Chapter 7 – Paleogeographic Evolution of the Cratonic Platform - Cambrian to Triassic

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Introduction

The formation of a Paleozoic passive margin on the western side of the North American proto-continent played an integral part in the growth of the Western Canada Sedimentary Basin. To consider the entire 4000 km length of this western trailing edge as a nontectonic margin would be an oversimplification, given that at least the United States portion was subjected to intense tectonic activity. The end product of this activity was the Antler Orogeny. This event had a significant influence on the late Paleozoic growth of the cratonic margin and platform.

The stratigraphy of the cratonic platform and margin is shown in Figure 7.1, in simplified form. Twelve maps depicting the interpreted paleogeography at selected lithostratigraphic levels illustrate the evolution of the cratonic platform and margin. Each interval is highlighted on the correlation charts accompanying the maps. The maps are a synthesis of the most recent literature on the depositional environments and distribution of facies for the stratigraphic units that they represent. Where there is a conflict of interpretation, the majority opinion is accepted; where there is no majority opinion, a compromise is presented. Because this is a synthesis, accuracy in the location of facies boundaries, erosional edges and stratigraphic equivalence is slightly distorted, for improved clarity. On all of the maps, areas of solid colour depict the preserved distribution of facies belts, the hachured areas their inferred original extent prior to erosional removal.

Growth of the Western Cratonic Margin

The North American proto-continent was isolated from a Late Proterozoic supercontinent by multi-phase rifting. The rifting created eastern and western continental margins, in the period between 730 and 555 Ma.

Ross et al.(1989) inferred that continental margin sedimentation began on the western side from about 730 to 726 Ma. According to Bond et al. (1984), initiation of the Iapetus Sea, creating the eastern continental margin, occurred probably between 625 Ma and 555 Ma.

Prior to the rifting that created the proto-Pacific passive margin, thick sequences of siliciclastics and carbonates belonging to the Purcell and Belt supergroups were deposited in intracratonic basins, created by early partial rifting (Winston et al., 1984). The thickness of this Upper Proterozoic sequence, some 15 km, and the presence of basaltic flows at various stratigraphic levels, implies a possible aulacogen as the site of sedimentation.

Ross et al. (1989) suggested that the rocks of the Windermere Supergroup that overlie the Purcell may represent, in part, initial continenal margin sediments. However, they suggest that paleocurrent evidence indicates that the sediments have an eastern and western source and that deposition appears to have been in a northwesterly trending deep trough, interpreted as being an indication of a rifted valley setting. The basal deposits of the supergroup are thought to be diamictites of glacial origin. The remainder of the succession appears to represent a shallowing-upward sequence that includes: graded pebbly and coarse-grained sandstone, and laminated mudstone passing upward into sandstone, siltstone, mudstone and carbonate. The lower strata are thought to represent turbidite and submarine-fan deposits and the upper, some of which contain trace and body fossils, are thought to be of shallow-water shelf origin. Readers are referred to Hein and McMechan (*this volume*, Chapter 6) for details of Proterozoic tectonics and sedimentation.

Cratonic Margin and Platform

Cambrian-Lower Ordovician Interval

Initial Continental Margin Wedge

A regionally extensive unconformity creating disconformable, angular and nonconformable relations between the Cambrian sequence and the underlying Precambrian on both the cratonic margin and platform, was developed following deposition of the Windermere Supergroup. Rocks of the Cambrian Gog Group probably represent initial growth of the continental margin wedge in the southern part of the Canadian Cordillera (Aitken, 1989). Farther to the north, rocks of similar age appear to have been deposited in a setting where syndepositional block faulting influenced sedimentation. The Gog rocks are predominantly quartz arenites with minor amounts of mudrocks and carbonates, all totalling 2.2 km in thickness (Aitken, 1989). Sedimentary structures, trace and body fossils, and general overall character of these rocks suggests shallow-water deposition (Hein, 1987). Their characteristics and thicknesses are typical of the rapid thermal subsidence phase of early growth of a passive margin. Readers are referred to Hein and McMechan (*this volume*, Chapter 6) for a more detailed accounting of the early growth of the continental margin.

The Earliest Cratonic Transgression

Figure 7.2 depicts the inaugural Phanerozoic inundation of the proto-North American continent at the Pika/Earlie/Deadwood stratigraphic level. The transgression is typified by a basal orthoquartzitic sandstone and a depositional dip lithofacies gradation (east-to-west) from inshore quartz sandstones through platform mudrocks to outer shelf carbonates. The depositional strike of these lithofacies is subparallel to the northwest trend of the proto-continental margin, except where they have a westerly strike following the inferred paleoshoreline of the Peace River/Athabasca Arch (Pugh, 1973). South of the arch, outboard deposits from the shelf-edge carbonates are thick, fine-grained siliciclastics, thought to have been laid down in a deep basin. The basinal region north of the arch was influenced by an active fault system producing horst and graben features (Aitken, 1989) and a variable lithological character.

The transition from eastern platform siliciclastics to outer shelf carbonates is distinctive because it is marked by an intertonguing relation that Aitken (1978) identified as Grand Cycles. He recognized seven Grand Cycles, of which the Pika is one of the earliest. Each is composed of a basal mudrock and an upper carbonate unit. The cycles are attributed to eustatic sea-level rises and falls and are considered to be excellent examples of fine-grained siliciclastic/carbonate parasequences. The carbonate portion of each parasequence exemplifies shoal-water conditions that in places terminate in typical peritidal deposits. The shelf margin is clearly recognizable, particularly south of the Peace River Arch, where it is marked by the Cathedral Escarpment (McIlreath, 1977), a typical lime-sand shoal bypass margin (McIlreath and James, 1979). Slind et al. (*this volume*, Chapter 8) present the detailed lithological characteristics of these strata.

The Cambrian-Lower Ordovician phase of the evolution of the cratonic platform was brought to a close by a significant relative sea-level drop. In the cratonic platform it is recorded as a sub-Middle Ordovician unconformity, an erosion surface of continental dimensions, representing a lacuna extending from Early to Middle Ordovician. The extent of subaerial exposure of the continental margin deposits is not evident because the unconformity merges with a sub-Devonian unconformity, at least as far north as the Peace River/Athabasca Arch.

Middle Ordovician-Silurian Interval

For convenience of reference this interval is divided into four subintervals (OS1 - OS4), each depicting a specific event in the depositional history of the cratonic platform during this period of geological time. The subintervals are similar to, but not necessarily synchronous with the subcycles described for this period by Cecile and Norford (*in press*).

The Second Cratonic Inundation - Subinterval OS1

For the 10 million year extent of this subinterval much of the southern part of the continental margin and the southwestern cratonic platform were under the influence of Montania and a northwest extension of it, commonly known as the West Alberta Ridge. Therefore, flooding of the cratonic platform appears to have been from the southeast, mainly in the Williston Basin area (Fig. 7.3).

Kent and Christopher (*this volume*, Chapter 27) indicate that the inauguration of subsidence of the Williston Basin was coupled with the deposition of the sediments that represent this subinterval. The basal sediments of this transgression are typically orthoquarzites, as found in the lower part of the Winnipeg Formation, but farther to the east, in central-southern Manitoba, there is a change of facies to mudrock. Depositional limits of these transgressive lithotypes are difficult to determine, but data from Paterson (1971) and Vigrass (1971) suggest that the northern and western depositional edge was not much beyond the present erosional edge. In the east, east-trending thickness patterns truncated by the present-day eroded edge of the Winnipeg infer a possible connection to Hudson Bay (McCabe,1967; Vigrass, 1971; Andrichuk, 1959).

Osadetz and Haidl (1989) and Cecile and Norford (*in press*) implied that the West Alberta Ridge was not submerged until Late Ordovician time, the implication being that sediment accumulation on the western platform, prior to that time, was limited to the area north and west of the Peace River/Athabasca Arch; the latter was probably also a positive element. Norford et al. (*this volume*, Chapter 9) show basinal deposits belonging to the Road River Formation occupying the basin north of the arch, as well as some carbonates on the shelf.

The Carbonate Sea - Subintervals OS2 to OS4

The clastic transgressive phase of subinterval OS1 was followed by a long period of mostly carbonate sedimentation over much of the proto-North American craton. Montania, the West Alberta Ridge and the Peace River/Athabasca Arch were positive when carbonate sediments first accumulated on the eastern platform. However, the former two were probably undergoing transgression, and the ridge at least was submerged by mid-Late Ordovician time, as implied by the presence of the Mount Wilson Formation at the extreme edge of the western platform (Osadetz and Haidl, 1989; Cecile and Norford, *in press*). Figure 7.4 shows that during subinterval OS2 carbonate sedimentation on the cratonic platform was confined to the Williston Basin area. Other evidence of sediment accumulation at this time is from the deep-basin rocks of the Road River Formation and the transgressive orthoquartzites of the Mount Wilson Formation (Fig. 7.1).

The lowest part of the carbonate succession representing subinterval OS2 is distinguished by a burrow-mottled dolomite that is one of the most extensive lithostratigraphic units on the North American continent, identifiable from the northern islands of Hudson Bay to northern Mexico. This lithotype marks the beginning of a series of cycles, each terminating in hypersaline basinal deposits represented by anhydrite. Based upon work by Kent (1960) and Andrichuk (1959), Figure 7.4 depicts the extent of the Lake Alma Anhydrite (Kendall, 1976) in the lowest cycle. The map shows a postulated strandline on the Precambrian hinterland between 100 and 200 km north of the erosional edge. This strandline location is based on the depositional thinning of relatively easily correlatable units within the Red River Formation, as presented in Haidl (1988). The seaway is interpreted as having been open to the east toward Hudson Bay, as inferred from the thickness trends illustrated by McCabe (1967, 1971). In spite of the lack of evidence to verify the interpretation, the Peace River/Athabasca Arch is postulated as a low, positive-relief feature, and it is also speculated that a carbonate shelf-to-basin transition existed to the west at this time.

Subinterval OS3 is illustrated in Figure 7.5, depicting the western Canadian cratonic platform at the time of maximum submergence of the proto-continent. The argillaceous influx represented by the Gunn Member of the Stony Mountain Formation appears to have come from the southeast. Osadetz and Haidl (1989) interpreted the argillaceous component to have had its source in the Taconic orogen. The distribution of sediments on the western platform is speculative, but the carbonates preserved in the Beaverfoot Formation, proximal to the platform-to-basin transition, can be considered as evidence that the western platform was inundated. The paleogeography of the continental margin illustrated on the map is a simplification of that described by Cecile and Norford (*in press*). They interpreted the continental margin to be a region of troughs, basins, embayments and promontories, the first three containing deep-basin-to-slope deposits and the last, shelf carbonates. Arguments for the location of the depositional edge on the Peace River/Athabasca and Precambrian hinterland are similar to those used for the previous map, as is the argument for linking the seaway to Hudson Bay.

