Waterways Basin. Depositionally it thins northward and westward as it downlaps the bank complexes of the transgressive phase and the Peace River Arch. Southward and eastward, the sequence thins as basinal clinothems grade laterally to the shelf carbonates and evaporites that make up the Souris River Shelf in the southern part of the basin.

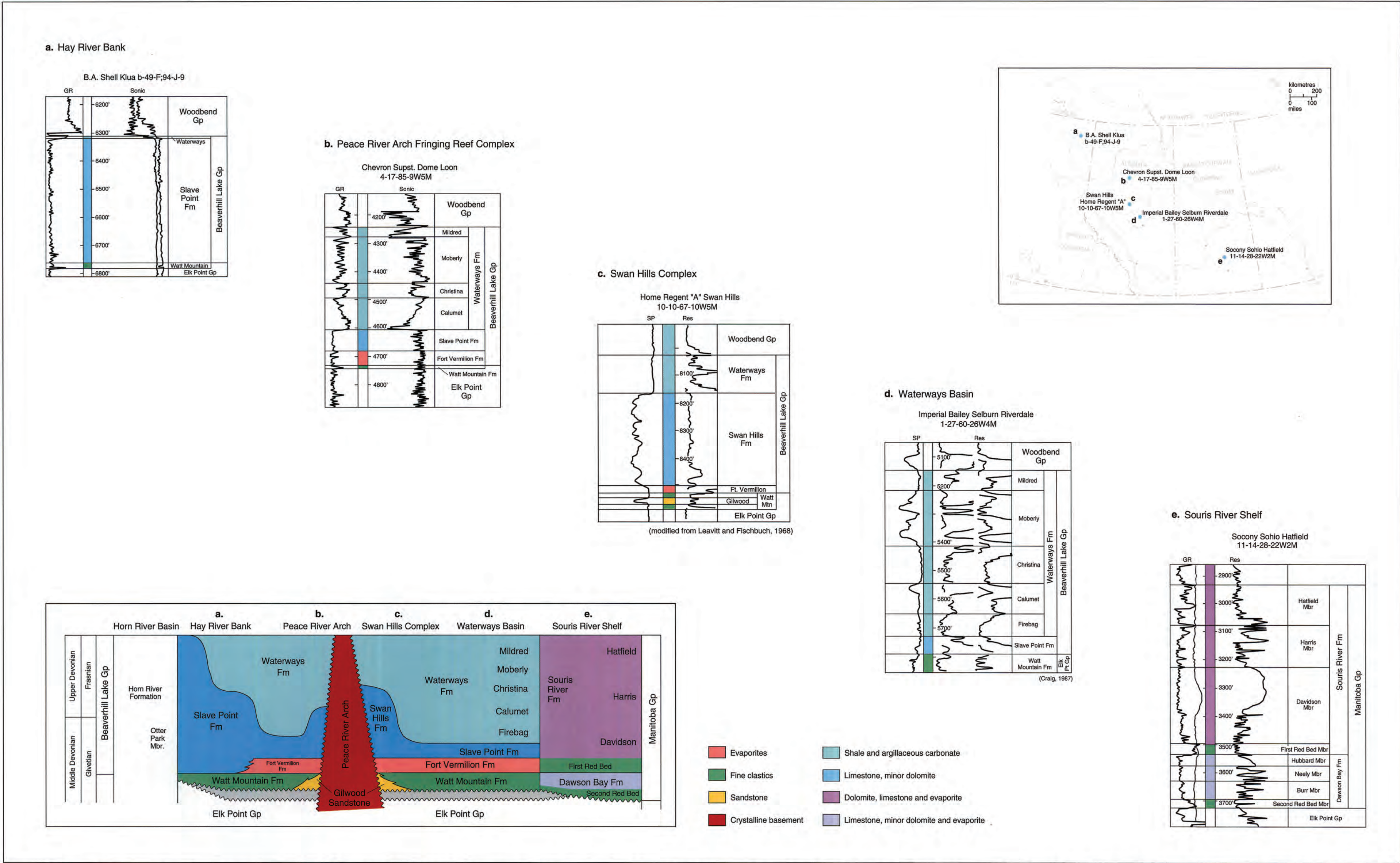


Figure 11.6 Subsurface reference wells. Vertical scale is Atlas standard 1:3000. **a.** B.A. Shell Klua b-49-F;94-J-9 is the reference well for the Hay River Bank area. It is a tie well for master cross sections A-A* (Fig. 11.8a) and B-B* (Fig. 11.9) and is included in Figure 11.18. **b.** The Peace River Arch Fringing Reef Complex is represented by the Chevron Supst. Dome Loon 4-17-85-9W5M well. The Slave Point and Fort Vermilion formations were cored and described in detail by Craig (1987). The Firebag Member of the Waterways Formation is absent through non-deposition, as a result of onlap. **c.** The Home Regent "A" Swan Hills 10-10-67-10W5M well is the subsurface type section for the Swan Hills Formation (Leavitt and Fischbuch, 1968). The section is modified to reflect the regional stratigraphy of the Swan Hills Complex. **d.** Craig (1987) proposed the Imperial Bailey Selburn Riverdale 1-27-60-26W4M well as the subsurface type section for the Waterways Formation. The well occurs within and is representative of the stratigraphy of the Waterways Basin. **e.** The Socony Sohio Hatfield 11-14-28-22W2M well represents the stratigraphy of the Souris River Shelf. Lane (1964) proposed this well as the subsurface type section for the Souris River Formation. Dunn's (1982a) member subdivision for the Dawson Bay Formation is illustrated.

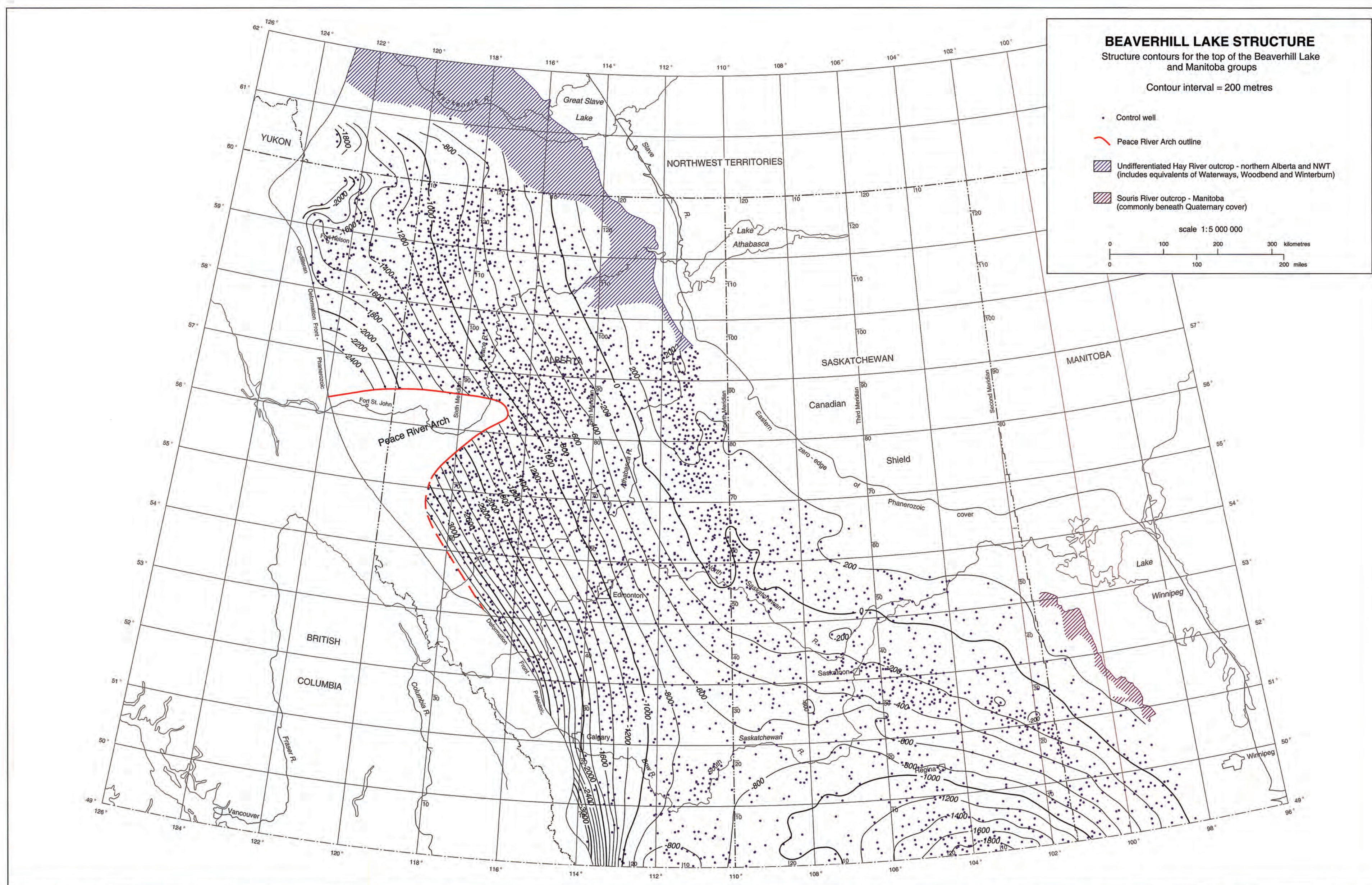


Figure 11.7 Regional structure map on the top surface of the Beaverhill Lake and Manitoba groups. Within Alberta, the surface has a monoclinical dip that increases in a westerly direction. The Horn River Basin in northeast British Columbia is depicted by a structural low. A structural ridge is evident in southeastern Alberta, reflecting post-Devonian tectonics associated with the Sweetgrass Arch. Post-Devonian tectonics are also reflected in southeastern Saskatchewan by the development of the Williston Basin during the late Paleozoic. Local anomalies reflect differential beveling of the Beaverhill Lake Group along the subcrop edge, and post-Frasnian salt dissolution in southern Saskatchewan.

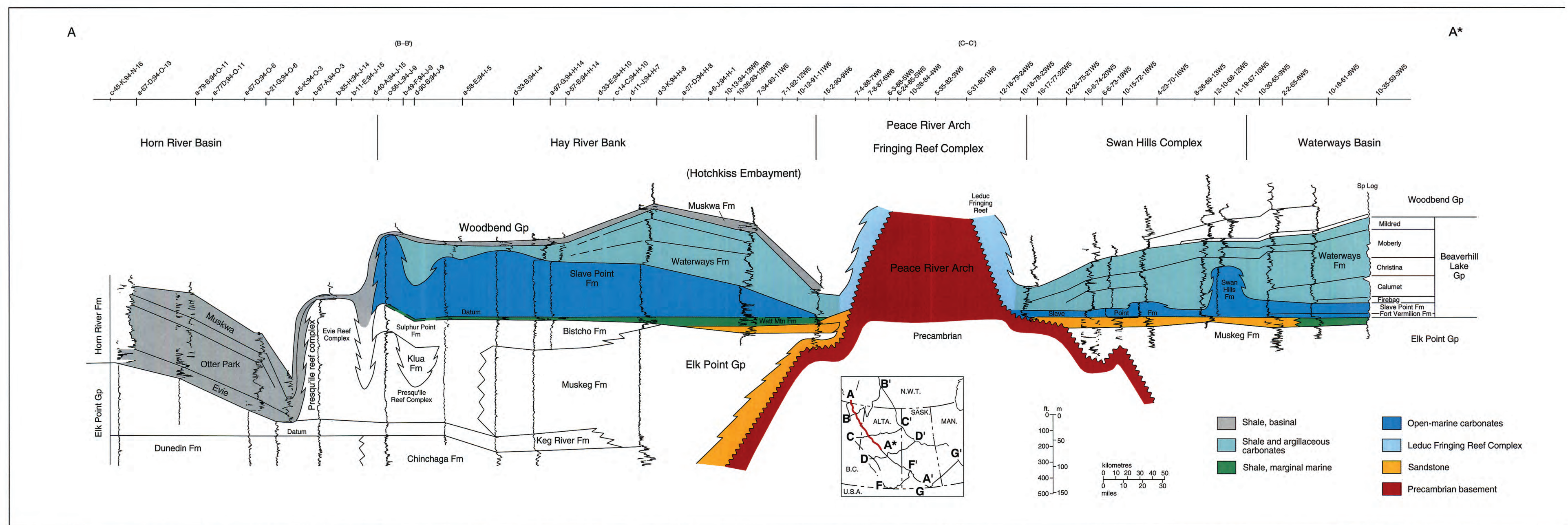


Figure 11.8a Master cross section A-A' (northern portion), illustrating the stratigraphic relationship between the Waterways Basin, Swan Hills Complex, Peace River Arch Fringing Reef Complex, Hay River Bank and Horn River Basin. The transgressive sequence thickens and forms the Swan Hills Complex, south of the arch. This complex is separated from the Peace River Arch Fringing Reef Complex, as illustrated, by a depositional thinning of the Slave Point Formation. The fringing reef complex depositional onlaps the Peace River Arch paleo-landmass. Along the north side of the arch the reef complex is separated from the Hay River Bank by the Hotchkiss Embayment. The transgressive sequence (Slave Point Fm) thickens northward to the margin of the Hay River Bank. The Waterways Formation thickens within the Hotchkiss and Klua embayments, reciprocating the thinning of the Slave Point Formation. The Evie Reef, a Horn River Basin reef complex, is illustrated by b-85-H; 94-J-14. The Horn River Basin consists of undifferentiated Givetian and Frasnian basinal sediments.

Regional Cross Sections

Regional stratigraphic relations are illustrated in the Atlas cross sections shown in Figures 11.8 (A-A'), 11.9 (B-B'), 11.10 (C*-C'), 11.11 (D-D'), 11-12 (F-F') and 11.13 (G-G'). For most of Alberta, the top of the Watt Mountain serves as the stratigraphic datum for the cross sections; it is regionally extensive, distinctive on logs, and is chronostratigraphically significant. It is interpreted as representing the base of a relative sea-level rise that caused marine conditions to develop over most of the basin. The top of the First Red Bed Member is used as datum in Saskatchewan and Manitoba (Figs. 11.8b, 11.12 and 11.13). This does not intend to imply that the Watt Mountain Formation and the First Red Bed are stratigraphically equivalent. The regional cross sections were constructed without any preconceived stratigraphic relations.

The Watt Mountain Formation is absent or difficult to distinguish in the north, so the top of the Chinchaga Formation (Elk Point Group) is used as a datum. This datum facilitates illustration of the underlying Elk Point stratigraphy, which influenced Beaverhill Lake deposition. As a result of the interrelationship of these two groups, both the Elk Point and Beaverhill Lake groups are illustrated on cross sections in the northern area (Figs. 11.9 and 11.10). Extended captions for each of the cross sections set out details of the stratigraphic relations.

Stratigraphic Problems

Several stratigraphic problems are manifest in the Beaverhill Lake Group: the stratigraphic affinity of the Watt Mountain Formation; the equivalence relations of the Dawson Bay Formation; the overall relation between the transgressive and regressive phases; and the non-equivalence of the tops of the Beaverhill Lake and Manitoba groups. These four issues are dealt with below.

The Watt Mountain Formation historically has been included within the Elk Point Group, however its stratigraphic affinity to the Beaverhill Lake Group suggests that it needs to be re-defined. Meijer Drees (1988) and Williams (1984) document the presence of a major unconformity at the base of the Watt Mountain Formation (Fig. 11.2) and suggest that it represents an erosional event and/or transgressive deposit. The Fort Vermilion or Slave Point formations gradationally overlie the Watt Mountain Formation (Fig. 11.2), forming a diachronous surface in the northern part of the basin.

The Dawson Bay Formation disconformably to unconformably overlies the Prairie Evaporite Formation of the Elk Point Group (Williams, 1984; Dunn, 1982a,b) and is transitional to disconformable with the overlying Souris River Formation (Dunn, 1982a). The stratigraphic equivalence within Alberta has not been satisfactorily resolved because of the limited biostratigraphic control within this time period (Braun et al., 1988). Several correlations have been proposed: with the Bistcho Member of the Elk Point Group (Moore, 1989); with the Slave Point Formation (Braun and

Mathison, 1986); and with the Watt Mountain Formation (Dunn, 1982a,b). Williams (1984) proposed that the Second Red Bed Member is equivalent to the Watt Mountain Formation, but did not discuss the equivalence of the remainder of the Dawson Bay Formation.

Braun and Mathison (1986) provided a discussion on the merits and limitations of possible stratigraphic correlations. Earlier, Braun and Mathison (1982) stated that ostracods in the Dawson Bay Formation indicate that it must be older than or barely equivalent to lowermost Slave Point Formation strata in northern Alberta and basal Swan Hills Formation strata in the Swan Hills area. Braun et al. (1988) indicated that the UDM 7 faunal zone (Fig. 11.2) is present within the lower Souris River Formation in southern Saskatchewan and the lower Slave Point in northern Alberta. Biostratigraphic constraints, although not absolutely definitive, suggest that the Dawson Bay is older than the Slave Point Formation and equivalent to the Watt Mountain and Fort Vermilion formations in northern Alberta. Furthermore, the Slave Point platform carbonates are equivalent to the lower part of the Souris River Formation. These data support the stratigraphic interpretations and correlations presented in this paper.

The Watt Mountain Formation is grouped with the Beaverhill Lake Group and assumed to be stratigraphically equivalent to the Dawson Bay Formation for this discussion (Fig. 11.2). This is based on the unconformable to disconformable relation of the Dawson Bay and Watt Mountain formations to the underlying evaporites and carbonates of the Elk Point Group, the transitional relation

with overlying strata, regional stratigraphic correlations, biostratigraphic constraints, and paleogeographic and depositional facies interpretations.

The stratigraphic relation between the transgressive phase (Slave Point and Swan Hills formations) and the regressive phase (Waterways Formation) remains controversial. Most recent work, including this paper, suggests that the two phases are distinct, non-contemporaneous sedimentary events. Sheasby (1971) and Wendte and Stoakes (1982) indicate that the phases exhibit an onlap relation in the Swan Hills Complex. Tooth and Davies (1989) and Gosselin et al. (1989) document the presence of a submarine hardground separating reefal carbonates of the transgressive phase from the Waterways Formation in the Peace River Arch Fringing Reef Complex. Braun et al. (1988) state that each phase has a distinct faunal assemblage and that the two exhibit an onlap relationship. Jansa and Fischbuch (1974) and Keith (1990), on the other hand, proposed that sedimentation within each phase was contemporaneous.

In summary, the authors believe that the transgressive and regressive phases are not contemporaneous and that their relation is one of onlap/downlap, based on the following criteria: 1) the distinct change in depositional style; 2) the presence of submarine hardground surfaces; 3) the distinctive faunal assemblage of each phase; and 4) the widely demonstrable onlap/downlap geometry, as illustrated in regional cross sections (Figs. 11.8 - 11.11) and other related diagrams (Figs. 11.19 and 11.23).

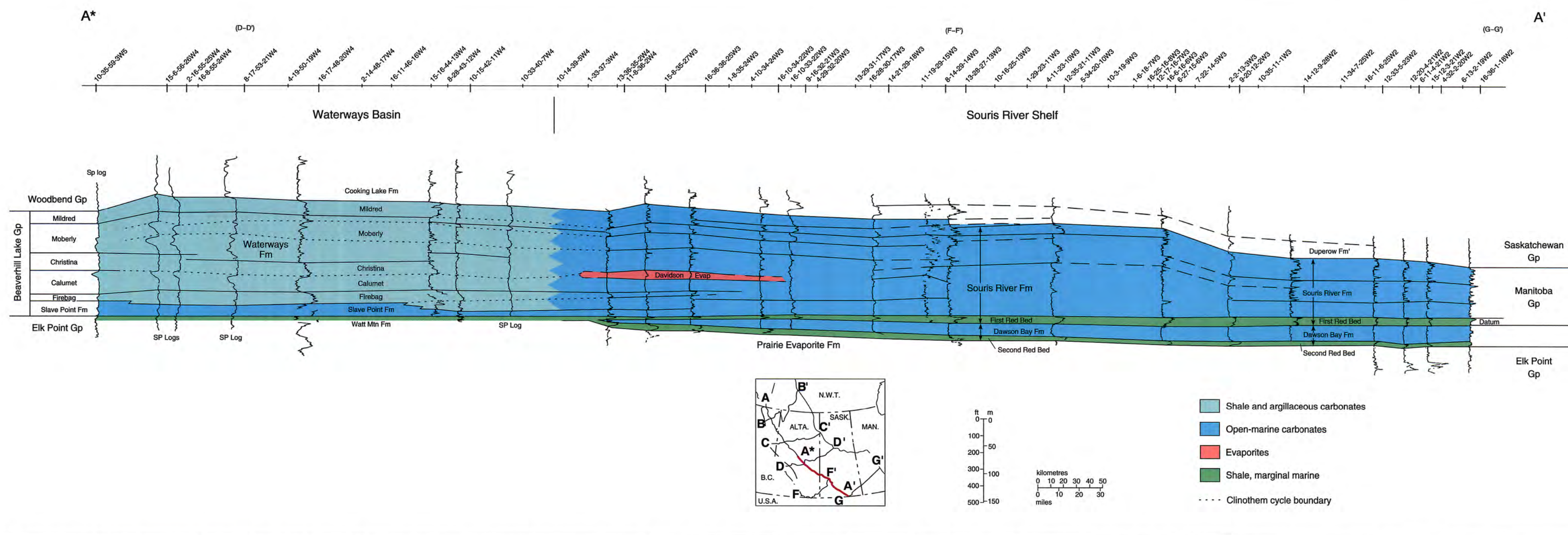


Figure 11.8b Cross section A-A' (southern portion), illustrating the relation between the dominant basinal strata of the regressive phase (Waterways Basin) and the shallow-marine carbonates and evaporites of the Souris River Shelf. The basin-slope strata (clinothem phase) of the Waterways Formation can be correlated with the shallow-marine strata (fandotherm phase) of the Souris River Formation. The facies change is illustrated diagrammatically as abrupt, but in detail the shelf carbonates prograde basinward into the Waterways Basin. Each successive clinothem cycle is generally thinner and is dominated by a greater proportion of carbonate (versus shale), suggesting infilling of the basin through time. The Mildred Member represents the lower portion of a clinothem cycle. The upper part is represented by at least some of the Cooking Lake Formation in Alberta or the lower portion of the Duperow Formation in Saskatchewan. The Slave Point Formation (platform facies) thins in a southeasterly direction and becomes indistinguishable within the Souris River Formation. The Watt Mountain Formation thins and becomes equivalent to the Dawson Bay Formation in southern Saskatchewan (Souris River Shelf).

The top of the Beaverhill Group (Waterways Formation) and the top of the Manitoba Group (Souris River Formation), as formally defined, do not occur at the same stratigraphic level (Fig. 11.8b). The top of the Manitoba Group occurs one stratigraphic cycle lower, within the regressive phase. This appears to have resulted from the fact that the top of the Beaverhill Lake Group was originally defined as being the base of the Cooking Lake Formation, which is not recognized in Saskatchewan. The division between the Manitoba and Saskatchewan groups was independently defined within this conformable succession.

Atlas Mapping

The top of the Beaverhill Lake Group is well documented in the Atlas database, as is the top of the Manitoba Group (Souris River Formation). The stratigraphic gap between the two, discussed above, is perpetuated in the Atlas isopach and structure maps (Figs. 11.3 and 11.7), however the difference (less than 10 percent of the contour interval) is not considered to significantly alter the overall contour patterns.

At the base of the subject succession, mapping difficulties are also manifest. In Alberta, the Watt Mountain Formation (despite the above cited stratigraphic arguments to the contrary) is included in the Elk Point Group (as per formal definition) and is excluded in the isopach maps in this chapter (Figs. 11.3 and 11.4). The principal reason for mapping on the Watt Mountain top rather than its base, is that the top picks are generally so much more reliable than picks on the underlying evaporites.

Similarly, in Saskatchewan and Manitoba, the isopach base of the subject succession is taken at the top of the Dawson Bay Formation, (Figs. 11.3 and 11.4) not the base, where the picks on the Prairie Evaporite salts (commonly collapsed through dissolution) are less reliable. The Figure 11.14 isopach of the Dawson Bay Formation depicts the geometry of the Dawson Bay sliver that, on stratigraphic grounds, is covered in this chapter, but in terms of Atlas mapping is embraced in the Elk Point Chapter (Meijer Drees, *this volume*, Chapter 10, Figs. 10.3 and 10.8).

Stratigraphic Framework

Two second-order depositional phases are recognized within the strata (Fig. 11.15): a transgressive "reefal" phase (a term introduced by Stoakes, 1988) and a regressive "basin-fill" phase. Each phase exhibits a distinctive style of deposition and consists of genetically related depositional cycles (parasequences). The phases are bounded by an unconformity or a surface of nondeposition (disconformity) and can be equated to a depositional "sequence" utilizing the sequence stratigraphic concept. Each cycle reflects a third-order depositional sequence.

The transgressive phase was deposited during a period of increasing rate of relative sea-level rise. This phase (isopached in Fig. 11.4) is prevalent in the western and northern parts of the basin, and comprises restricted- to shallow-water carbonates of the Watt Mountain, Fort Vermilion, Slave Point and Swan Hills formations (Fig. 11.15) that form an extensive carbonate bank complex. (The

Watt Mountain and Dawson Bay Formation intervals are isopached separately in Fig. 11.14 because of data base limitations). The bank complexes comprise several shallowing-upward "reefal" cycles that are a response to episodic pulses of relative sea-level rise. The banks developed in a transgressive to aggradational depositional style.

The regressive phase refers to deposition during a relative sea-level fall or decreasing rate of relative sea-level rise. This phase (isopached in Fig. 11.5) dominates the southern and eastern part of the basin and comprises shales and argillaceous carbonates of the Waterways Formation and shallow-marine carbonates and evaporites of the Souris River Formation (Fig. 11.15). These sediments form numerous basinal to ramp depositional cycles. Each cycle, and the entire sequence, exhibits a basinward progradation of the platform margin facies. This indicates that the rate of sediment accumulation was greater than the accommodation space, producing a relative sea-level fall. As a result, the sequence is referred to as the "regressive phase". The basinal to slope portion of this phase infills the intraplatform basin and onlaps the bank complex of the transgressive phase.

Stratigraphic History

The initial transgression of the seas into the Elk Point Basin during the Late Givetian deposited a thin detrital to marginal-marine unit unconformably overlying the restricted-marine deposits of the Elk Point Group (Fig. 11.16a). This initial deposit consists of green

shales of the Watt Mountain Formation and red to green dolomitic mudstones of the Second Red Bed member. The Watt Mountain shale is interpreted as representing a brackish water to lacustrine depositional environment in the Swan Hills area (Jansa and Fischbuch, 1974). In southern Saskatchewan and Manitoba the shallowing-upward carbonate sequence of the Dawson Bay Formation was deposited within a local sub-basin possibly created by dissolution of underlying Elk Point salts. Flanking the Peace River Arch, arkosic sandstones of the Gilwood member were deposited as a fluvial-deltaic complex (Jansa and Fischbuch, 1974) that prograded into a marginal-marine body of water. In the northern part of the basin, along the Hay River Bank margin, open-marine carbonates were deposited.

An increased rate of relative sea-level rise allowed for deposition of restricted-marine carbonates and evaporites of the Fort Vermilion Formation (Fig. 11.16b), which gradationally overlies the Watt Mountain Formation. The Fort Vermilion Formation in central Alberta represents a restricted coastal depositional environment consisting of a hypersaline subaqueous lagoon grading landward to a tidal flat and continental sabkha as it onlapped the landmass (Jansa and Fischbuch, 1974). In northern Alberta the evaporites grade northwestward into open-marine carbonates that become indistinguishable from overlying Slave Point carbonates. Southward from Swan Hills, the Fort Vermilion Formation thins and may be equivalent to the dolomitic mudstones of the First Red Bed Member in the southern part of the basin.