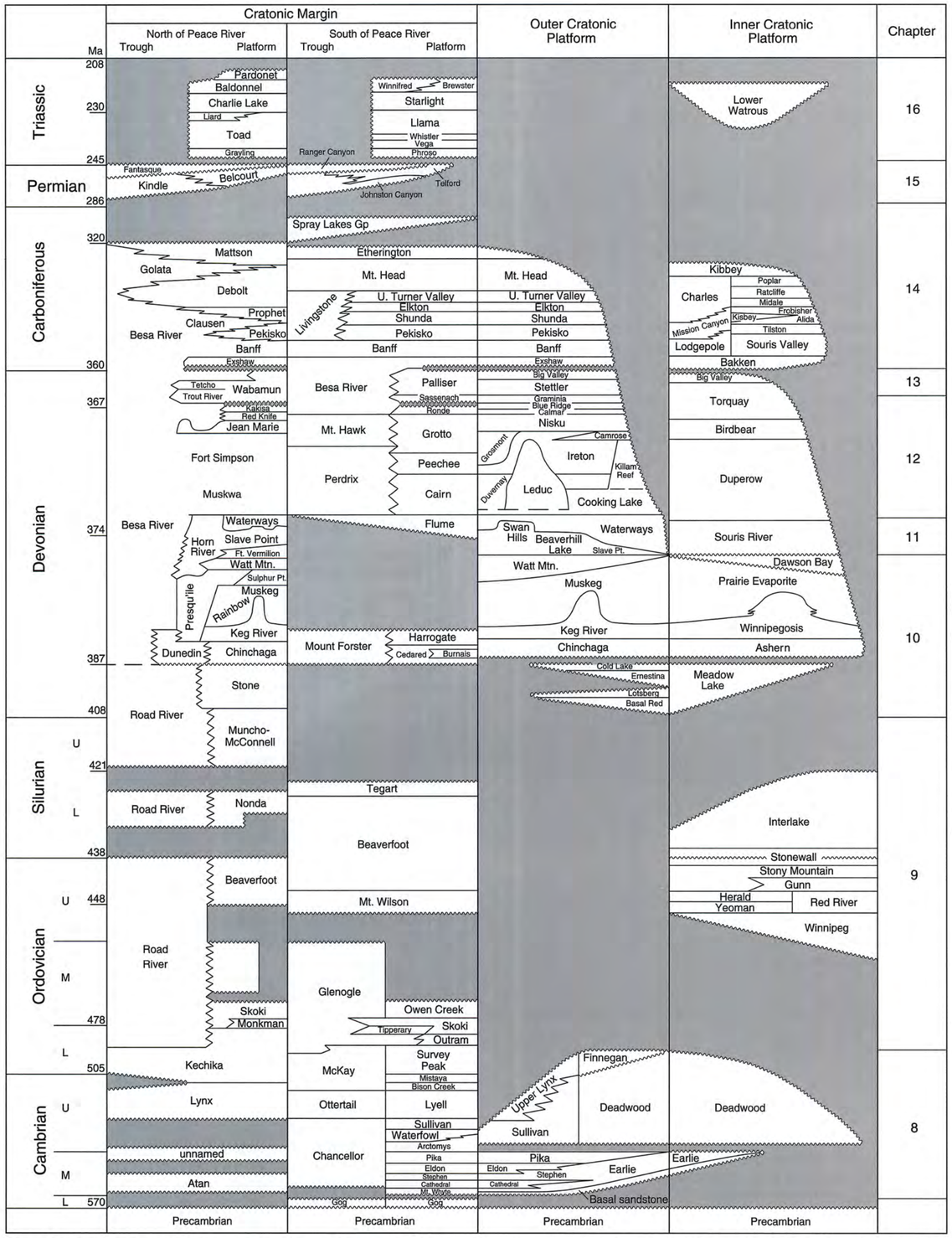


Figure 7.1 Correlation chart showing the composite stratigraphic succession for the eastern and western parts of the cratonic platform, and for the cratonic margin. The cratonic margin columns, where possible, identify stratigraphic units at the platform margin and in the deep basin for areas both north and south of the Peace River Arch/Embayment. The extreme right hand column lists the chapters to which the reader may refer for more detailed information on lithologies and facies relations.

Figure 7.6 portrays the fourth subinterval, the time of a shrinking carbonate sea. It is also within this stratigraphic interval that recognizable ecological reefs are identified on the eastern platform. Baillie (1951) and Stearn (1956) both described reefs from the Cedar Lake Formation of the Interlake area of Manitoba. Jamieson (1979) and Kent (1984b) also reported the presence of reef-like rocks in two borehole cores from south-central Saskatchewan.

In the eastern platform this subinterval is represented by the rocks of the Interlake Formation, which appear to make up a shallowing-upward megasequence. The lower part of the succession is clearly subtidal, but the upper part contains an assortment of lithological features (Norford et al., *this volume*, Chapter 9) that have been interpreted as indicators of a range of depositional and diagenetic mechanisms produced by subaerial exposure, vadose alteration (Haidl, 1987) and freshwater sedimentation (Magathan, 1987). The shallowing-upward megasequence was obviously a prediction of the end of the carbonate sea on the eastern platform and was followed by a period of exposure lasting some 36 million years.

The western platform may have been covered by carbonate deposits as well, but if so, their extent was significantly restricted by an enlarged Peace River/Athabasca Arch. Evidence of the presence of shelf carbonates on the western platform is found in the Nonda Formation north of the arch (Norford et al., 1966) and in the upper Beaverfoot and Tegart farther south. The continental margin continued to be a region of troughs, basins, and embayments in which slope and deep-basin deposits, mainly shales, were laid down. Platformal promontories, on which typical shelf carbonates were deposited, flanked the basins and embayments (Morrow, 1984; Cecile and Norford, *in press*). The break in the depositional record that is so pronounced on much of the cratonic platform does not appear to be present in the continental margin rock record, particularly north of the Peace River/Athabasca Arch, where the succession is continuous from latest Silurian to earliest Devonian (Cecile and Norford, *in press*).

Devonian-Lower Carboniferous Interval

This interval is divided into six subintervals (DM1 to DM6) to facilitate the presentation of specific events in its sedimentary history. The interval presents three contrasting styles of sediment distribution pattern, and five subinterval maps (Figs. 7.7 - 7.11) are employed to show them, three representing the Devonian and two the Lower Carboniferous.

The embryonic Devonian seaway was confined to a basin flanked by the Peace River Arch, the West Alberta Ridge and the Swift Current Platform in the west and south, the Laurussian hinterland to the north, and the Severn and Sioux arches to the east, extending as far to the southeast as the Transcontinental Arch. The initial inundation of this basin was from the northwest, a distinct contrast from the two previous depositional intervals.

A Coastal Hypersaline Basin - Subinterval DM1

The distribution of the facies in this subinterval is best described by reference to Figure 10.2 (Meijer Drees, *this volume*, Chapter 10). It shows that the eastern platform was a land surface, and the first Devonian sediments were deposited in a sub-basin lying between the Peace River Arch and Laurussian hinterland, terminated to the southeast at a low ridge of lower Paleozoic rocks commonly known as the Meadow Lake Escarpment.

The transgressive beds are characterized by a basal sandstone, and the remaining sediments in the basin consist of redbed sandstone, siltstone, and claystone. Interbedded with these are thick evaporite deposits of anhydrite and halite. Fuzesy (1980) interpreted the evaporites to have extended at least as far as the present erosional edge of Phanerozoic rocks in central-western Saskatchewan. Low bromine concentrations in the halite suggest a possible freshwater influence during salt deposition (Moore, 1989). An ostracod-bearing limestone, which is probably the equivalent of the ostracodal limestone of the Ernestina Lake Formation, is present as far east as the present Phanerozoic erosional edge (Kent, unpublished data), suggesting that Fuzesy's assumption concerning the distribution of evaporites is valid and that the depositional limits of the Lower Elk Point Subgroup/Meadow Lake Formation, comprising this subinterval, were at least 100 km beyond the present erosional edge.

The coastal basin deposits pass northwestward into typical carbonate platform sediments situated on what is known as the McDonald Platform. Moore (1989) reported that the oldest Devonian coral/stromatoporoid reef development has been recognized in the carbonates of the McDonald Platform. Outboard from the carbonate platform are the typical fine-grained, siliciclastic, deep-basin deposits of the Road River Formation.

Basinal Reefs and Hypersaline Basins - Subinterval DM2

The opening phase of this subinterval is characterized by a marine, carbonate-depositing sea that transgressed the platform through a southeast-trending trough-like depression, the Elk Point Basin, extending from northeast British Columbia to southern North Dakota. Williams (1984) presented several alternatives for the shape of the basin, particularly with regard to the location of the north margin. A slight variation on his alternative "C" is the one employed in Figure 7.7. The deposits of this sea imply relatively normal marine conditions, with a stenohaline biota dominated by brachiopods and crinoids. This initial period of sedimentation was one in which rates of subsidence and sedimentation were approximately equal, but it was followed by a time of catch-up deposition when carbonate wedges formed at the margins, while banks and both ecological and stratigraphic reefs grew on the basin floor (Fig. 7.7). There are probably several hundred reefs in the basin. Moore (1988) identified almost two hundred from the publications he reviewed, and there are another twenty or more in east-central Saskatchewan (Gendzwill and Wilson, 1984). Undoubtedly, there are many others that have not been discovered and an estimate of three hundred would not be out of order.

A sizable barrier reef (Keg River-Pine Point, part of the Presqu'ile barrier complex) developed across the northern end of the basin, extending northeastward from the Peace River Arch to a positive feature on the Laurussian hinterland, beyond the present erosional edge. In addition, there were several broad carbonate banks that may have restricted parts of the basin floor. In fact, Bebout and Maiklem (1973) and Moore (1989) implied that the banks may have been sufficiently extensive to isolate the basin floor into several sub-basins. Most of the bank accumulations appear to have been in northwestern Alberta; however, Wardlaw and Reinson (1971) suggested that there may also have been extensive bank growth in the Saskatoon area of central Saskatchewan.