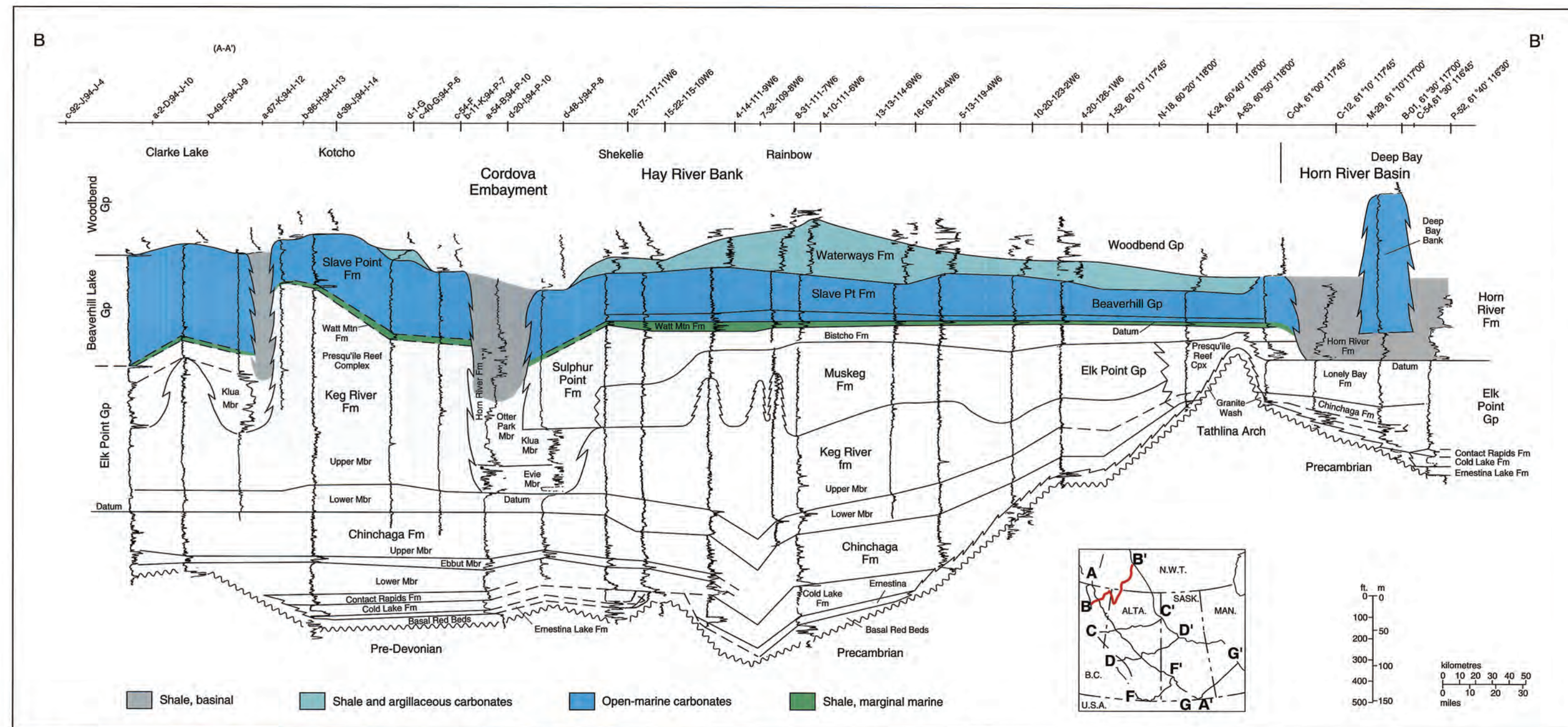


Figure 11.9 Cross section B-B', illustrating a southwest-northeast transect from Clarke Lake in northeastern British Columbia, across the Hay River Bank to Deep Bay in the southern Northwest Territories. The Hay River Bank margin (well C-04) formed proximal to the Tathlina High, a Middle Devonian paleotopographic high. The Elk Point succession thins stratigraphically in a northeasterly direction. The Deep Bay Bank (well B-01) developed within the Horn River Basin. Within the Cordova Embayment (d-20-I; 94-P-10), shelf carbonates of the Elk Point and Beaverhill Lake groups grade abruptly to basinal strata of the Horn River Formation. The regressive phase Waterways Formation depositionally onlaps (downlaps) the bank complex along the bank margin.

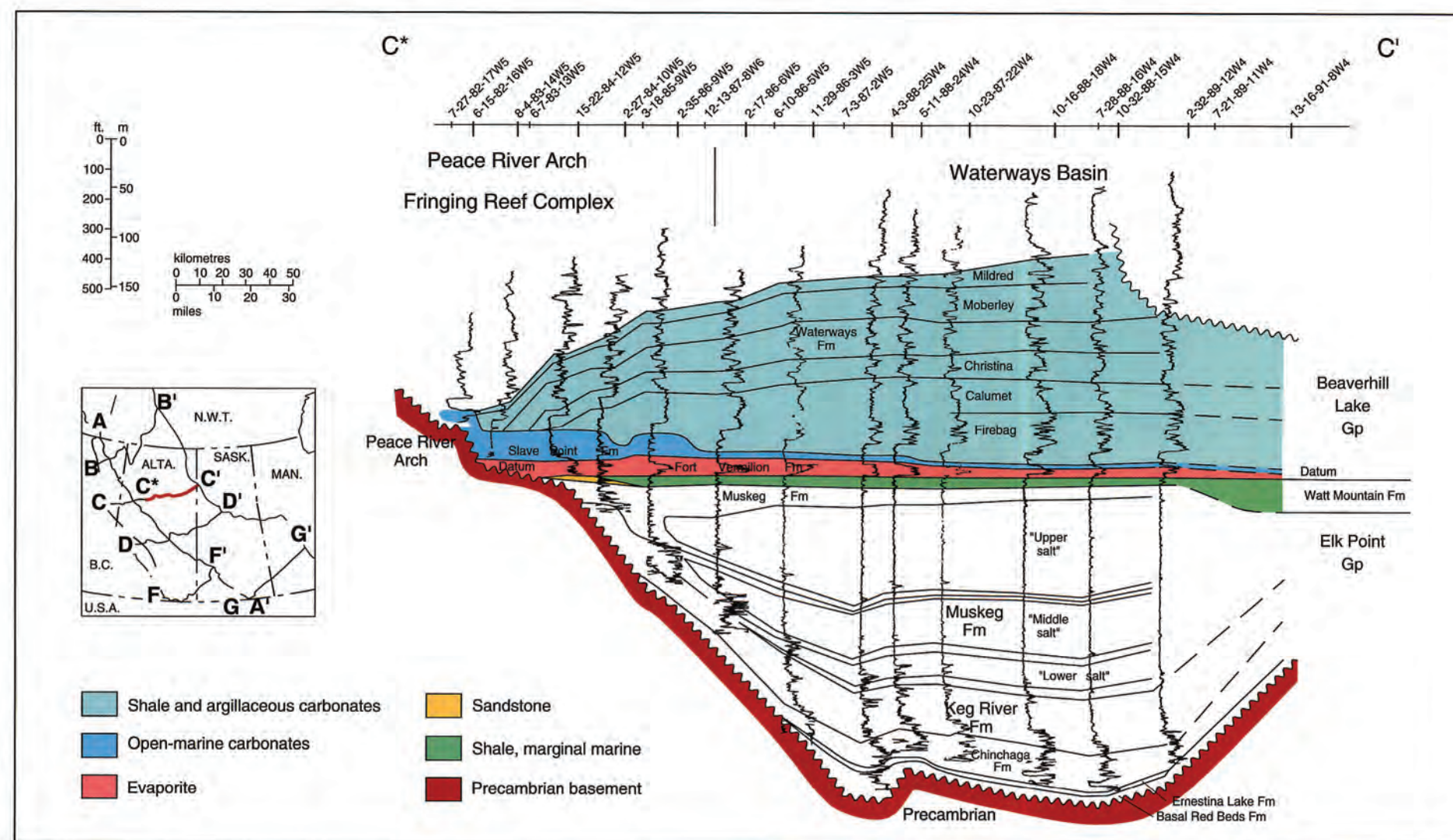


Figure 11.10 Cross section C*-C', along the axis of the Peace River Arch. The underlying Elk Point Group depositionally onlaps the arch in a westerly direction. The Beaverhill Lake transgressive reefal sequence thickens and develops a bank complex marginal to the arch. The regressive phase onlaps (downlaps) the bank complex.

Relative sea level continued to rise and open-marine carbonates of the Slave Point Formation were deposited over the entire basin (Fig. 11.16c). A carbonate bank (the Hay River Bank) developed in the northern part of the basin with its reefal margin generally coincident with the underlying Elk Point barrier reef. Southward, the Slave Point Formation formed the platform for subsequent reef growth of the Swan Hills Complex (Swan Hills Formation) and the Peace River Arch Fringing Reef Complex (the Slave Point Formation or, locally, the Swan Hills Formation). In southern Saskatchewan and Manitoba, and southeastern Alberta, the Slave Point Formation is correlated to the basal shallowing-upward cycle of the Souris River Formation (Fig. 11.15).

The regressive phase is represented by the Waterways Formation and its Souris River equivalent (Fig. 11.16d). Numerous clinoform-forming shale and argillaceous carbonate cycles infilled the Waterways Basin in a westerly and northerly direction. The shallowing-upward clinoforms "shingle" and thin in a westward and northward direction as they downlap the reefal carbonates of the transgressive phase. Southward the clinoforms grade laterally to shallowing-upward carbonate-evaporite sequences (Moore, 1990) of the Souris River Shelf (Figs. 11.1 and 11.15).

Regional Facies Development

Six paleogeographic areas are recognized for the Beaverhill Lake Group (Fig. 11.1):

1. Horn River Basin
2. Hay River Bank
3. Peace River Arch Fringing Reef Complex
4. Swan Hills Complex
5. Waterways Basin
6. Souris River Shelf

Each area is discussed independently because of its unique stratigraphic relations. The boundaries between the areas are transitional, particularly where Waterways basin-fill sediments onlap the bank complexes of the transgressive phase.

Horn River Basin

The Horn River Basin of northeastern British Columbia, southern Yukon and Northwest Territories is situated seaward of the "barrier-reef" complex (Fig. 11.1). The Horn River Formation consists of Givetian-Frasnian basinal shales stratigraphically equivalent to reefal carbonates of the Elk Point and Beaverhill Lake groups (Fig. 11.17). Numerous reef complexes (Evie, Roger, Yoyo and Sierra in northeastern B.C. and Horn Plateau Reefs and Deep Bay Bank in southern N.W.T.) developed during the Givetian within the Horn River Basin (Fig. 11.18).

What effect did post-Elk Point regression and subsequent relative sea-level rise have on these reef complexes? Three scenarios exist: reef growth was terminated; the reef complexes were subaerially exposed but reef growth was reestablished during the upper Givetian; or reef development continued during the Givetian without any significant hiatus. Lack of faunal evidence and the absence of a lithologically distinct Watt Mountain shale create a stratigraphic correlation problem.

The recognition of a Watt Mountain "shale" equivalent in the region would provide valuable evidence of a stratigraphic "event"; however, two problems limit its credibility. Firstly, the source of the "shale", the Peace River Arch, is far distant from the Horn River Basin. Williams (1981) shows the recognizable limit of the Watt Mountain Formation occurring east of the Hay River Bank margin. Secondly, Meijer Drees (1988) suggests that the Watt

Mountain "shale" represents a paleokarst along the margin of the Hay River Bank. Therefore its stratigraphic significance is limited because it could occur at the top of or within underlying Elk Point carbonates.

In northeastern British Columbia the Watt Mountain "shale" is generally absent or poorly developed in these basinal reef complexes. The Evie reef complex is illustrated in Figure 11.8a by b-85-H, 94-J-14. The top of the reef-to-Chinchaga interval is considerably thinner than in a barrier reef well (b-49-F, 94-J-9), but a shaly unit occurs at approximately the Watt Mountain stratigraphic level, suggesting that possibly the upper portion of the Evie reef may be upper Givetian in age. In the southern Northwest Territories the Watt Mountain "shale" is absent in the Horn Plateau reefs (Williams, 1981) and poorly developed in the Deep Bay Bank (Meijer Drees, 1990). The Deep Bay Bank, illustrated in Figure 11.9 by well B-01, appears as a stratigraphic anomaly as a result of depositional thinning of the Elk Point sequence in the vicinity of the Tathlina High. Skall (1975) suggests that marine carbonate sedimentation occurred within the basin during post-Elk Point regression.

The lack of a distinctive Watt Mountain shale, the presence of carbonates at approximately the same stratigraphic position, and the documentation of marine carbonate deposition equivalent to the Watt Mountain Formation suggest that the Horn River Basin reef complexes continued to develop throughout Givetian time without being significantly affected by the post-Elk Point regression and hiatus.

Hay River Bank

The paleogeography of the underlying Elk Point (Presqu'île) barrier reef complex influenced Beaverhill Lake deposition. The post-Elk Point transgression led to development of an extensive carbonate bank complex with its barrier margin roughly coincident with the underlying Elk Point barrier reef margin (Fig. 11.16). An erosional and/or transgressive event represented by a thin green shale bed, the Watt Mountain Formation, (Meijer Drees, 1988; Williams, 1984) separates the two stages of barrier reef growth. The Watt Mountain "shale" is absent or poorly developed along the barrier margin (Figs. 11.8a, 11.9 and 11.17), suggesting continuous "reefal" sedimentation (similar line of reasoning to that discussed for the Horn River Basin reef complexes). The Late Givetian-Early Frasnian barrier margin grew aggradationally and prograded seaward (westward) from the underlying barrier, commonly by several kilometres, and up to 30 km in the Clarke Lake area (Fig. 11.17). The Slave Point reefal carbonates thin depositionally within the Klua embayment (d-90-B; 94-J-15; Fig. 11.8a) and grade abruptly to basinal shales of the Horn River Formation (Otter Park Member) within the Cordova embayment (Fig. 11.9, represented by d-20-I, 94-P-10).

The bank complex developed aggradationally as a cyclic succession of shallowing-upward reefal cycles. Primary facies have been completely destroyed as a result of pervasive "Presqu'île" style dolomitization along the barrier trend. Eastward from the barrier, the bank is undolomitized and consists of several shallowing-upward carbonate sequences. A localized intraplatform sub-basin (or possible embayment), known as the Hotchkiss embayment, separates the Hay River Bank from the Peace River Arch Fringing Reef Complex (Fig. 11.17). Reefal buildups such as Hamburg and Cranberry developed within this basin and along the northern margin of the Peace River Arch Fringing Reef Complex.