Most of the basinal reefs appear to have been initiated by growth of crinoidal colonies (Langton and Chin, 1968; Martindale and Macdonald, 1990; Kent and Minto, 1991), but above the crinoidal interval the composition varies considerably. Those in the proximal end of the Elk Point Basin (northwestern Alberta) appear to be ecological reefs dominated by coral/stromatoporoid framework builders (Langton and Chin, 1968). Those in the basin on the eastern cratonic platform are stratigraphic reefs composed of peloid- and codiacean algae-rich lime mudstone to wackestone, in the lower parts, with a climax reef of coral/stromatoporoid and red algae (Gendzwill and Wilson, 1987; Martindale and MacDonald, 1990; Kent and Minto, 1991) in the upper 30 m. They take on assorted morphologies, from low-relief, mound-like features through pinnacles and pinnacle complexes, to flat-topped reefs

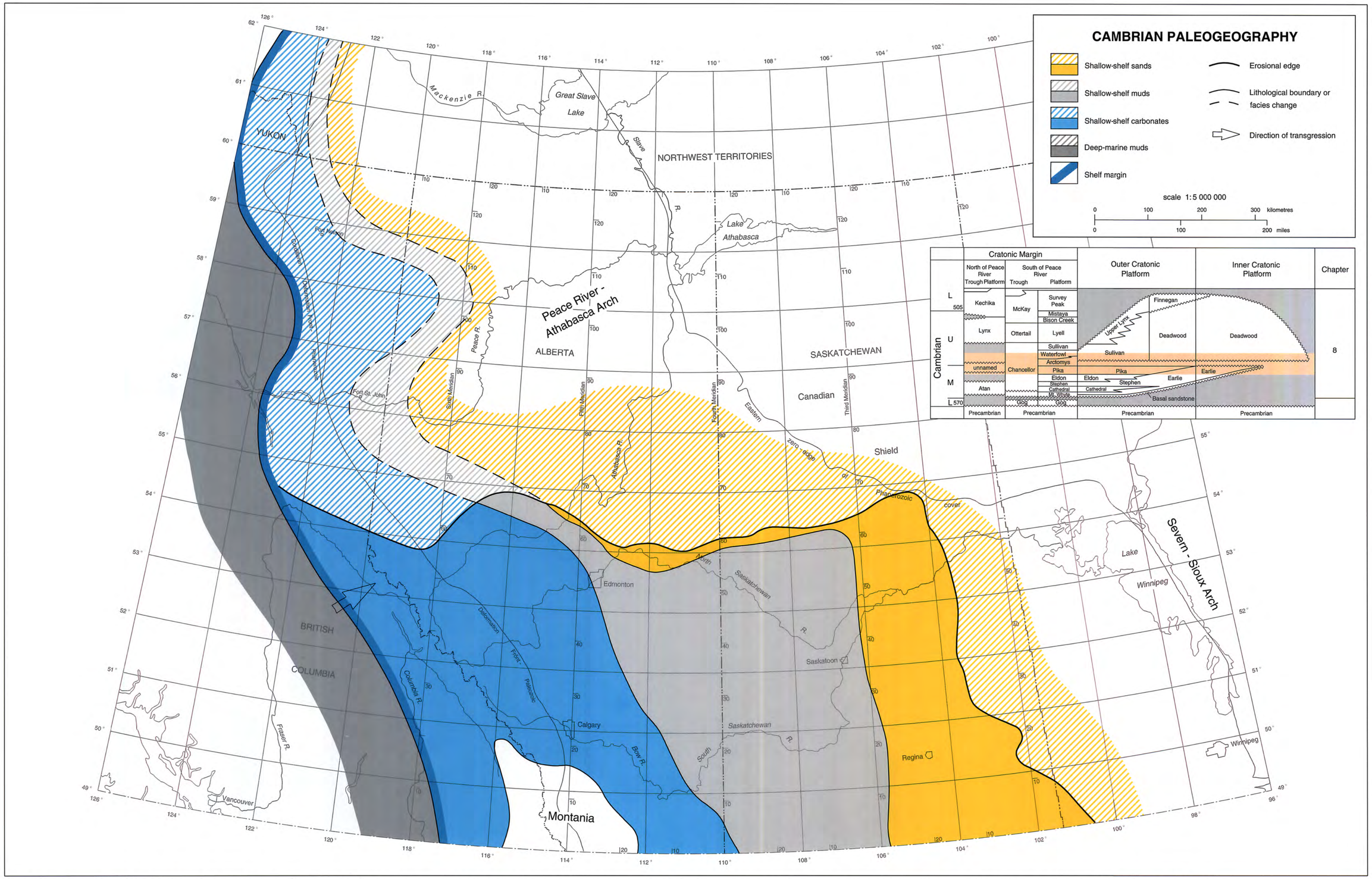


Figure 7.2 Paleogeography of the cratonic platform and margin in the Cambrian-Early Ordovician interval. The flooding surface over which the Cambrian sea transgressed the platform was not flat, but was, in fact, interrupted by several Precambrian monadnocks, particularly on the eastern platform (Sawatzky et al., 1960).

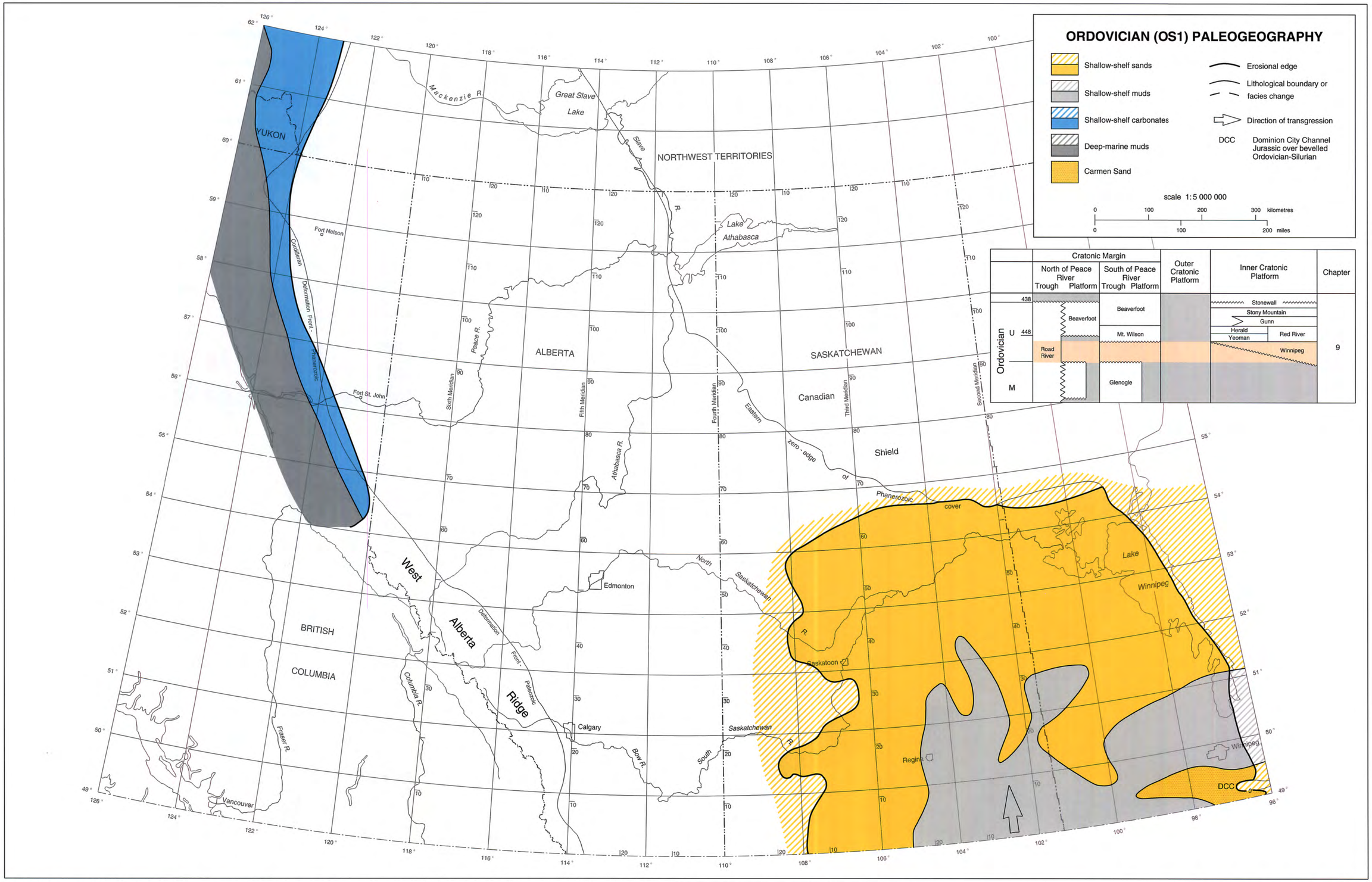


Figure 7.3 Paleogeography of the cratonic platform and margin during subinterval OS1. The sandstone/mudrock relation in Manitoba is more complex than can be illustrated on a map, because the sandstones and mudrocks are interbedded and in places there are localized thick accumulations of one rock type or the other (Andrichuk, 1959; Vigrass, 1971).

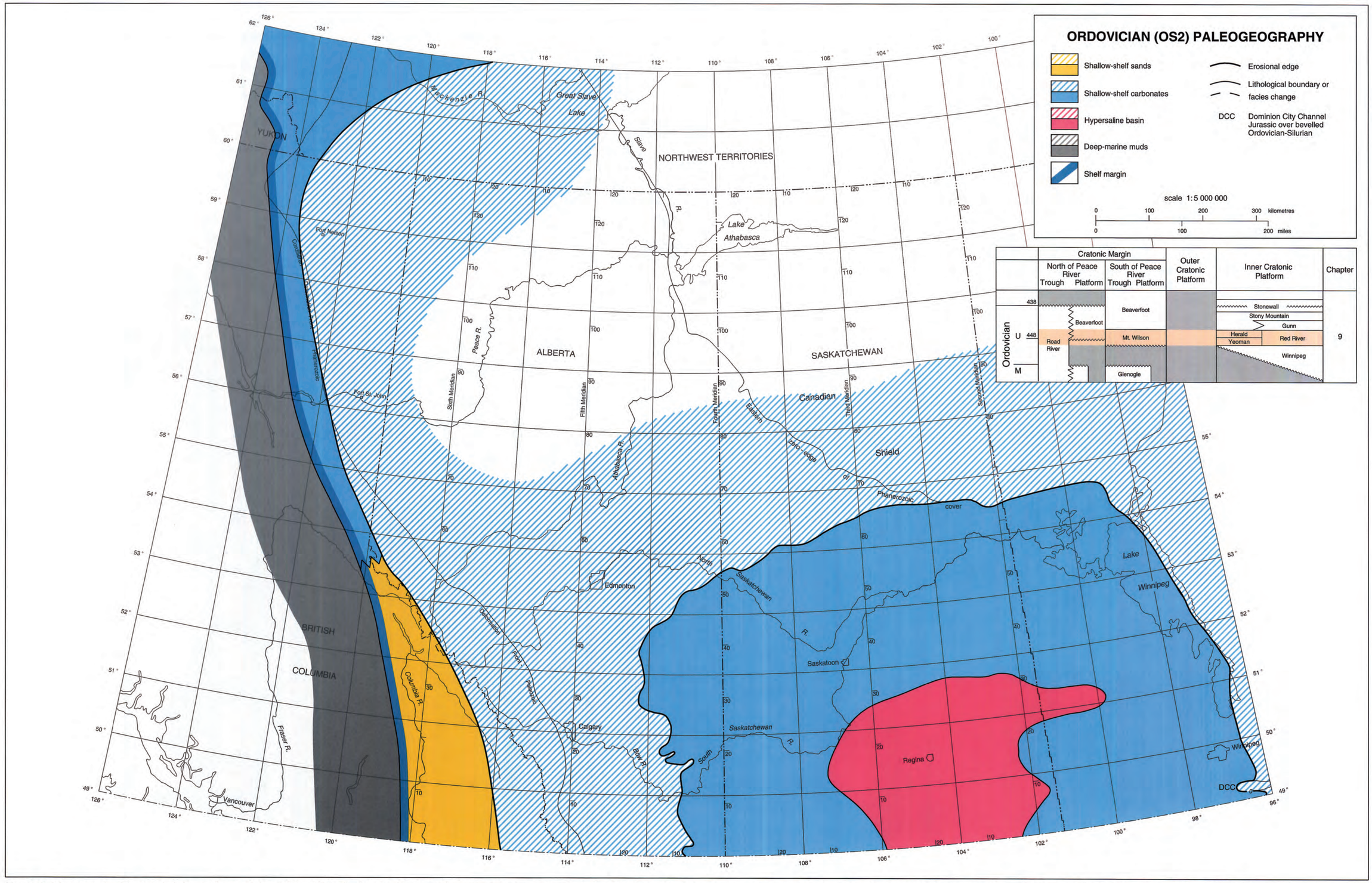


Figure 7.4 Paleogeography of the cratonic platform and margin during subinterval OS2. The deposits of the hypersaline basin are dominantly layered anhydrite. Rocks beyond the limits of the hypersaline basin are intensely dolomitized and their origin is not easily determined; however, they are thought to have been shallow marine.