The regressive phase (the Waterways Formation) thins westward and is absent along the barrier reef trend (Fig. 11.18). The basinal clinothems depositionally downlap the barrier reef trend. The Waterways Formation thickens locally within the Klua and Hotchkiss embayments (Figs. 11.8a and 11.17)

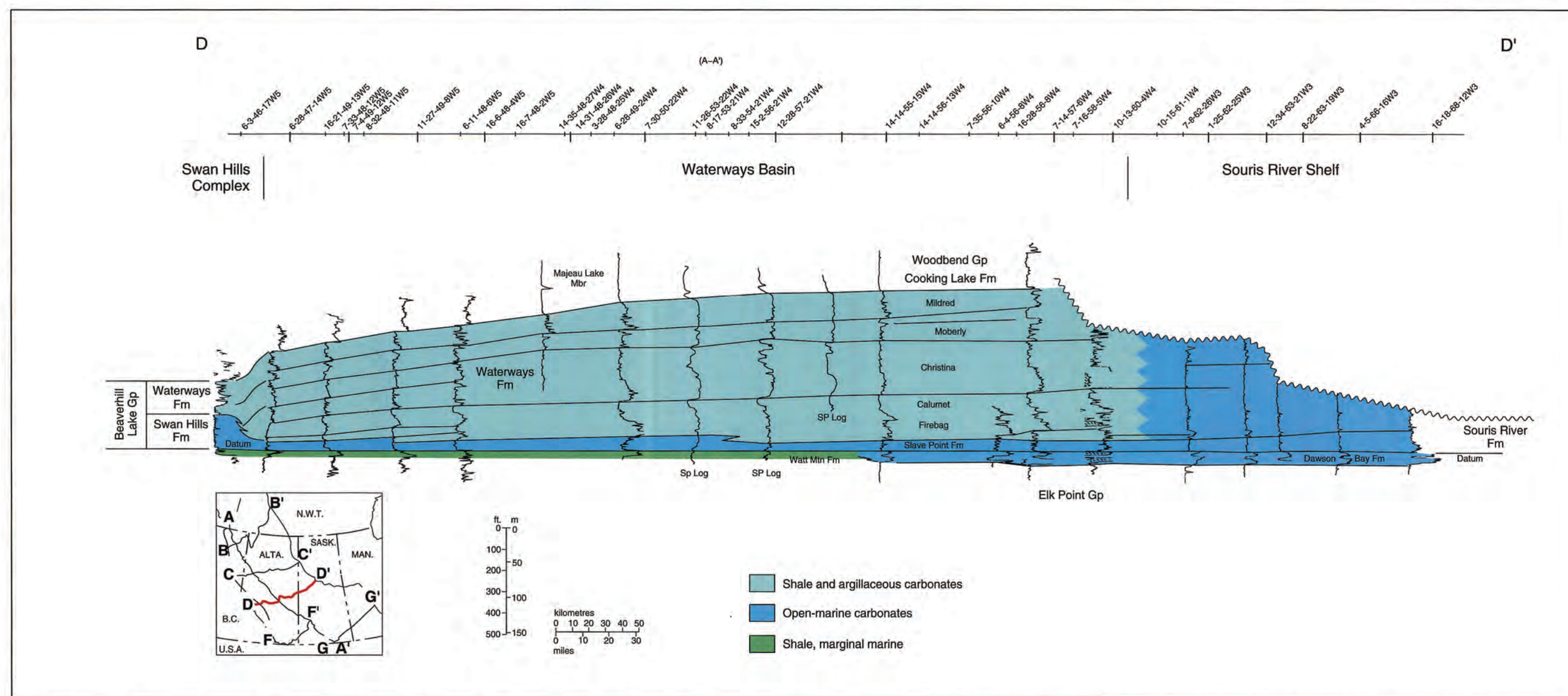


Figure 11.11 Cross section D-D', illustrating the stratigraphic relations between the Souris River Shelf, Waterways Basin and Swan Hills Complex in an east-west direction. The basin-fill regressive phase dominates most of the section. Clinothem sequences can be correlated regionally. These basinal to slope cycles grade laterally into shallowing-upward carbonate-evaporite cycles of the Souris River Shelf. Westward the clinothems depositionally downlap the Swan Hills Complex.

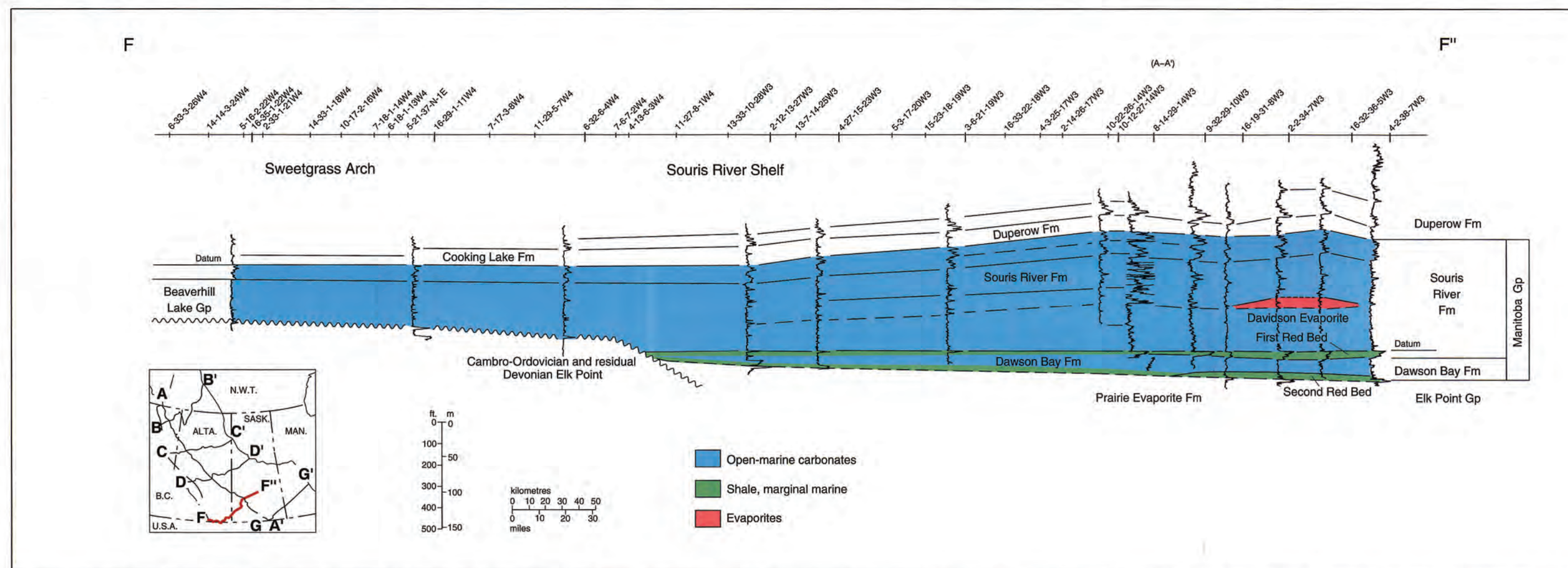


Figure 11.12 Cross section F-F', depicting the Souris River Shelf in southeastern Alberta and southwestern Saskatchewan. It is composed of several shallowing-upward carbonate-evaporite sequences. The Dawson Bay Formation thins as it depositionally onlaps the Sweetgrass Arch, a pre-Devonian paleotopographic high.

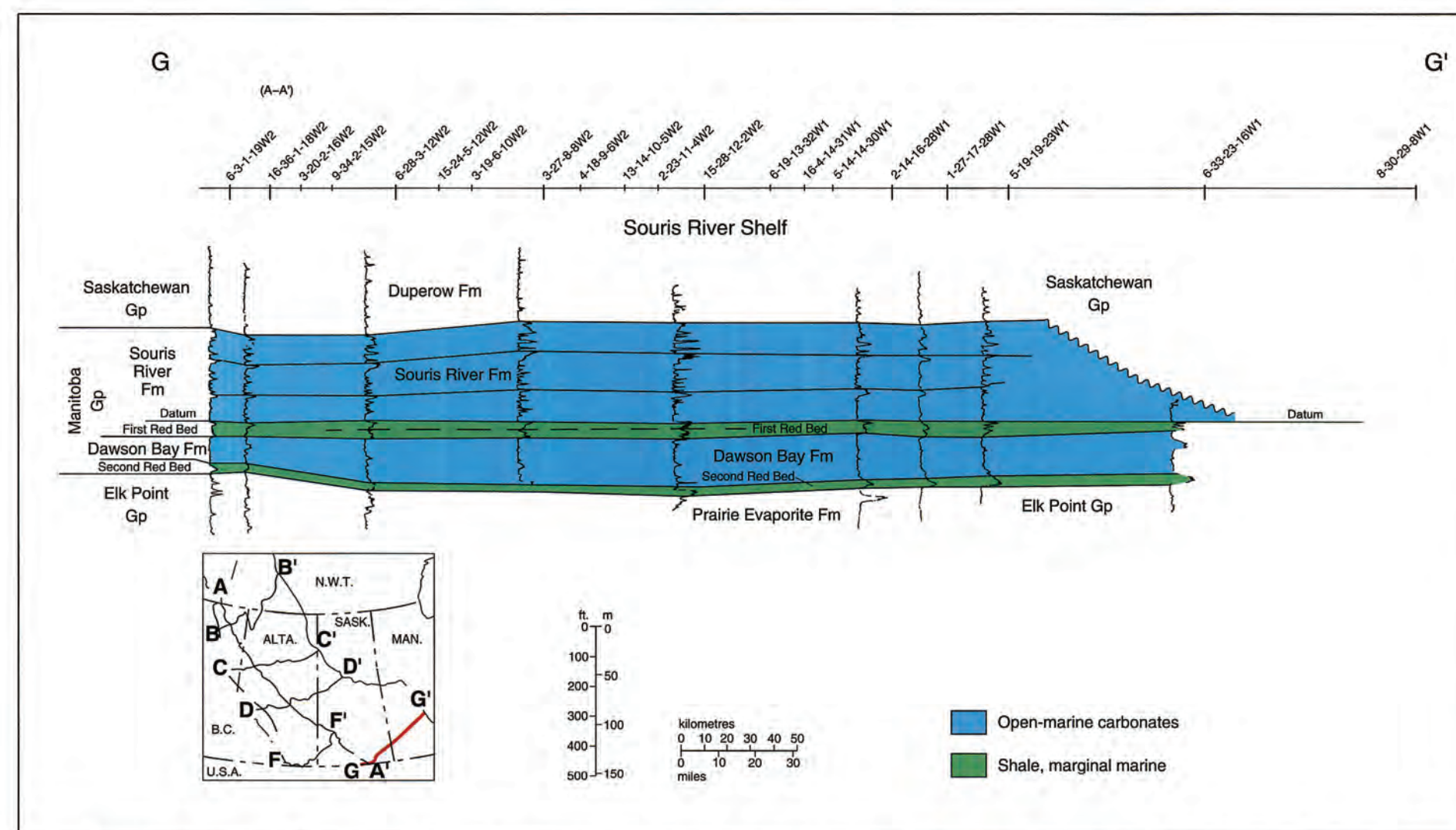


Figure 11.13 Cross section G-G', illustrating Manitoba Group stratigraphy in southeastern Saskatchewan and southwestern Manitoba. The Second Red Bed Member of the Dawson Bay Formation unconformably overlies evaporites of the Elk Point Group and represents a unit transitional to the overlying carbonates of the Dawson Bay Formation. The Dawson Bay Formation forms a deepening-upward transgressive sequence. The First Red Bed Member of the Souris River Formation disconformably to unconformably overlies the Dawson Bay Formation and is transitional with the carbonates of the Souris River Formation (regressive phase). The Souris River Shelf is composed of several, regionally correlatable, shallowing-upward carbonate-evaporite cycles.

Peace River Arch Fringing Reef Complex

An extensive bank complex that fringed the emergent Peace River Arch developed during the transgressive phase. Paleotopography of the arch greatly influenced sedimentation during that time. The carbonate bank complex is composed of several shallowing-upward "reefal" cycles that formed in response to episodic rises in relative sea level. The cycles were stacked aggradationally and in a backstepping manner as the sea transgressed the Peace River Arch (Fig. 11.19). Clinothems of the regressive phase downlapped onto the bank complex and the arch.

Initial deposition consisted dominantly of arkosic sandstones (Gilwood Member, Watt Mountain Formation), which were deposited as a fluvial-deltaic complex that radiated from the Peace River Arch (Fig. 11.16a). Along the southern flank of the arch, the deltaic system was extensive, with development of several clastic barrier island systems (Jansa and Fischbuch, 1974). Paleotopography along the north side of the arch was steeper (O'Connell et al., 1990) and Gilwood sands (Manning sand, now obsolete) were deposited as a series of thick, laterally discontinuous fluvial channels (Rottenfusser and Oliver, 1977). Isolated fluvial-deltaic deposits occur along the eastern flank of the arch in the Evi (Tp 87, R 12 W5M) and Utikuma-Nipisi (Tp 78-80, R 8 and 9 W5M) areas. Relative sea level continued to rise and restricted carbonates and evaporites of the Fort Vermilion Formation (Fig. 11.16b) were deposited in a hypersaline shelf depositional environment (Craig, 1987). The transgressive sequence was capped by open-marine carbonates (Slave Point Formation) that formed an extensive carbonate platform flanking the Peace River Arch (Fig. 11.16c). A high-energy shoal-reef environment (thamnoporid-stromatoporoid floatstone to rudstone facies) developed within the platform (Tooth and Davies, 1989; Gosselin et al., 1989). This high-energy facies became localized and provided a suitable substrate for subsequent bank development.

A shallow-water carbonate ramp depositional model with reef rimmed platforms or banks has been proposed by Craig (1987) for this area. Paleoenvironmental interpretations illustrate distinct lateral facies variations across the bank complex (Fig. 11.19), which is composed of several shallowing upward "reefal" cycles, each 10 to 15 m thick. A relative rise of sea level initiated each cycle, which shallowed upward as the rate of relative sea level rise decreased. Individual cycles can be separated by a basinward shift in facies within a vertical sequence.

A high-energy reef margin (cycle 1) developed along the seaward margin of the bank complex, largely coincident with the underlying platform shoal-reef facies (Fig. 11.20). It is referred to as the Sawm-Gift trend. The sedimentology and stratigraphy of the Gift pool (Tp 78, R 10 W5M), situated along this trend, is discussed by Tooth and Davies (1989). Reefal buildups like Red Earth (Tp 88, R 8 W5M; Fig. 11.20) occur basinward (east) of the bank margin. A stratigraphically younger reef margin (cycle 2) known as the Slave-Seal trend, developed farther landward (Fig. 11.20) in response to relative sea-level rise. Paleohighs were localized and influenced reef growth along this trend (e.g., Slave, Tp 84, R 14 W5M; Dunham et al., 1983). Local areas on the cycle 1 bank were able to keep up with the rise in relative sea-level and a second "reefal" cycle developed aggradationally (e.g., Evi, Tp 87, R 12 W5M; Gosselin et al., 1989). Younger "reefal" buildups (i.e., Springburn Member) are present farther landward, representing another backstepping reef margin (cycle 3, Fig. 11.19).

The shale-argillaceous carbonate clinothems of the regressive phase (Waterways Formation) thin in a shingling pattern as they downlap and positionally pinch out against the reef complexes and the Peace River Arch (Figs. 11.10 and 11.19). A hardground surface (Tooth and Davies, 1989; Gosselin et al., 1989) generally occurs at the top of the Slave Point carbonates, separating the positionally distinct sequences.

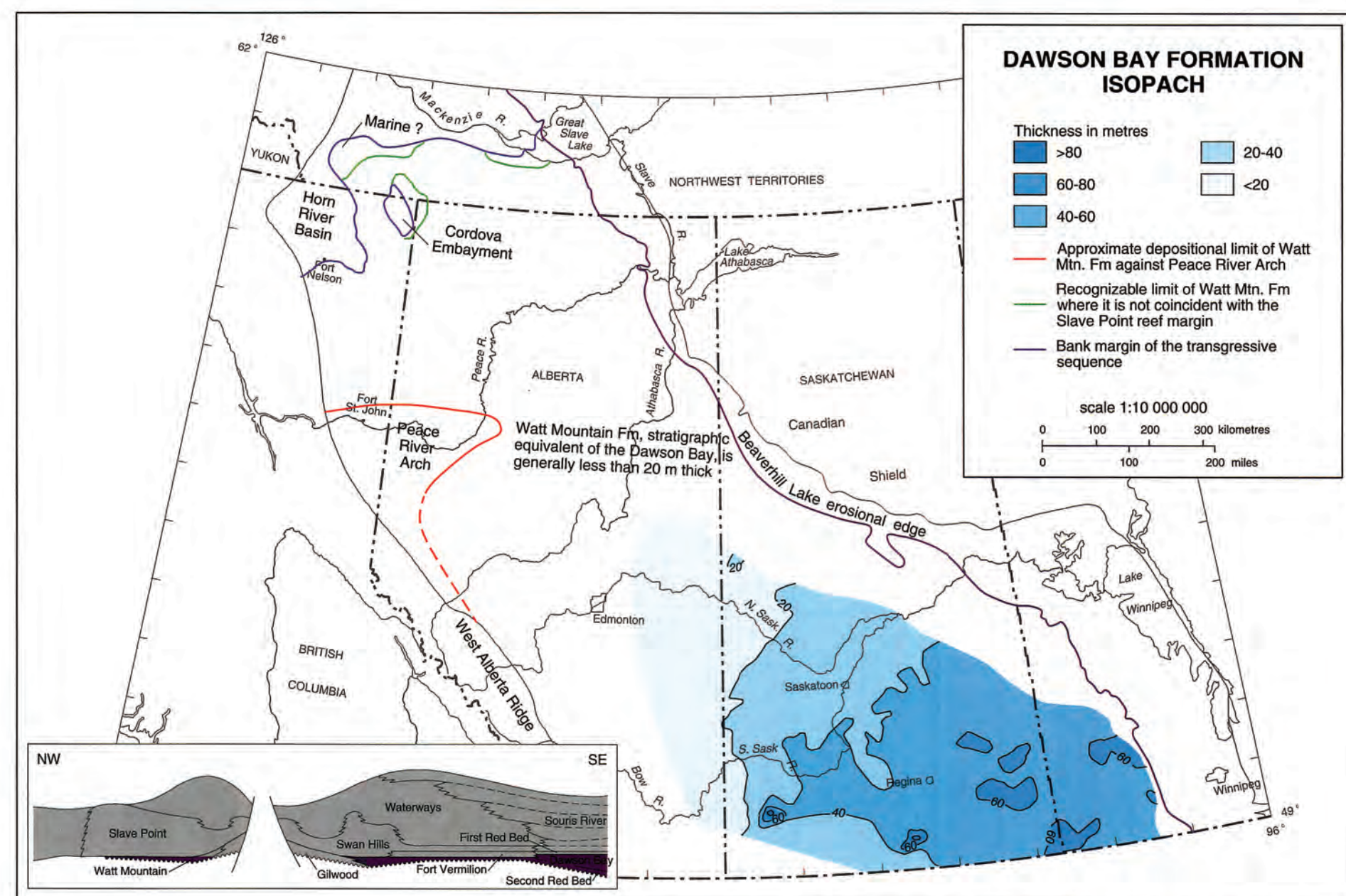


Figure 11.14 Dawson Bay and Watt Mountain isopach map. The Dawson Bay Formation thickens to over 60 m in the Dawson Bay Basin in parts of southern Saskatchewan. It is stratigraphically equivalent to the Watt Mountain Formation in Alberta, which is generally less than 20 m thick, except in the vicinity of the Peace River Arch (PRA), where the Gilwood Member constitutes a fluvial-deltaic sequence. Its thickness varies from approximately 20 m in the Mitsue area (south of the PRA) to up to 70 m along the north flank of the PRA (Rottenfusser and Oliver, 1977). Its distribution cannot be mapped regionally due to limitations of the database, however it has been mapped south of the PRA by Jansa and Fischbuch (1974) and north of the PRA by Rottenfusser and Oliver (1977). The Watt Mountain Formation thins northward from the PRA, coincident with the thinning of the Gilwood sandstone. Along the reef margin of the Hay River Bank, the Watt Mountain "shale" becomes difficult to identify and its recognizable limit is illustrated (from Williams, 1981).

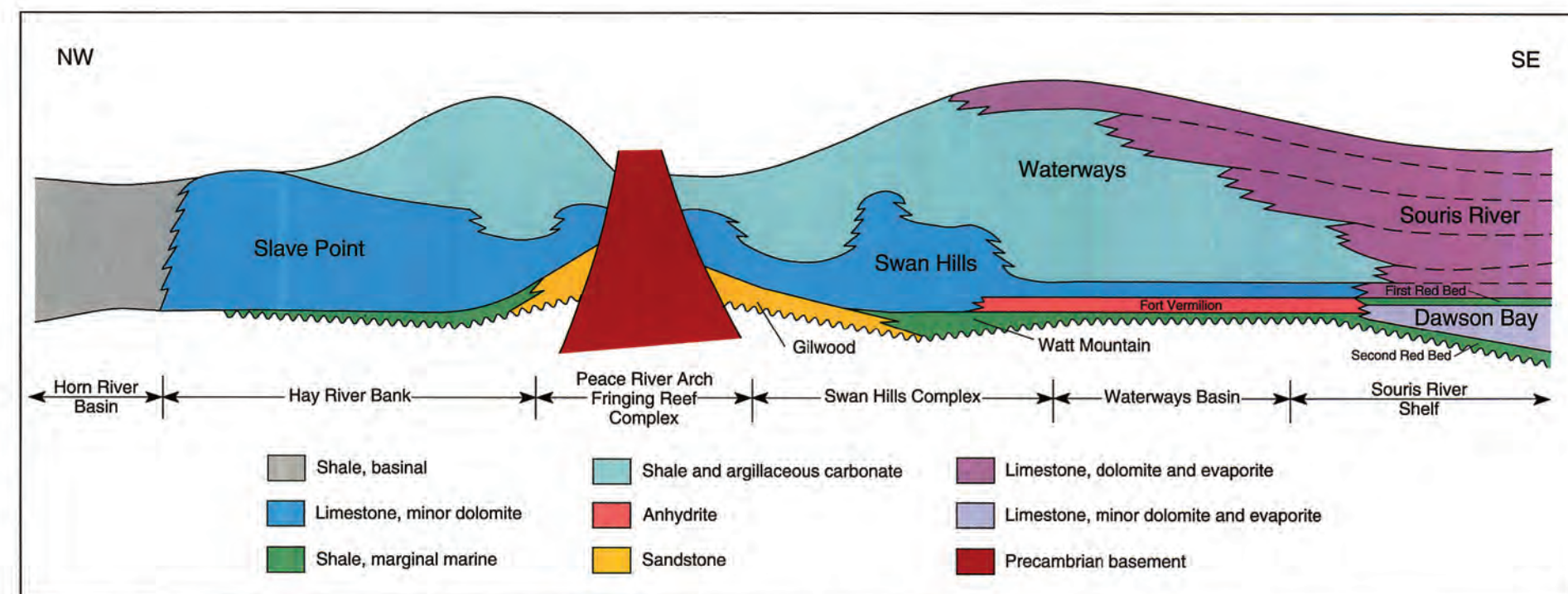


Figure 11.15 Regional schematic cross section illustrating the stratigraphy of the Beaverhill Lake Group, based on master cross section A-A' (Fig. 11.8).

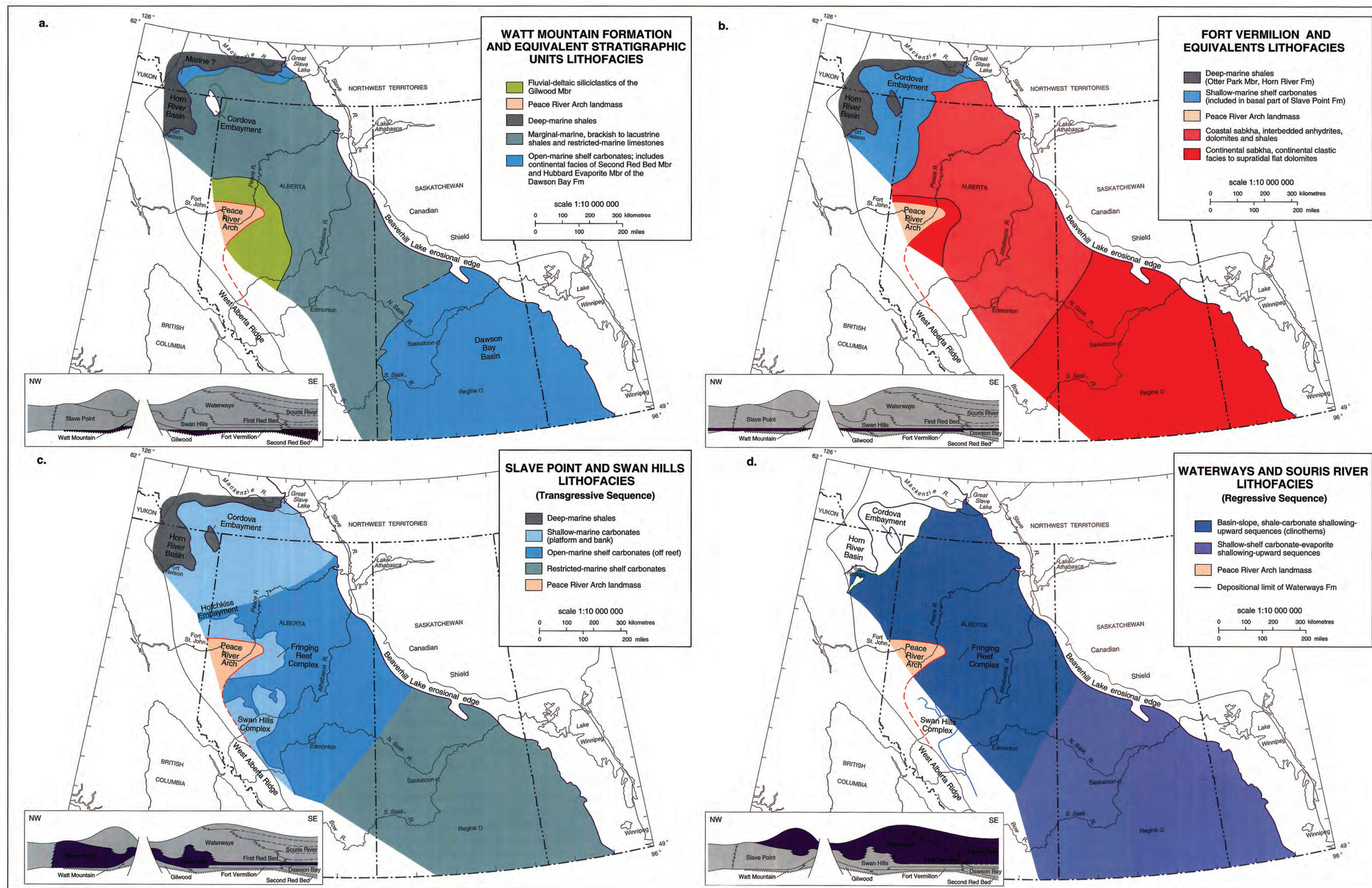


Figure 11.16 Beaverhill Lake Group paleogeography and facies maps, illustrating the development through time of the Beaverhill Lake sequence. The transgressive sequence is depicted in a to c and the regressive sequence in d. The initial transgression (a) deposited a marginal-marine unit (Watt Mountain Formation). Arkosic sandstones (Gilwood Member) were deposited as a fluvial-deltaic system that prograded into the marginal-marine body of water flanking the Peace River Arch. The Dawson Bay Basin was infilled by a deepening-upward transgressive sequence (Dawson Bay Formation). An incursion of open-marine waters from the east is postulated because of the presence of normal-marine fauna in the Dawson Bay Formation. In the northern part of the basin open-marine carbonate sedimentation continued with minimal influence of the post-Elk Point hiatus, particularly along the bank margin. Relative sea level continued to rise, resulting in restricted-marine conditions over the majority of the basin (b). The facies change from open-marine to restricted-marine to continental sedimentation in a southeasterly direction indicates a southward-advancing seaway. A tidal flat to continental facies flanked the Peace River Arch and basinal conditions existed in the Horn River Basin. By the time of Slave Point deposition, marine conditions developed over most of the Elk Point Basin (c). The development of a shallow-marine carbonate platform provided a substrate for subsequent reef growth. Carbonate bank complexes overlying the Elk Point bank complex developed in the northern part of the basin (Hay River Bank) and flanking the Peace River Arch and West Alberta Ridge. The bank complexes consist of a number of shallowing-upward reefal cycles that formed in response to episodic pulses of relative sea-level rise. The intra-platform basin (Waterways Basin) was a site of basinal to off-reef sedimentation during this time. Restricted-marine carbonates equivalent to the Slave Point platform were deposited in the southern part of the basin. The intra-platform basin became infilled by the regressive sequence (d). A shelf complex developed in southern Saskatchewan (Souris River Shelf), consisting of a series of shallowing-upward carbonate-evaporite cycles (Souris River Formation). These cycles grade laterally northwestward to shallowing-upward shale-carbonate clinothem cycles that were deposited in a basin to slope depositional setting. The clinoforming cycles depositionaly downlap the transgressive reef complexes. Basinal conditions existed within the Horn River Basin.