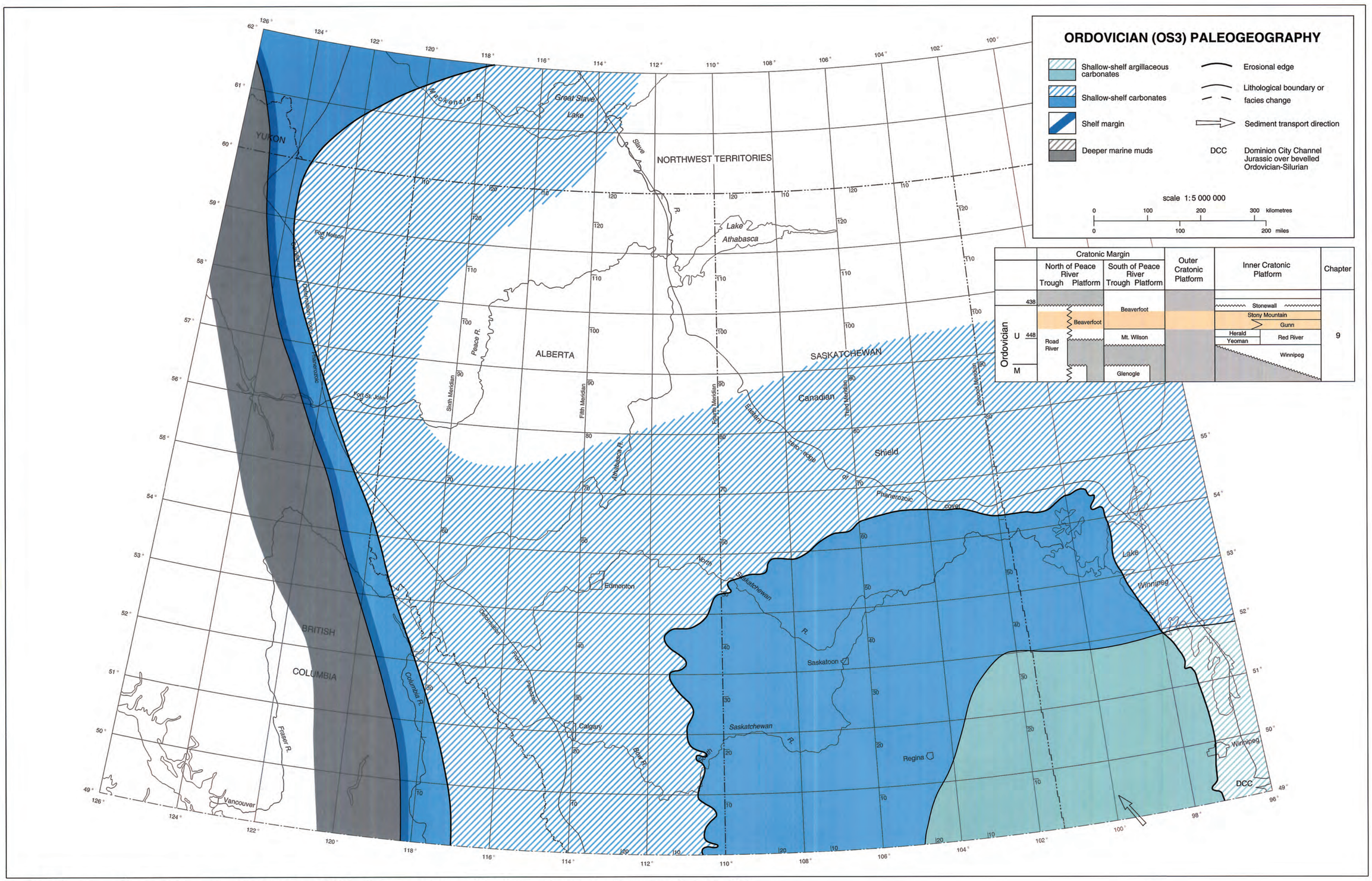


Figure 7.5 Paleogeography of the cratonic platform and margin during subinterval OS3. The environment illustrated as muddy is, in fact, an argillaceous carbonate with some interlaminated mudrock.

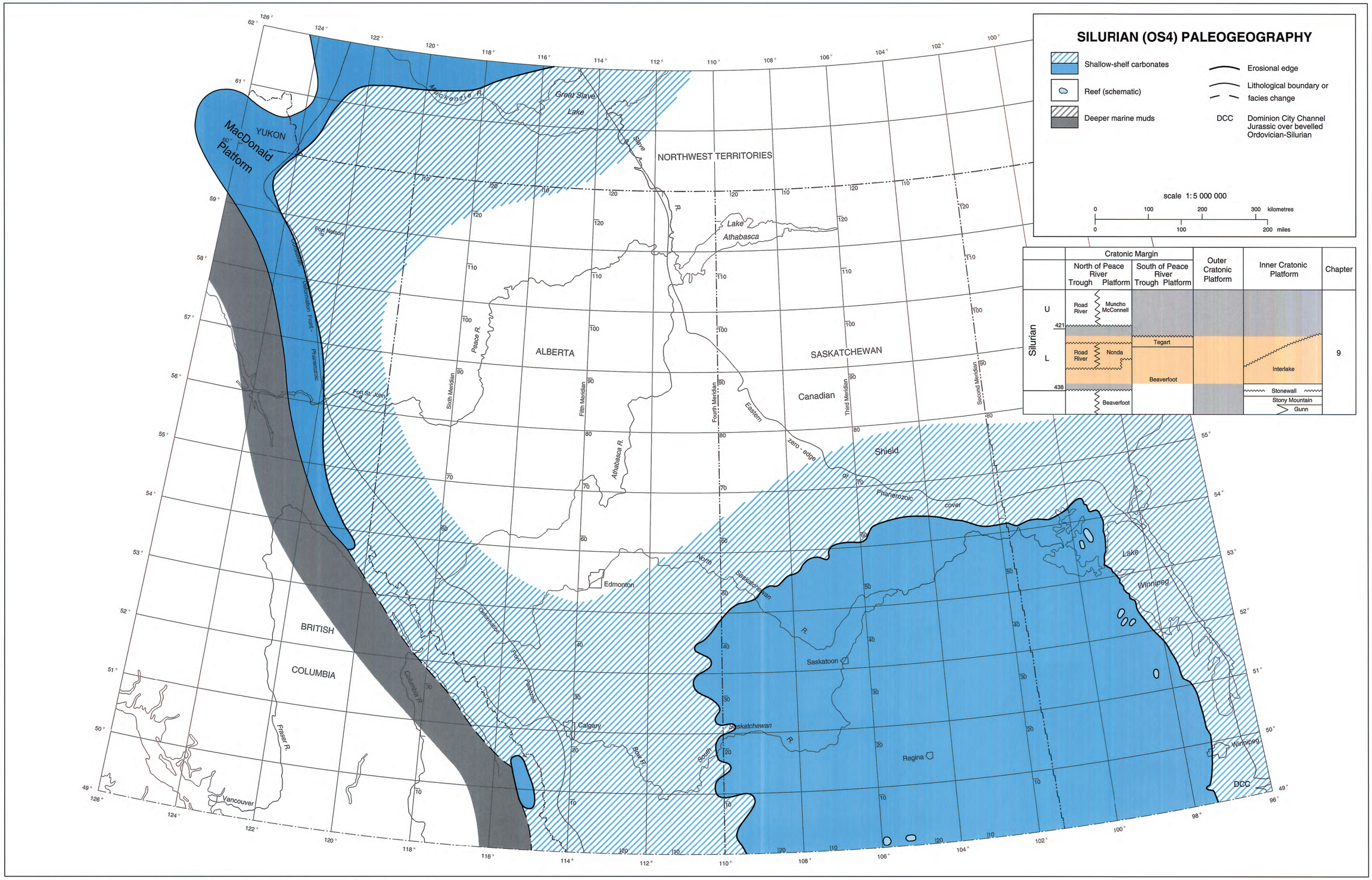


Figure 7.6 Paleogeography of the cratonic platform and margin during subinterval OS4. Note the locations of reefs in this carbonate seaway.