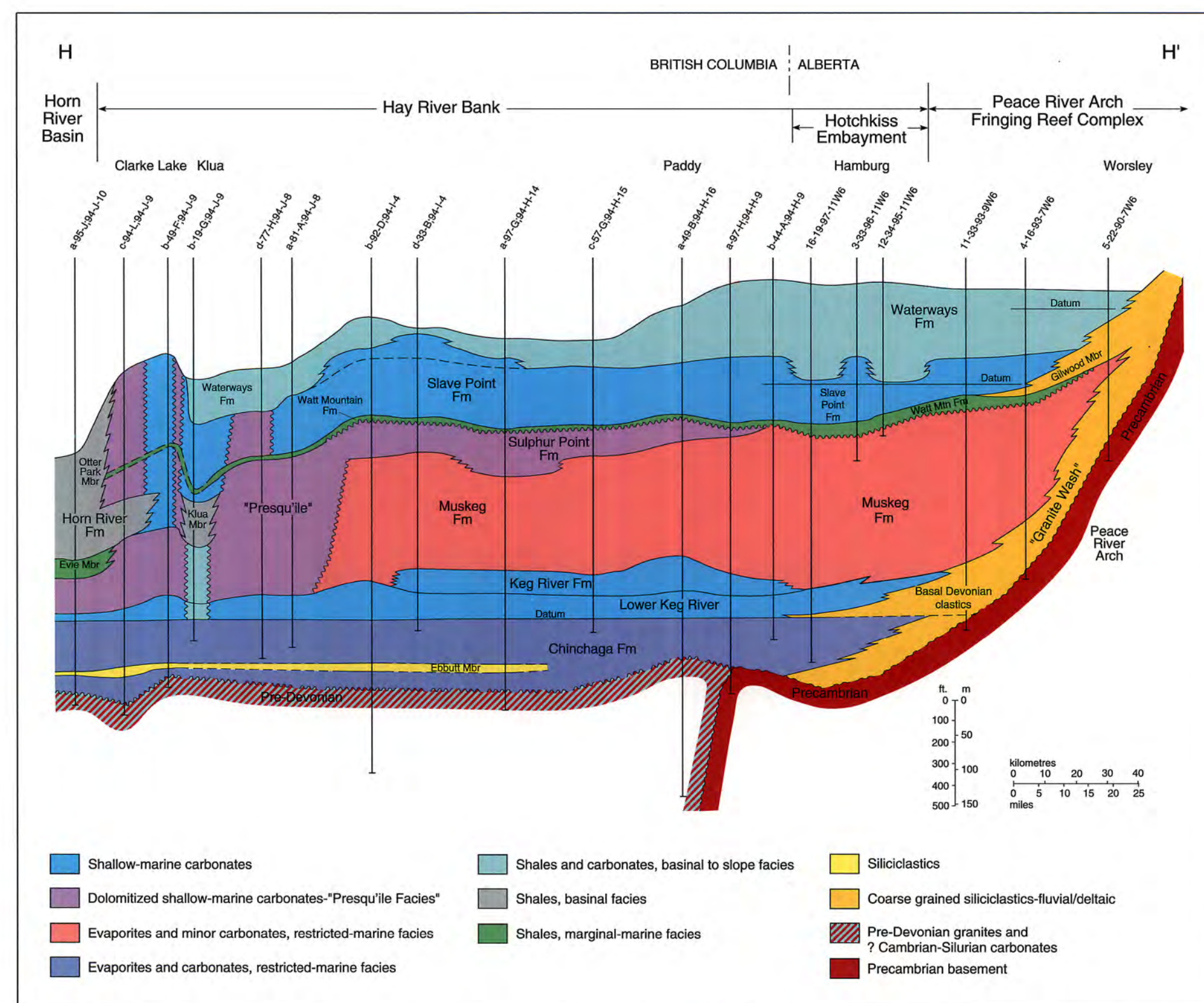


Figure 11.17 Stratigraphic cross section H-H', illustrating Beaverhill Lake and Elk Point stratigraphy from the barrier margin of the Hay River Bank southward, as the whole succession overlies the Peace River Arch. The Elk Point stratigraphy is illustrated because of the interrelationship of the two groups in this area. Shallow-marine carbonates of the transgressive sequence (Slave Point Formation) thin southward as they overlap the Peace River Arch. Hamburg (3-33-96-11 W6M) and Cranberry (not illustrated) are significant gas pools within the Slave Point Formation (Fig. 11.3) that developed as reef complexes within the Hotchkiss Embayment, or along the northern bank margin of the Peace River Arch Fringing Reef Complex. The Slave Point Formation is pervasively dolomitized along the bank margin of the Hay River Bank and marginal to embayments within the underlying Elk Point Bank complex (i.e., Klua Embayment, represented by b-19-G; 94-J-9). The upper part of the bank complex (Slave Point Formation) prograded farther basinward over the underlying Elk Point bank margin. The regressive phase (Waterways Formation) overlapped the Hay River Bank margin to the north and the Peace River Arch to the south. It filled the local paleotopography of the underlying bank complex (i.e., Hotchkiss Embayment). Note that the vertical scale (1:6800) is slightly contracted from the Atlas standard (1:6000) and the horizontal scale expanded. Line of section H-H' is shown on Figure 11.18.

Swan Hills Complex

The bank complex (Swan Hills Complex; Fig. 11.21) that flanked the West Alberta Ridge along the western margin of the basin (Fig. 11.1) developed during the transgressive phase. South of the Peace River Arch, the Gilwood Member formed a fluvial-deltaic complex (Jansa and Fischbuch, 1974) that prograded into a lacustrine to marginal-marine body of water during post-Elk Point relative sea-level rise (Fig. 11.16a). The Gilwood Member thins in an eastward and southward direction and the Watt Mountain Formation consists of green waxy shales with thinly interbedded limestones. Continued sea-level rise resulted in restricted-marine conditions, and evaporites and argillaceous dolomites of the Fort Vermilion Formation were deposited (Fig. 11.16b). The evaporites thin in a southeasterly direction and are stratigraphically equivalent to the First Red Bed Member, a continental facies. Open-marine carbonates of the Slave Point Formation cap the transgressive sequence (Fig. 11.16c). The Slave Point Formation formed a platform facies

that acted as a substrate for subsequent reef growth of the Swan Hills Formation.

The bank complex developed as a series of shallowing-upward reefal cycles, each 10 to 15 m thick (Fig. 11.22). A relative rise of sea level initiated each cycle and drowned the previous reefal cycle (Wendte and Stoakes, 1982). As a result the cycle boundaries are identified by a basinward shift in facies within a vertical sequence. The rate of relative sea-level rise subsequently decreased, producing a shallowing-upward sequence. Each cycle developed a windward, high-energy reefal margin (eastward facing) that developed either aggradationally or progradationally (Wendte and Stoakes, 1982). The reef margin separated the low-energy reef interior from the open-marine basin. Wendte and Stoakes (1982) provide a detailed discussion of the various depositional environments and their lateral and vertical facies variation, and present a paleobathymetric profile.

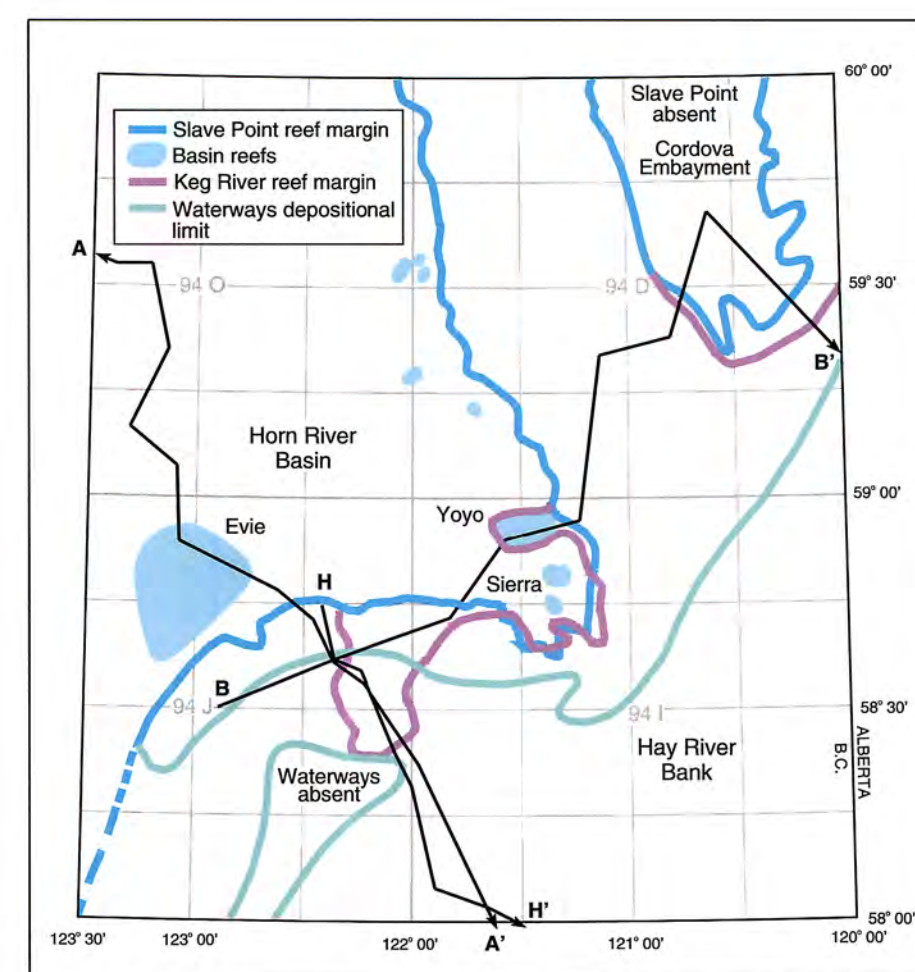


Figure 11.18 Paleogeographic map of the Horn River Basin and Hay River Bank. The reef margin of the transgressive phase (Slave Point), the basin reefs, and the depositional limit of the regressive phase (Waterways Formation) are illustrated. Where the underlying Elk Point barrier margin is not coincident with the Slave Point reef margin it is illustrated separately.

The cycle 1 reef margin developed coincident with a high-energy reef-shoal facies of the platform. This reef margin was probably influenced by paleotopography on the platform. Jansa and Fischbuch (1974) suggest that paleotopography of the underlying Gilwood delta complex and resulting differential compaction was the major influence on paleotopography. The cycle 2 reef margin developed farther landward (westward) as a result of the relative sea-level rise that drowned the cycle 1 reef. Basinward of the cycle 2 reef margin, deposition in localized areas on the cycle 1 bank was able to keep up with the rise of sea-level and cycle 2 reefs developed (i.e., Judy Creek, Swan Hills South, etc.). Subsequent pulses of relative sea-level rise developed shallowing-upward reefal cycles aggradationally on cycle 2 banks (Judy Creek; Wendte and Stoakes, 1982) or backstepped the complex farther landward. As a result the Swan Hills complex evolved as a series of backstepping, reef-rimmed banks and isolated reef complexes.

The bank complex continues southward along the west Alberta Ridge into southern Alberta. The Caroline Field (Tp 34, R 4 W5M) is situated along the reefal margin of the complex. As illustrated in Figure 11.23, the bank consists of several shallowing-upward reefal cycles that backstep in a westward direction as a result of episodic pulses of relative sea-level rise. Farther westward the bank complex is overlain by Frasnian carbonates, forming a continuous carbonate succession.

Porosity development in the Swan Hills area is associated with the high-energy reef margin facies of each shallowing-upward cycle (Wendte and Stoakes, 1982). Dolomitization occurs in some banks or reefs (Kaybob South, Rosevear, etc.) and is commonly associated with the bank-margin facies, suggesting a facies relationship. Porosity development in the Caroline Field is a function of facies and dolomitization along the bank margin.