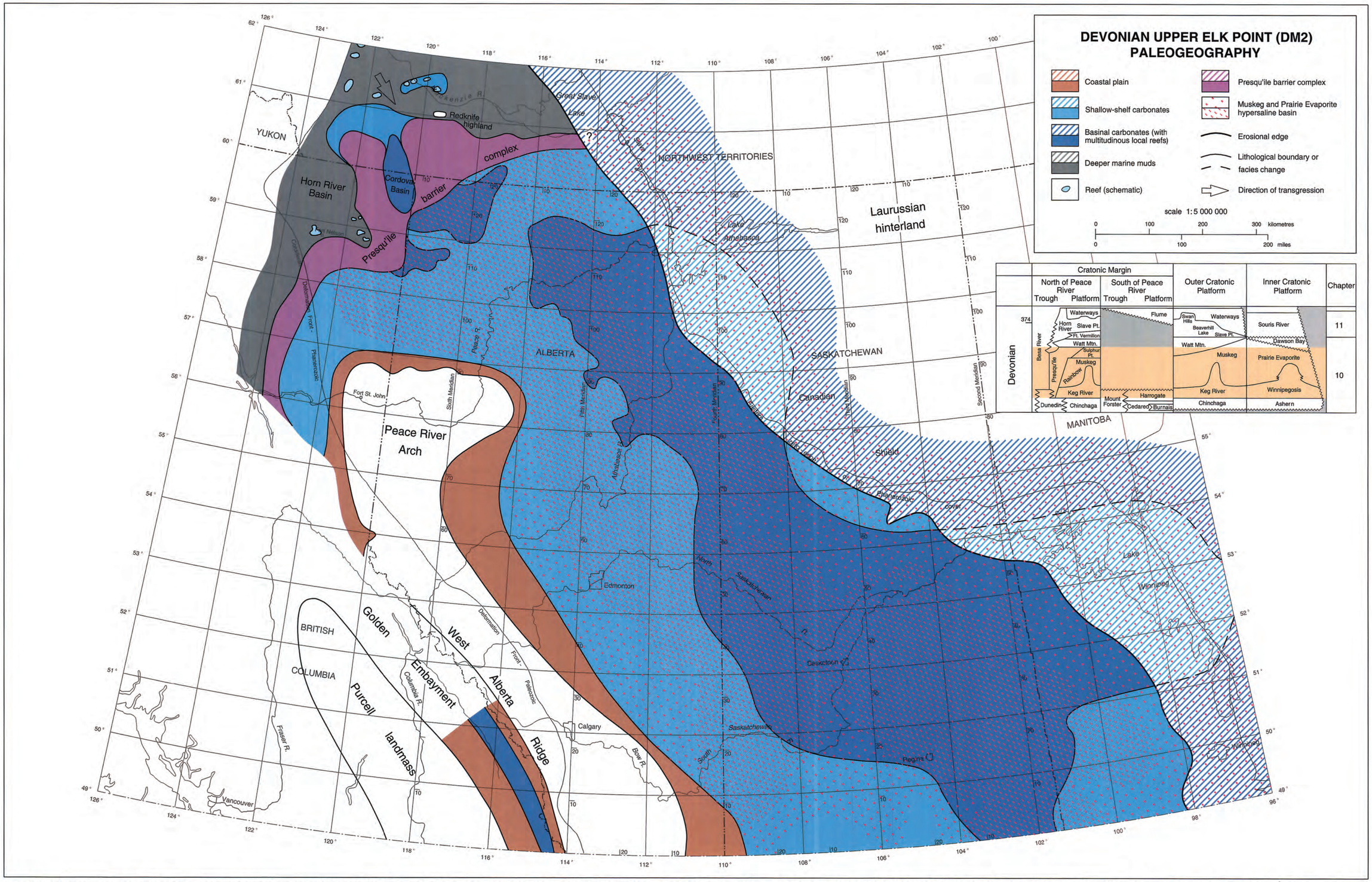


Figure 7.7 Paleogeography of the cratonic platform and margin during subinterval DM2. Moore (1989) showed the La Crete sub-basin isolated from both the Black Creek sub-basin and the Saskatchewan sub-basin by extensive carbonate banks. This map depicts a more conservative interpretation. The evaporite infill in the basin includes anhydrite on the basin floor and enclosing the reefs, and halite and potash across the central portion of the Saskatchewan sub-basin.

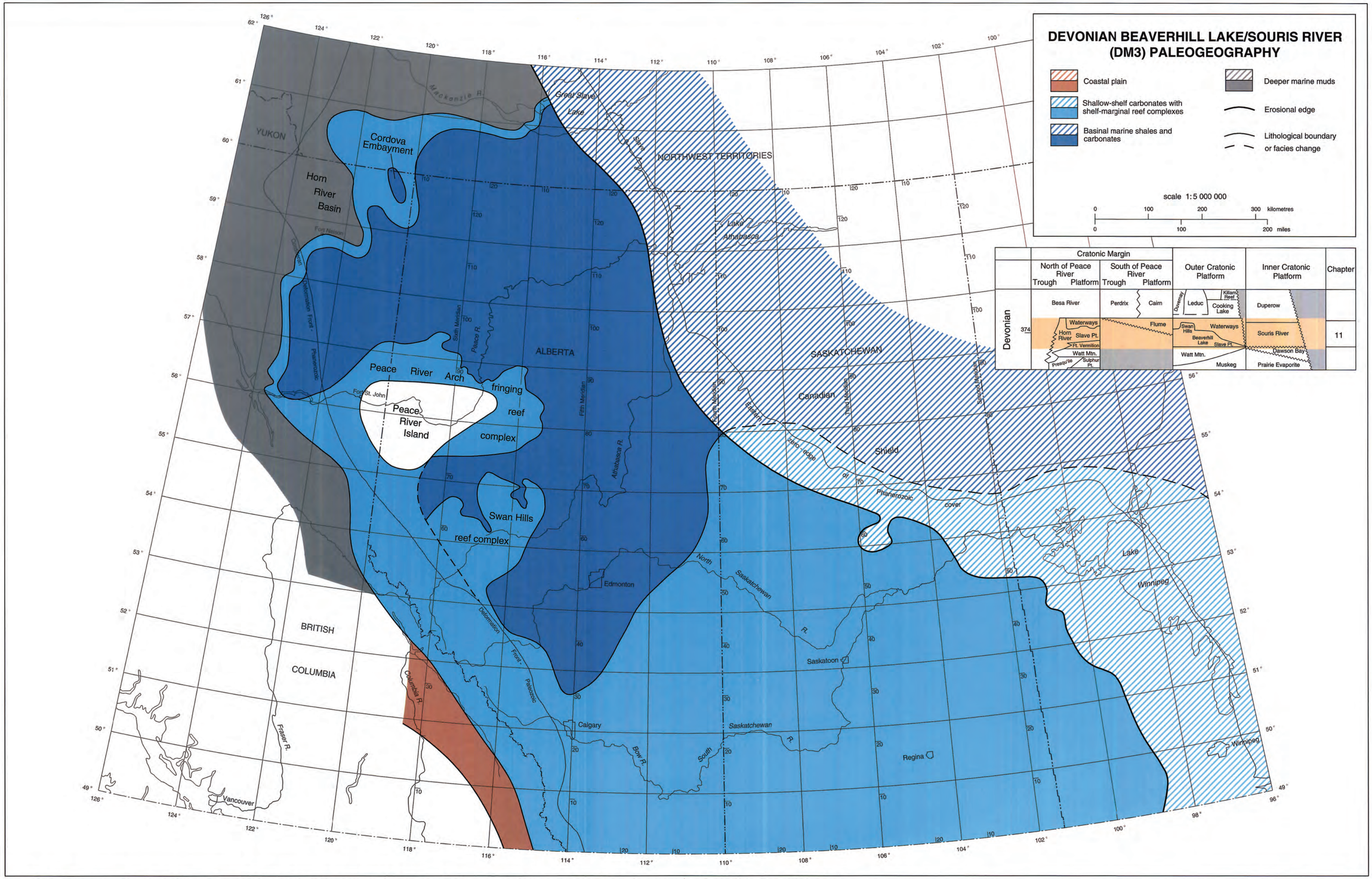


Figure 7.8 Paleogeography of the cratonic platform and margin during subinterval DM3. Fine-grained siliciclastics of the basinal marine deposits are interpreted as having been sourced in the hinterland to the north and east.

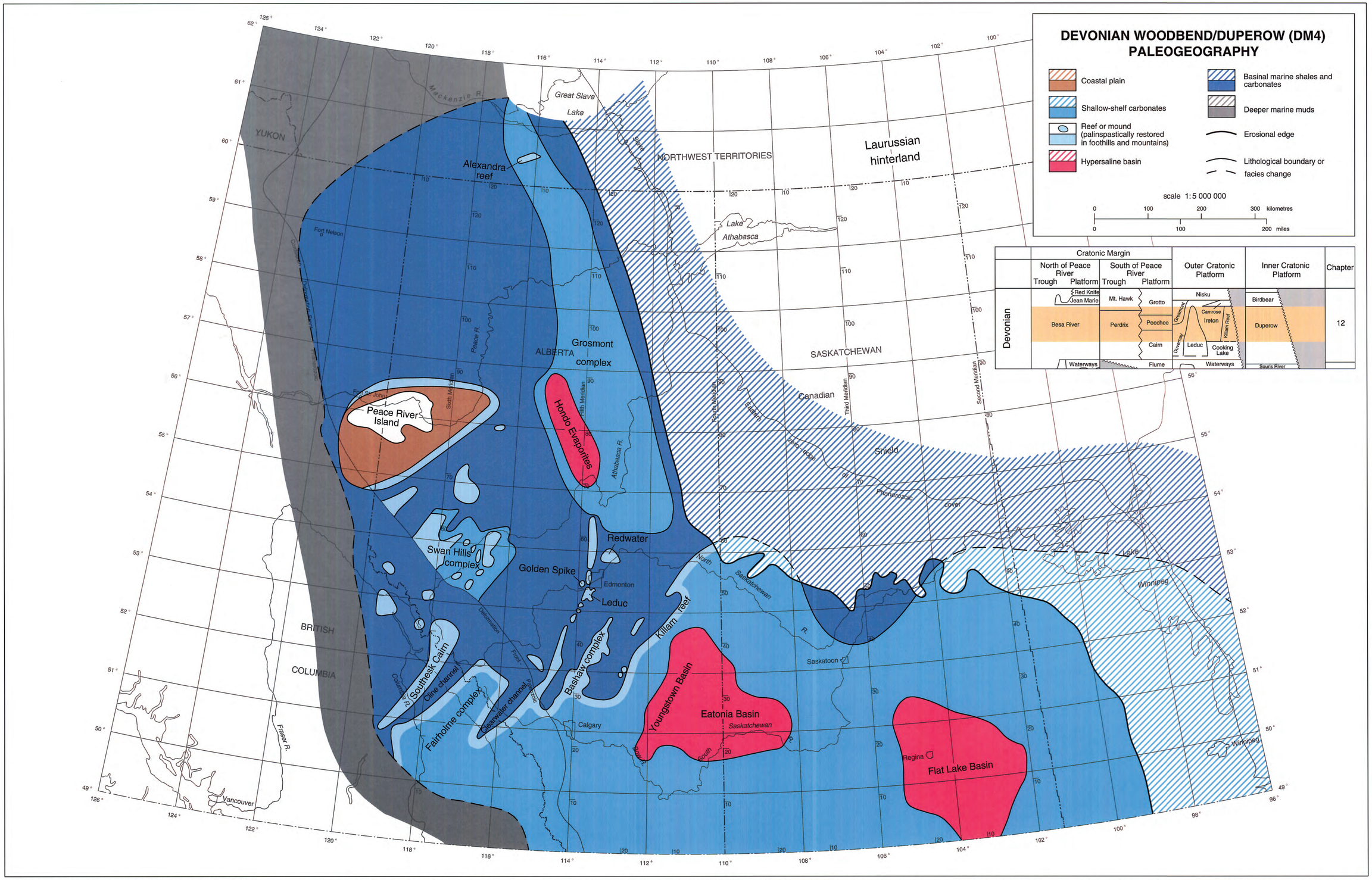


Figure 7.9 Paleogeography of the cratonic platform and margin during subinterval DM4. The outline of reefs on the cratonic margin is based largely on Moore (1989). Palinspastic restoration of their positions stems from Mountjoy (1980). The hypersaline basins on the eastern platform have some anhydrite but contain mainly halite. Thicknesses of the evaporites are in the order of 30 m (Kent, 1968b; Dunn, 1976).

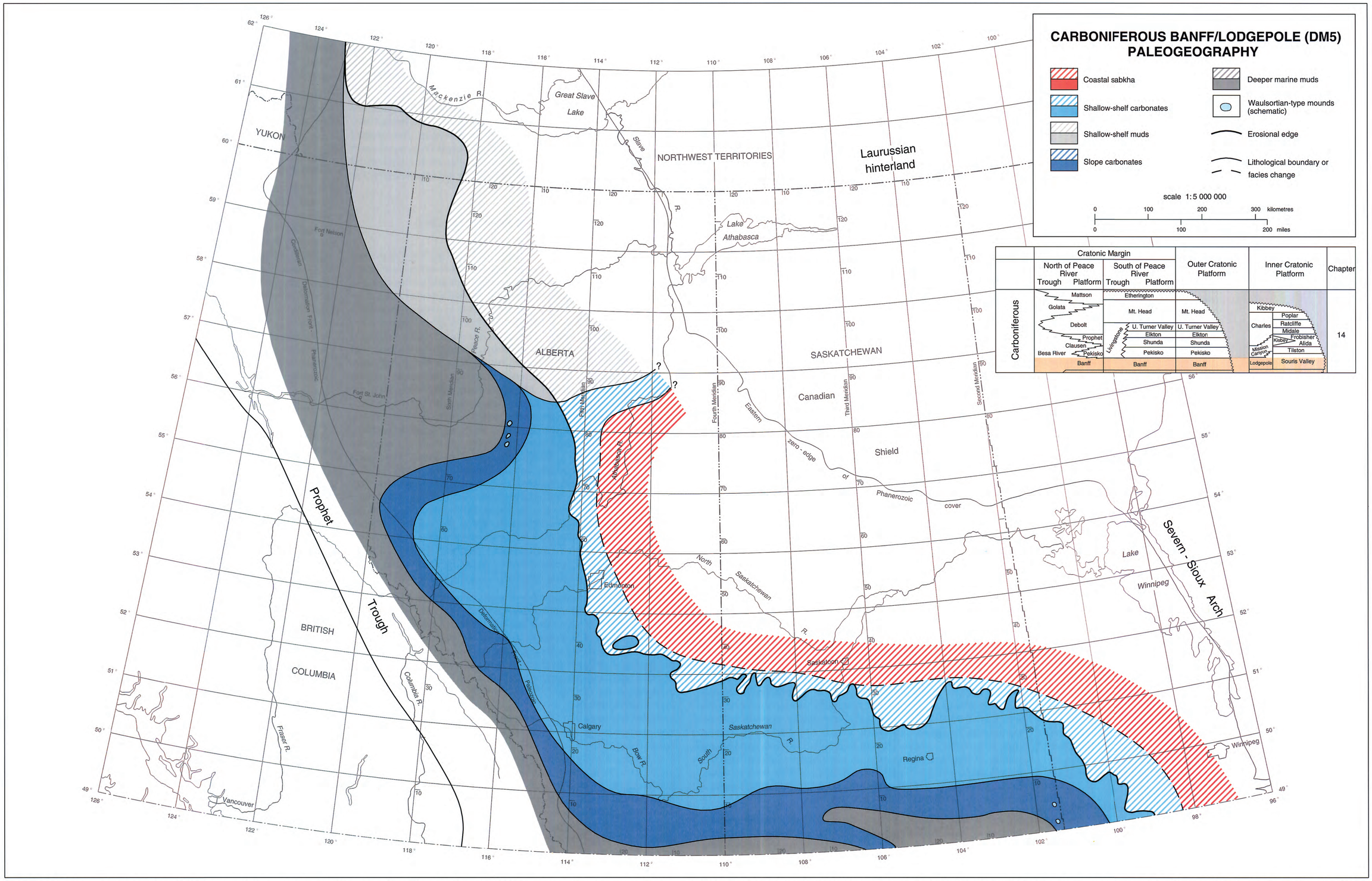


Figure 7.10 Paleogeography of the cratonic platform and margin during subinterval DM5. The distribution of Lower Carboniferous lithofacies suggests deposition on a relatively narrow shelf (similar to the coast of the United Arab Emirates of the Persian Gulf), leading to the inferred location of the Lower Carboniferous shoreline and the landward coastal sabkha.

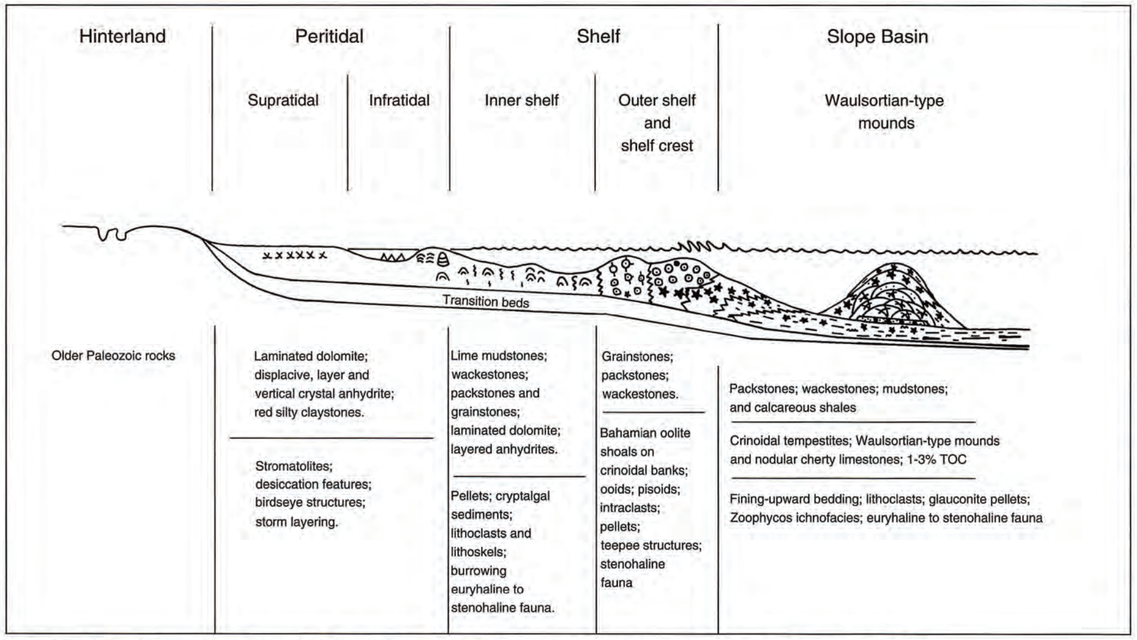


Figure 7.11 Schematic cross section depicting the lithofacies distribution of the Mississippian shelf-to-basin transition (after Sereda and Kent, 1987).

(Langton and Chin, 1968: McCabe, 1987) and isolated platforms similar to those described by Read (1985). They also have contrasting heights, ranging from 30 m high mound-like accumulations on the basin slope in Manitoba (McCabe, 1987), to 100 m high reefs at the distal end of the basin in southeastern Saskatchewan, to those that attain heights of 200 to 250 m or more along the basin axis, extending into northwestern Alberta.

The Keg River-Pine Point Barrier Reef eventually isolated the Elk Point Basin from the open sea, possibly through one of the scenarios described by Williams (1984). The restriction led to evaporative drawdown (Maiklem, 1971) and the commencement of evaporite deposition. Halite is the dominant deposit in much of the basin, but an end phase of deposition in the eastern platform is represented by potash deposits. At the proximal end of the basin, Bebout and Maiklem (1973) identified an assortment of anhydrite facies ranging from displacive-supratidal through shallow- and deep-subaqueous to replacement forms. It is arguable that all the distal evaporites were deep-water/deep-basin deposits. Kendall (1989) used a seepage model, similar to that of the Macleod Basin of southwestern Australia (Logan, 1987), to account for the deep basin/shallow water origin for much of the accumulated halite. The assortment of evaporite facies recognized by Bebout and Maiklem (1973) helps to corroborate Kendall's hypothesis. Immediately beyond the barrier reef, isolated reefs, similar to the Sierra Reef Complex (Collins and Lake, 1988) and reefs of the Horn River Formation (Williams, 1981) developed on a broad carbonate platform prior to subsidence and the deposition of fine-grained siliciclastic sediments (Moore, 1989).

A positive element, the Purcell landmass, appears to have existed in eastern British Columbia during this subinterval (Morrow and Geldsetzer, 1988). It was proximal to, but separated from, the West Alberta Ridge by the Golden Embayment. According to Morrow and Geldsetzer, the landmass and embayment may have extended as far north as the MacDonald Platform on the western margin of the Peace River Arch. In the early stages of deposition, the floor of the embayment was covered by shallow-water, sandy carbonates, but with time the sandy carbonates were restricted to the margins of the embayment and normal marine, carbonate sedimentation took place in the central part. The biota of this normal marine phase is typically stenohaline, including brachiopods, corals, crinoids and trilobites (Morrow and Geldsetzer, 1988).

The Carbonate Ramp - Subinterval DM3

Moore (1989) interpreted the cratonic platform during this subinterval as a ramp, an appropriate depiction of the depositional setting, given that the Middle Devonian sea extended over the southern margin of the Elk Point Basin and spread across the north flanks of the relatively low-lying central Montana hinterland, creating a seafloor with a shallow slope toward central Alberta.

During this subinterval (Fig. 7.8) the eastern cratonic platform was covered by a shallow sea in which there was cyclic deposition of shallowing-upward sequences of carbonates to evaporites (Kent, 1984a). The cycles are commonly punctuated by widespread influxes of mudrock. The original source of these mudrocks appears to have been from the central Montana hinterland, but in time, as the proportion of fine-grained siliciclastic material entering the ramp area increased significantly, the source appears to have changed to a northern one (Kent, 1984a). The inference that there may have been a facies change to a more detrital depositional setting at the northern margin of the eastern platform is based largely on Kent (1968a) and Paterson et al. (1978), both of whom indicated an increase in the fine-grained detrital content of rocks of subintervals DM3 and DM4 in that direction.

Figure 7.8 shows that the Peace River Arch dominated a sizable portion of the western platform and was yoked by an intraplatform basin filled with mixed fine-grained detrital/carbonate deposits, probably similar to those postulated to have been present along the northern margin of the eastern platform. The intraplatform basin was partly enclosed by a carbonate shelf that also encircled the Peace River Arch, and upon which were situated shelf marginal reefs belonging to the Swan Hills and Slave Point complexes (Jansa and Fischbuch, 1974; Tooth and Davies, 1988; Moore, 1989). The reefs generally have a distinctive zonation of biota from margin to interior and are dominated by stromatoporoids and corals (Fischbuch, 1968; Leavitt, 1968; Jansa and Fischbuch, 1974).

Moore (1989) indicated that the northwest outboard margin of the entire cratonic platform was protected by a carbonate barrier reef-complex that passed laterally into the deep-basin, fine-grained siliciclastics of the Besa River Formation. There is no clear evidence to disclose what the depositional setting was on the continental margin southwest of the Peace River Arch, but it is quite likely that deep basinal conditions prevailed.