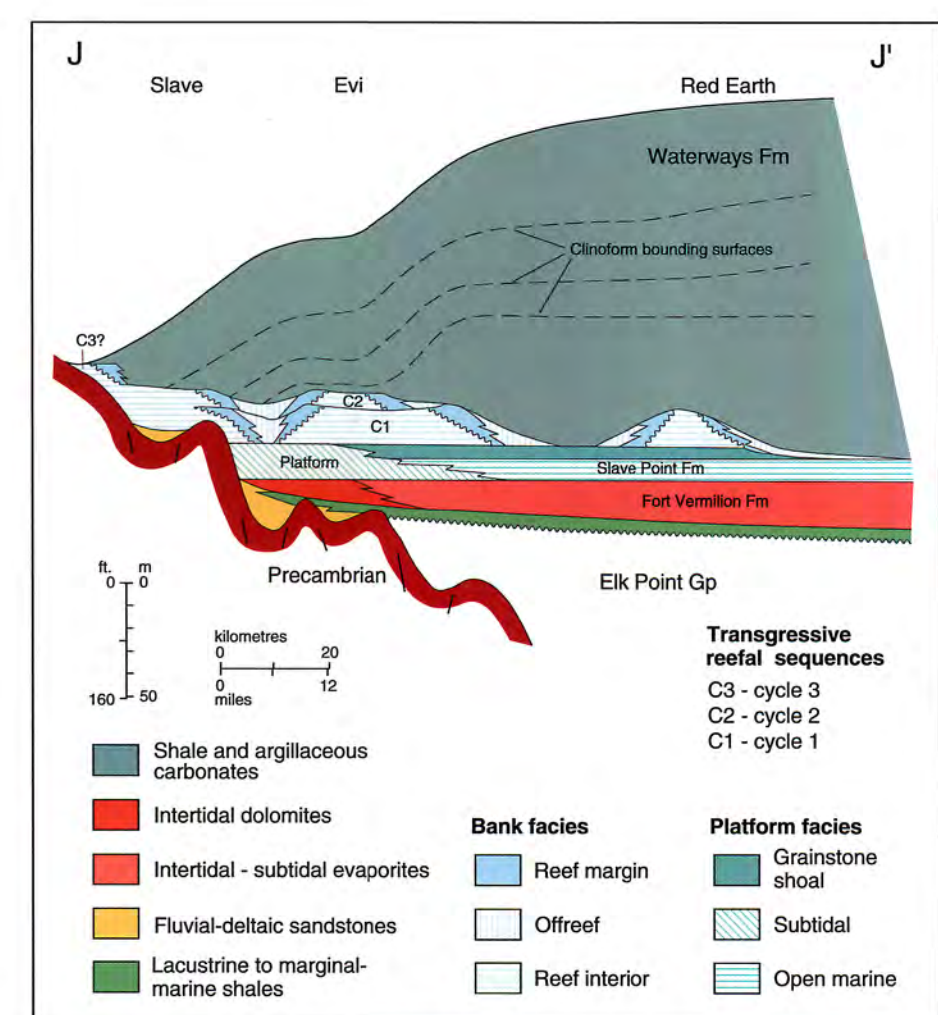


Figure 11.19 Stratigraphy of the Peace River Arch Fringing Reef Complex. The bank complex of the transgressive phase developed in a backstepping manner and is composed of several shallowing-upward "reefal" cycles. The stratigraphy is based on interpretations by Gosselin et al. (1989) for Evi, Dunham et al. (1983) for Slave, and unpublished regional stratigraphy by the senior author. The paleotopography of the Precambrian surface influenced the development of the bank complex. The clinothems of the regressive phase overlap (downlap) the bank complex and the paleo-landmass. Line of section J-J' is shown on Figure 11.20.

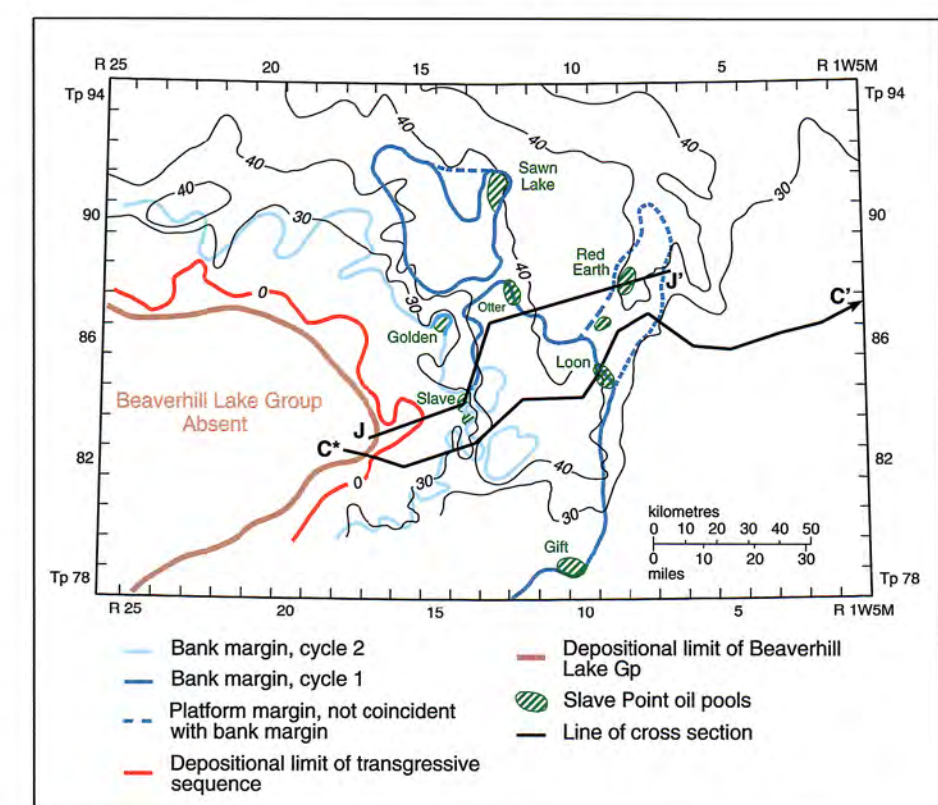


Figure 11.20 Peace River Arch Fringing Reef Complex paleogeographic map illustrating the bank margins, depositional edges and isopachs of the transgressive phase. The locations of sections J-J' (Fig. 11.19) and C'-C' (Fig. 11.10) and major Slave Point oil pools are indicated.

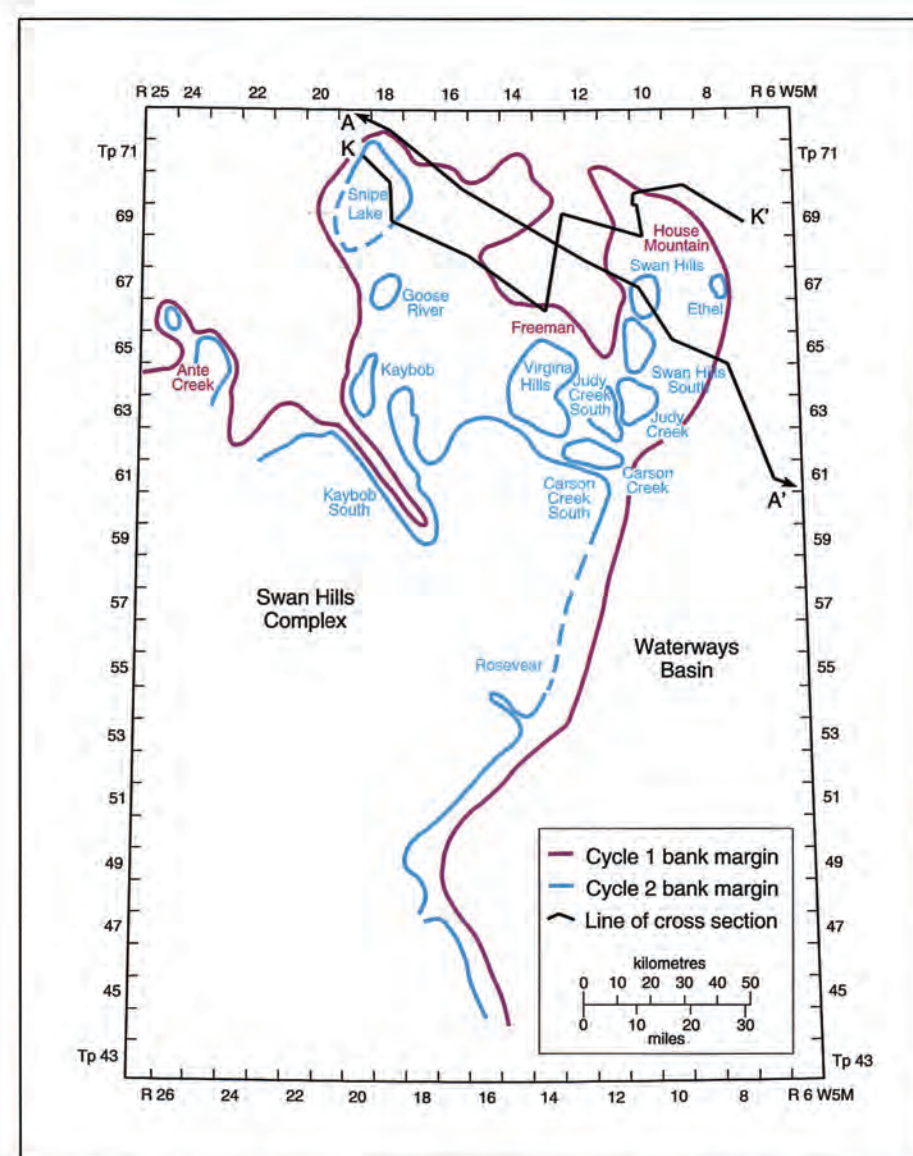


Figure 11.21 Swan Hills Complex paleogeographic map illustrating the cycle 1 and 2 bank margins of the transgressive phase. Younger "reefal" cycles developed aggradationally on the cycle 1 and 2 banks, but are not illustrated in detail (refer to Jansa and Fischbuch, 1974). The bank margins are modified from previous workers, mainly Jansa and Fischbuch (1974).

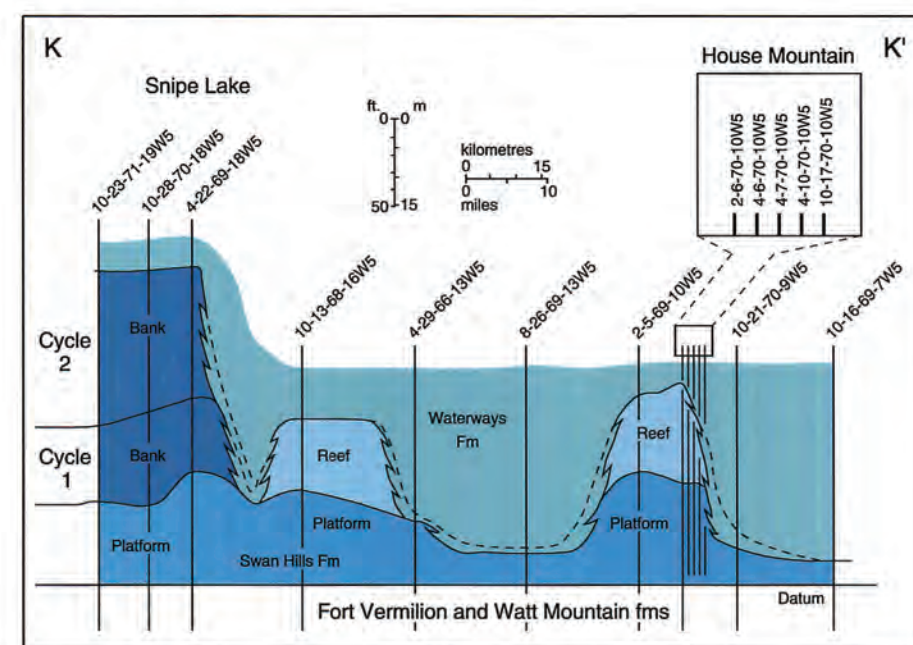


Figure 11.22 Stratigraphic cross section K-K', portraying the stratigraphy of the transgressive sequence across the Swan Hills Complex. The cross section is taken from Jansa and Fischbuch (1974) with the depositional facies simplified. Line of section K-K' is shown on Figure 11.21.

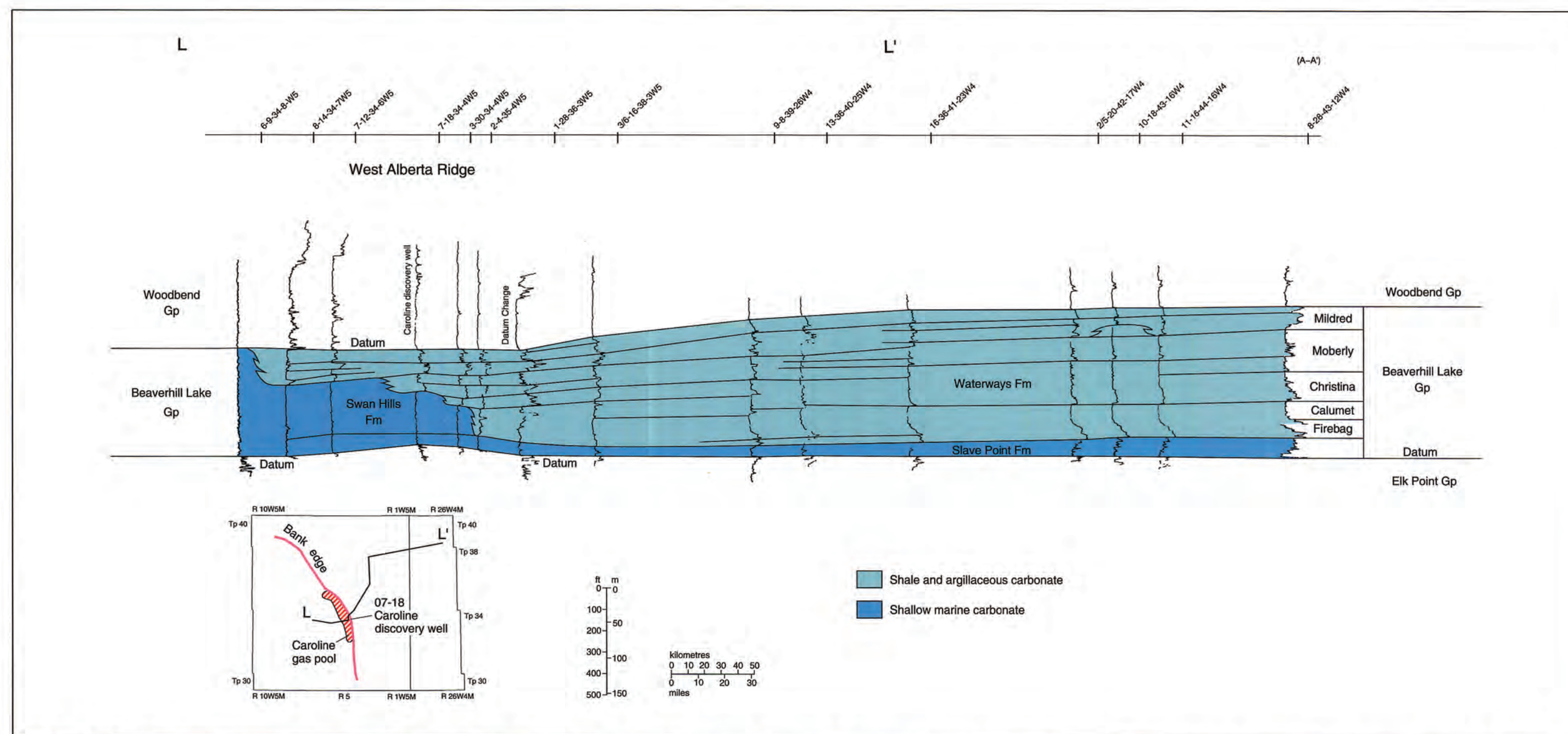


Figure 11.23 Caroline area stratigraphic cross section L-L'. The Swan Hills Complex marginal to the West Alberta Ridge in the Caroline area developed as a series of westward backstepping, shallowing-upward "reefal" cycles. A high-energy reefal facies developed along the bank margin of each cycle. Westward, the Swan Hills reef complex merges and becomes difficult to distinguish from overlying carbonates of the Woodbend Group. The regressive sequence (Waterways Formation) downlapped the transgressive reef complex in a westward direction.