Reefs, Shale Basin and Carbonate-evaporite Shelf - Subinterval DM4

Subinterval DM4 was a continuation of DM3 (Fig. 7.9). The eastern platform was covered by an extremely shallow-water shelf sea; a modern analogue with respect to water depth and sediment types might be Florida Bay. Rocks belonging to the Duperow Formation are representative of this subinterval. They consist of numerous shallowing-upward, evaporite-bearing cycles (Kent, 1984a) commonly terminating in anhydrite. Within the shelf sea there were at least two large, hypersaline sub-basins, Youngstown-Eatonia and Flat Lake, in which halite was deposited (Kent, 1968b, 1969; Dunn, 1976). The Duperow Formation succession also reflects an increase in the influx of fine-grained siliciclastic sediment toward the close of this subinterval. The mudrocks appear to have had their source along the northern margin of the eastern platform (Kent, 1984a, 1968a). This proposal corroborates Oliver and Cowper's (1963) interpretation. They used westerly dipping clinoforms as evidence for the siliciclastic fill in the eastern part of the Ireton Shale basin having had a northeasterly source. On the other hand, Stoakes (1980) inferred that the siliciclastics of the eastern basin were carried by southerly currents flowing between the Peace River Arch and the Grosmont Complex. He attributed the western dip of the clinoforms to clockwise circulation within the eastern basin. A northern source for the siliciclastics does not preclude their accumulation proximal to the Laurussian hinterland, as shown in Figure 7.9. A longshore current with a southerly flow could easily have passed between the Grosmont Complex and that hinterland.

The shelf deposits extended into eastern Alberta where they terminated at the Killam shelf marginal reef complex, marking the northwesterly transition to a basinal setting in which an assortment of reefs, carbonate banks and isolated platforms grew. [References to these reefs are too numerous to be cited in this overview; the reader is referred to Switzer et al. (*this volume*, Chapter 12), Moore (1988) and others *in* Geldsetzer et al. (1988) for additional information on this topic.] Reef growth was inaugurated on a broad carbonate ramp, the consequence of a Late Givetian to Early Frasnian transgression (Morrow and Geldsetzer, 1988). Although fine-grained siliciclastic sediment was deposited on much of this ramp, the reefs were established on paleobathymetrically positive features, and their extremely rapid growth rate outpaced the accumulation of terrigenous sediments. The eastern side of the ramp was occupied by an elongate, carbonate shoal upon which developed the Grosmont complex. This complex grew vertically, as a series of shallowing-upward parasequences (Cutler, 1983; Theriault, 1988) forming an isolated platform of Bahama Banks dimensions (Read, 1985) that included carbonate shelf, reef and evaporite facies. A typical reef on this complex is the Alexandra Reef (Jamieson, 1971).

North of the Peace River Arch, which appears to have been flanked by a carbonate shelf and reefs, the platform was sufficiently submerged to preclude reef growth, and terrigenous sediment covered its entire surface. It is quite likely that the fine-grained terrigenous platform deposits merged with deeper water, fine-grained siliciclastics of the continental margin region.

Late Frasnian and Fammenian deposition on the cratonic platform is described in Chapters 12 and 13 (Switzer et al., and Halbertsma, *this volume*).

Banff-Lodgepole and Rundle-Mission Canyon Subintervals (DM5 and DM6)

The first four subintervals reflect two styles of sediment distribution on the cratonic platform, beginning with an elongated intracratonic embayment and closing with a broad carbonate shelf, marginal to a reef-bounded shale basin. The third style is illustrated by the Banff-Lodgepole (DM5) and Rundle-Mission Canyon (DM6) subintervals. Sedimentation patterns during these subintervals, to a degree, reflect the early encounters of the western cratonic margin with outboard terranes. The principal developments at this time were: 1) formation of an ancestral Williston Basin, opening to the Antler foredeep through the Central Montana Trough; 2) shaping of the Prophet Trough (Richards, 1989), an extension of the Antler Foreland Basin, stretching the length of the western Canadian cratonic margin; and 3) the creation of a marine embayment at the former site of the Peace River Arch in the northern part of the cratonic platform margin.

Rocks of the Prophet Trough are the initial hint of the growth of a convergent margin on the western edge ot the North American proto-continent. The trough was the northern extension of the Antler Foreland Basin and in earliest Carboniferous time (Banff-Lodgepole) it was flanked on the east by a hinge zone that, according to Richards (1989), appears to have been influenced, in part, by faults. The western margin of the trough was probably a result of the Antler Orogeny or a related event. It consisted of a positive rim of arc and plutonic rocks. Because of the igneous nature of the rim, siliciclastics as well as carbonates and submarine volcanics were deposited in the trough proximal to the western margin (Richards, 1989). Sediments along the eastern side of the trough changed both paleogeographically and through time. In earliest Carboniferous time (Banff-Lodgpole) the northern part of the trough was dominated by fine-grained siliciclastic sediment, as demonstrated by the Besa River Formation. At this time the Peace River Embayment merged with the Prophet Trough. South of the embayment, rocks of the Banff assemblage suggest that the trough sediments were fine-grained siliciclastics, spiculitic lime mudstones, and chert. The cratonic platform was under the influence of a shallow, clear-water sea, and sedimentation was marked by transgressive/regressive cycles of skeletal-oolitic carbonates passing landward into restricted carbonates and to nearshore siliciclastics and evaporites (Richards, 1989). The slope deposits vary from typical ramp carbonates to shallowly inclined, carbonate-rich clinoforms.

The Williston Basin and Prophet Trough were separated by an antecedent of the Sweetgrass-North Battleford Arch and the depositional strikes of their shelf-to-basin facies bowed around the arch (Fig. 7.10). A model of the facies relations in the Williston Basin was proposed by Edie (1958) and enhanced by Kent (1974, 1978, 1984b) and Sereda and Kent (1987) (Fig. 7.11). Sereda and Kent (1987) and Sereda (1990) identified the slope deposits as rhythmically bedded, fining-upward couplets of skeletal grainstone, packstone and wackestone interpreted as tempestites, and the basinal rocks as organic-rich, lime mudstone laminite as well as thinly bedded, argillaceous lime mudstone and chert layers. Sereda and Kent

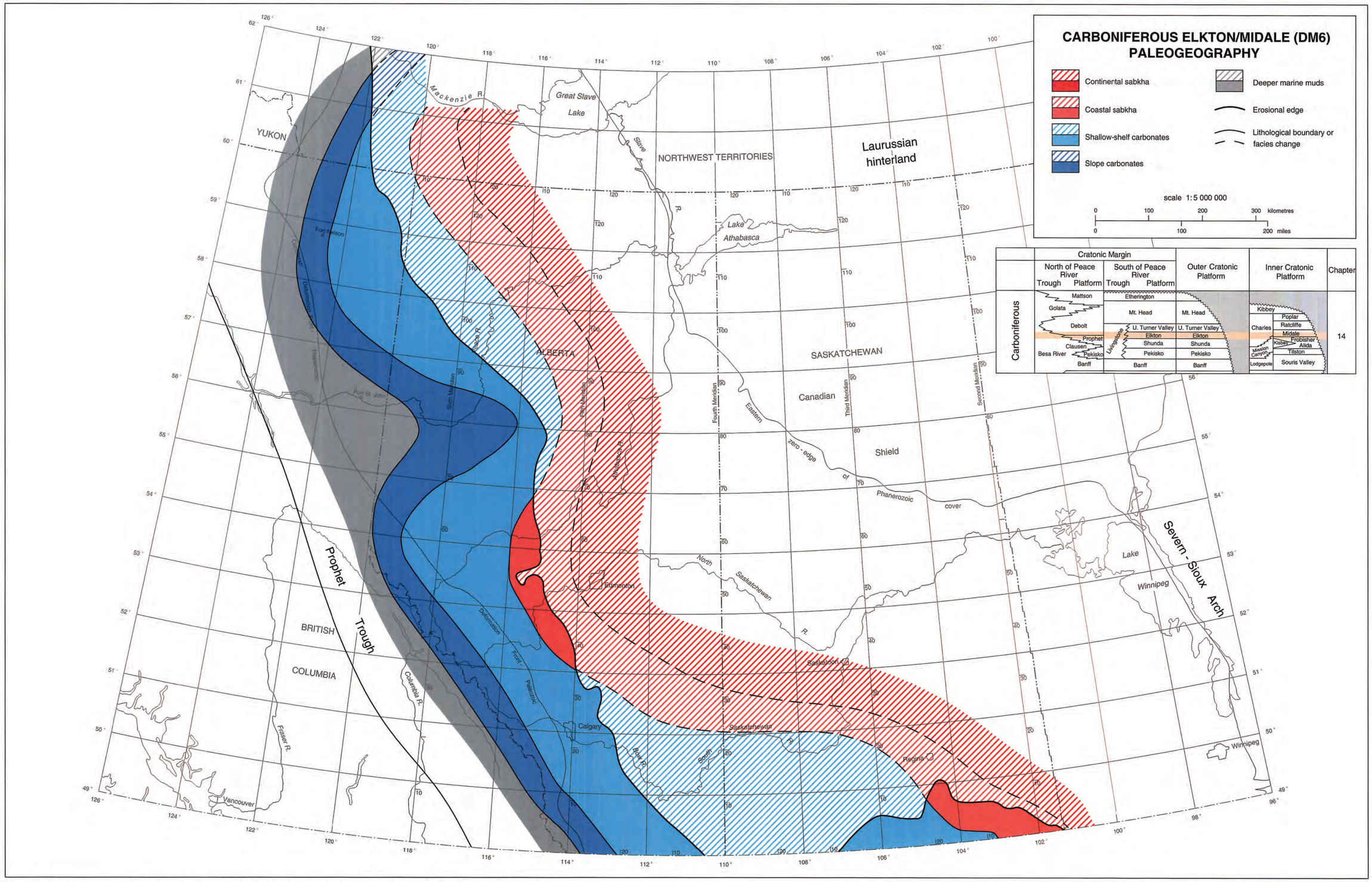


Figure 7.12 Paleogeography of the cratonic platform and margin during the Rundle-Mission Canyon subinterval (DM6). Continental sabkhas inferred.