The clinothems of the regressive phase (Waterways Formation) depositionally downlap onto the bank complex (Fig. 11.23) and infill interbank areas. These impermeable carbonates provide top and lateral seals for hydrocarbon accumulations associated with the bank complexes. Sheasby (1971) indicates that deep-water sediments of this phase were derived from the east and are significantly younger than the shallow-marine carbonates of the bank complex. Numerous workers report the presence of a hardground surface at the top of the Swan Hills Formation. It is thought that the hardground represents a submarine hardground (Wendte and Stoakes, 1982), marking a transition period between the depositional sequences. Biostratigraphic evidence indicates a distinct faunal change between the two successions, suggesting non-contemporaneous deposition (Braun et al., 1988).

The Swan Hills Complex is separated from the Peace River Arch Fringing Reef Complex in the vicinity of Latitude 55°N (Fig. 11.1). The platform (Slave Point Formation) changes from a shallow-marine facies within the bank complexes to an open-marine facies in the interbank areas. During subsequent periods of reef development the area remained a site of basinal sedimentation and later became infilled with clinothems of the regressive sequence.

The evolution of the two bank complexes is very similar (Fig. 11.24). Both complexes have a platform composed of shallow-marine facies, and high-energy reef-shoal facies formed the base for subsequent reef growth (Jansa and Fischbuch, 1974; Tooth and Davies, 1989; Gosselin et al., 1989). Periodic pulses of relative sea-level rise formed shallowing-upward "reefal" cycles 10 to 15 m thick that are stacked aggradationally or in a backstepping manner. The Swan Hills Complex developed more aggradationally and formed a thicker transgressive reefal sequence than the Peace River Arch Fringing Reef Complex, which formed as a series of backstepping banks. This was probably the result of greater basin subsidence (accommodation space) in the Swan Hills area than in the area flanking the Peace River Arch.

Waterways Basin

The regressive phase (Waterways Formation) of the Beaverhill Lake Group dominates the intra-platform basin (Fig. 11.1). The basin is infilled by shale-carbonate clinothem cycles that extend westward and northward and downlap onto the bank complexes.

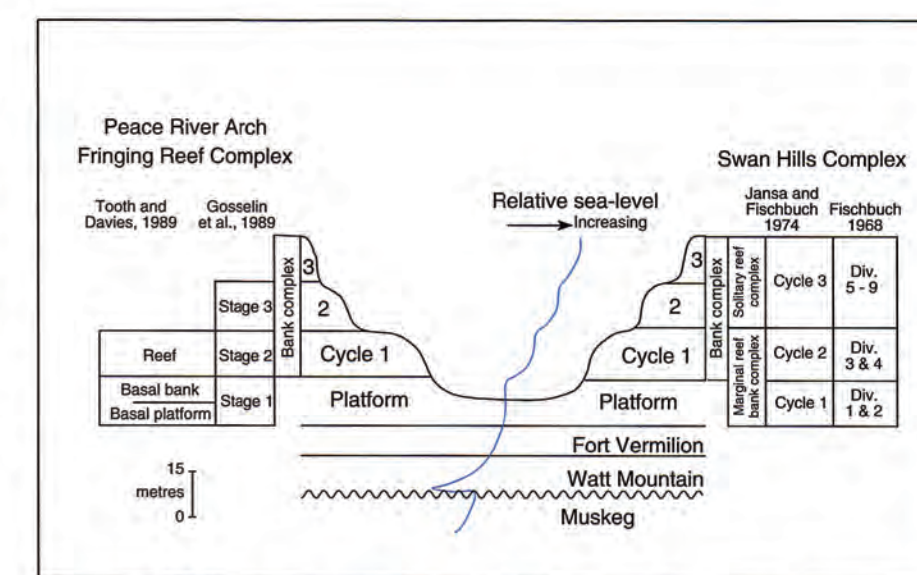


Figure 11.24 Peace River Arch Fringing Reef Complex - Swan Hills Complex correlation panel. Correlation of the transgressive reef cycles from the Peace River Arch Fringing Reef Complex and the Swan Hills Complex represents the senior author's interpretation. A relative sea-level curve is presented for the transgressive sequence. Each cycle was initiated by a relative sea-level rise. As the rate decreased the bank grew to sea level, forming the characteristic shallowing-upward "reefal" cycle.

The transgressive phase consists of the Watt Mountain, Fort Vermilion and Slave Point formations (Fig. 11.6d). Post-Elk Point transgression deposited green, waxy shales with thinly interbedded limestones (Watt Mountain Formation) that grade vertically to evaporites with interbedded dolomites and shales (Fort Vermilion Formation). This deepening-upward succession is capped by open-marine limestones (Slave Point Formation) that were deposited in an off-reef to basinal depositional environment (Fig. 11.16a, b, c). The lack of platform facies development precluded subsequent reef growth.

The transgressive phase (Fig. 11.16d) averages about 20 m in thickness within the basin area (Fig. 11.4). The Slave Point Formation is only 5 to 6 m thick within the basin, but thickens westward as it develops into a platform and bank complex. The Fort Vermilion gradually thins in a southerly direction and becomes stratigraphically equivalent to the First Red Bed Member. The Watt Mountain Formation remains relatively constant in thickness until it becomes stratigraphically equivalent to the Dawson Bay Formation in the southern portion of the basin (Fig. 11.14).

The regressive phase (Waterways Formation) is composed of numerous shallowing-upward shale-carbonate clinothem cycles that infilled the basin (Fig. 11.11). The Waterways Formation was originally subdivided into five lithostratigraphic members (Crickmay, 1957), but the shale-carbonate clinotherm cycles do not correspond to this lithostratigraphic subdivision. Each cycle is composed of a shale base that grades vertically to argillaceous carbonate, representing a basin to slope depositional environment. The shelf depositional environment is represented by the carbonate evaporite cycles of the Souris River Formation in the southern part of the basin (Figs. 11.8b and 11.11). The transition between the clinotherm cycles of the Waterways Basin and the shallowing-upward cycles of the Souris River Shelf are illustrated as abrupt (Figs. 11.8b and 11.11); however, the relation is in fact progradational and very transitional, as illustrated schematically in Figure 11.15.

Southern Bank

In the region of the Souris River Shelf, the transgressive phase is represented by the Dawson Bay Formation, the First Red Bed Member and the basal shallowing-upward cycle of the Souris River Formation (Fig. 11.6e). The Dawson Bay Formation represents a deepening-upward transgressive sequence, unconformity bounded, deposited within the Dawson Bay Basin (Fig. 11.16a). The Second Red Bed Member, a dolomitic mudstone, represents initial deposition following exposure and erosion of the Elk Point surface (Fig. 11.16b). As relative sea level continued to rise, restricted-marine carbonates of the Burr Member (Dunn, 1982a, b) were deposited (Fig. 11.6e). Dunn (1982a, b) documented the presence of numerous hardgrounds that are interpreted as representing periods of nondeposition or subaerial exposure within the Dawson Bay Basin. The Burr Member is overlain by open-marine carbonates of the Neely Member (Fig. 11.6e), indicating continued relative sea-level rise. Carbonates of the Neely Member contain "reefal" beds consisting of normal-marine fauna, corals and stromatoporoids. The sequence is capped by restricted-marine carbonates and anhydrites and, locally, by the Hubbard Evaporite, a halite unit, indicating a fall in relative sea level. These sediments were deposited in a sabkha environment (Dunn, 1982b).

The Dawson Bay Formation is illustrated in Figure 11.8b to be stratigraphically equivalent to the Watt Mountain Formation in northern Alberta. Dunn (1982) stated that the Dawson Bay Formation is equivalent to the Watt Mountain Formation, but also included the First Red Bed Member within the stratigraphic section. This interpretation does not conflict with the biostratigraphic data (Braun and Mathison, 1986) but does pose two questions: what was the origin of the sub-basin, and what was the direction of the marine incursion?

During the exposure of the Elk Point Group, solutioning of the underlying salts may have created a local depression. The deposition of Dawson Bay carbonates within such a topographic low could have caused continued subsidence and created an aurally extensive sub-basin. Carbonate sedimentation changed to evaporite sedimentation as relative sea-level fell (rate of sedimentation greater than accommodation space) and the beds eventually became subaerially exposed by the end of Dawson Bay deposition.

Braun and Mathison (1986) and Dunn (1982b) identified an ostracod within the Burr Member that is typical of the Michigan area, suggesting an incursion of a seaway from the southeast. However ostracods found in the normal-marine Neely Member exhibit a western affinity (Braun and Mathison, 1986). This suggests an initial southeasterly marine influence followed by a northerly influence during deposition of the Dawson Bay sequence. The northern part of the basin was periodically subaerially exposed during deposition of the Burr and Second Red Bed members. Multiple exposure surfaces within the Burr Member (Dunn, 1982b) may reflect tectonic pulses associated with the Peace River Arch, as suggested by Braun and Mathison (1986). This paleo-landmass divided the basin into two local sub-basins during early Dawson Bay deposition. Within the upper portion of the Watt Mountain Formation in northern Alberta, limestone beds are present, indicating a marine influence from the north. This marine incursion may have extended farther southward along the eastern side of the interior basin into the Dawson Bay Basin, providing the western faunal influence during Neely Member time. The marine influence was terminated as the Dawson Bay sequence was capped by restricted-marine carbonates, evaporites and halite. In Alberta, continental to marginal-marine deposits of the Watt Mountain Formation gave way to restricted-marine conditions as the sea advanced farther southward. The Fort Vermilion Formation exhibits a facies change (Fig. 11.16b) in a southeasterly direction and is thought to be correlative with the First Red Bed Member of the Souris River Formation. The open-marine Slave Point Formation also exhibits a facies change to a restricted facies in a southerly direction (Fig. 11.16c) and may be equivalent to the lower cycle of the Davidson Member of the Souris River Formation.

The remainder of the Souris River Formation was deposited during the regressive depositional phase. The Souris River Formation is made up of numerous shallowing-upward carbonate-evaporite cycles (Figs. 11.12, 11.13) that form the Souris River Shelf (a carbonate platform). These carbonate-evaporite cycles prograde basinward (northwest) to shale-carbonate clinothem cycles that constitute the Waterways Formation in Alberta. The cyclic carbonate-evaporite sequences continue into the Woodbend succession (Duperow Formation) without any significant hiatus (Switzer et al., *this volume*, chapter 12).

Summary

The Late Frasnian to Early Givetian aged Beaverhill Lake Group is composed of two distinct depositional phases; a transgressive 'reefal' phase and a regressive 'basin-fill' phase. During the transgressive phase, the intra-cratonic basin became segregated into bank complexes and basinal areas. The regressive phase infilled the interbank and basinal areas and overlapped the bank complexes of the transgressive phase.

The transgressive phase was deposited during a period of relative sea-level rise. A shallowing-upward depositional sequence was deposited above exposed and eroded evaporite sediments of the underlying Elk Point Group. Continental to marginal-marine sediments of the Watt Mountain Formation, evaporites and restricted marine carbonates of the Fort Vermilion Formation and open-marine carbonates of the Slave Point Formation constitute this transgressive sequence. A fluvial-deltaic system developed flanking the Peace River Arch and a marine sub-basin developed in southern Saskatchewan during Watt Mountain/Dawson Bay deposition. The southward-advancing sea produced open-marine conditions over the majority of the basin by the end of the Slave Point (lower Slave Point in the northern basin). The (lower) Slave Point formed a platform for subsequent reef and Bank development. The bank complexes are composed of cyclic shallowing-upward reefal sequences (Swan Hills or upper Slave Point formations) which formed as a result of episodic fluctuations of relative sea-level rise. The response of the bank complexes to the relative sea-level rise ranges from vertical aggradation (Hay River Bank) to transgressive backstepping (Peace River Arch Fringing Reef Complex), or a combination of both (Swan Hills Complex).

The regressive phase was deposited during a period of relative sea-level fall or decreased rate of relative sea-level rise. The Souris River Shelf, composed of cyclic shallowing-upward sequences (Souris River Formation), developed in the southern portion of the basin. The lack of basin accommodation and/or sea-level fall gave rise to a progradational depositional style. The shelf sequences prograded northward to basin-slope clinothem cycles (Waterways Formation) that infilled the inter-bank and basin paleotopography and overlapped the bank complexes.

This sedimentation style was initiated during Beaverhill Lake Group deposition and continued and became accentuated during subsequent Woodbend and Winterburn deposition.

Acknowledgements

The authors appreciate the assistance offered by Katy Ma during the initial stage of the compilation. Input provided by Nic Meijer Drees into the stratigraphy of the northern portion of the basin was invaluable. Discussions with Steve Switzer enhanced the understanding of the stratigraphic relation between the Beaverhill Lake and Woodbend groups. The support provided by Sceptre Resources Limited in the preparation of the figures and text is greatly appreciated.

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Frontispiece 12.0 Devonian reefal facies. Stromatoporoidal dolomites of the Devonian Caim Formation (Leduc equivalent) on the shoulder of Mt. Rundle, White Man Gap, above Canmore, Alberta. The vugs are produced mostly by near-surface solution processes, but the groundmass dolomite has good intercrystalline porosity of the type that characterizes many of the most important petroleum reservoirs in Woodbend-Winterburn strata of the Alberta subsurface. Photograph by G.D. Mossop.