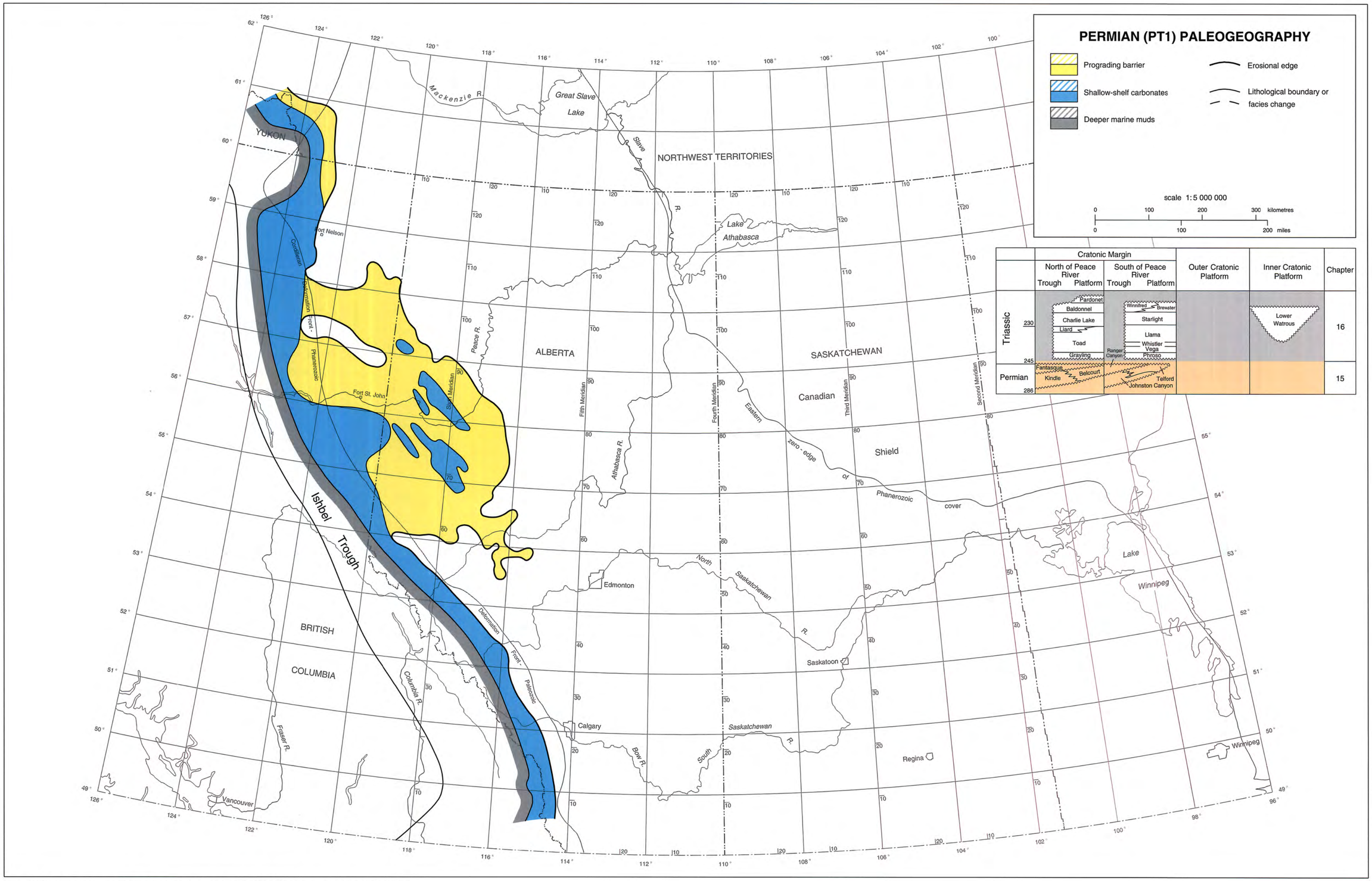


Figure 7.13 Paleogeography of the cratonic platform and margin during the Permian part of subinterval PT1.

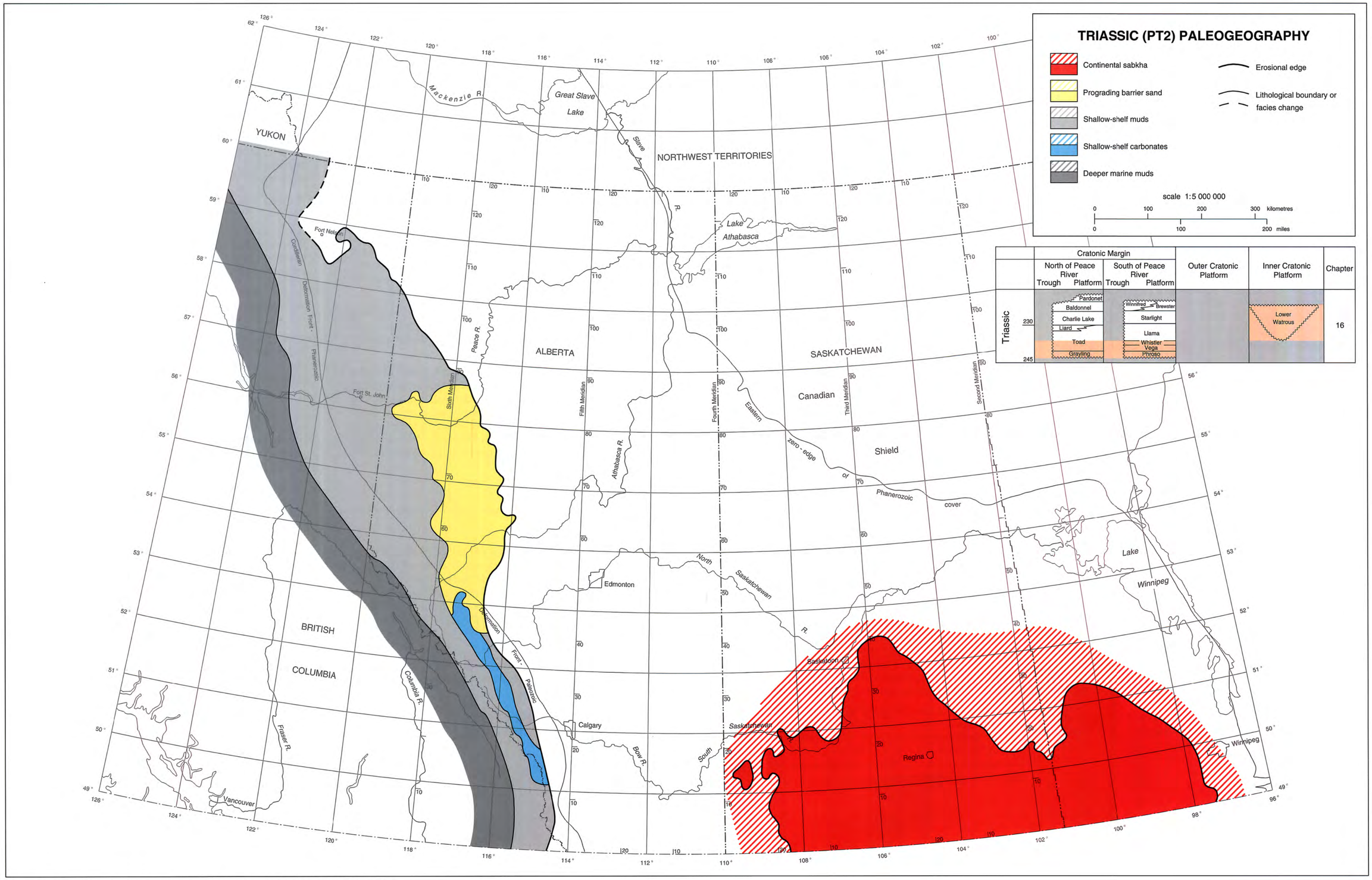


Figure 7.14 Paleogeography of the cratonic platform and margin during the Triassic subinterval (PT2).

(1987) also delineated a cluster of Waulsortian-type mounds in the lower slope setting of extreme southeastern Saskatchewan. Other mounds in the same subinterval have been found in a comparable paleobathymetric setting in the Central Montana Trough (Cotter, 1963; Stone, 1972) and the Peace River Embayment (Morgan and Jackson, 1970; Davies et al., 1988).

The rocks on the eastern platform are much like those along the pericratonic margin, consisting of transgressive-regressive cycles of skeletal-oolitic carbonates (Richards, 1989). However, the nearshore carbonates, siliciclastics and evaporites were probably eroded from the eastern platform. Sereda (1990) and Young and Rosenthal (1991) showed that the shelf, slope and basinal rocks comprise sets of parasequences.

In the Rundle-Mission Canyon subinterval the carbonate depositional setting for the Williston Basin was more ramp-like, and although the sequence is marked by transgressive/regressive cycles, there is an overall progradation toward the basin centre with peritidal carbonates prograding over inner and outer shelf deposits. Figure 7.12 is an attempt to depict this progradation, and the peritidal and shelf facies are shown as having migrated basinward with respect to their postulated position in Figure 7.10. The western platform is marked by a similar progradational shelf sequence but the shelf break is much better defined; the shelf carbonates pass into slope carbonates, which in turn pass into basinal siliciclastics in the Prophet Trough (Richards, 1989).

North of the Peace River Embayment, which was a well defined feature during this subinterval, the depositional setting continued to be one in which fine-grained siliciclastic and spiculitic carbonates accumulated. In latest Early Carboniferous time most of the western margin became dominated by deltaic, coastal plain, and fluvial deposits, as represented by the Mattson assemblage (Richards, 1989).

Upper Carboniferous to Triassic Interval

Demise of Passive Margin Sedimentation - Subintervals PT1 and PT2

The shallowing-upward cycles of the Lower Carboniferous heralded the significant drop in sea-level that is characteristic of the PT interval on the cratonic platform. Continental sedimentation on the eastern platform may have commenced as early as the late Early Carboniferous, as evident from the Poplar Beds of the Madison Group and the Kibbey Formation of the Big Snowy Group in southeastern Saskatchewan, which have recognizable continental characteristics. In addition, the rocks of the Mattson assemblage demonstrate a switch to coastal plain and continental sedimentation along the western platform in latest Early Carboniferous time (Richards, 1989). At the present time, rocks of the Upper Carboniferous-Permian subinterval have limited distribution in the foothills and Rocky Mountains, probably for two reasons: 1) their deposition was confined to the ancestral continental margin; and 2) according to Henderson (1989) they have been truncated by at least four major unconformities.

Henderson (1989) suggested that the dominance of siliciclastics in these strata is related to the drifting of Pangaea into subtropical and warm temperate latitiudes where carbonate sedimentation was subdued. Any carbonates that were deposited were formed in a mixed siliciclastic-carbonate setting.

Upper Carboniferous rocks are the most areally restricted. In their few occurrences, Henderson (1989) recognized shallow- to deep-shelf deposits as well as aeolian coastal dunes as seen in the Storelk Formation of the Spray Lakes Group.

In the Permian rocks (Fig. 7.13), shelf, slope and basin deposits are recognizable (Henderson et al., *this volume*, Chapter 15), but according to Henderson (1989), with the exception of some nearshore and peritidal carbonates, the remaining rocks appear as though they were deposited below fairweather wave base. They contain a preponderance of phosphatic deposits and coarse- and fine-grained clastics. The former are commonly glauconitic. In places the slope sediments are starved deposits, as indicated by abundant phosphatic sediments. Elsewhere, particularly north of the Peace River Embayment, they are covered by turbidites. The basinal rocks, preserved mainly on the eastern side of the Ishbel (Prophet) Trough, are generally spicular chert, argillaceous limestone, siltstone and shale. The nature of the western margin of the trough is speculative, at best. Henderson (1989) suggests that the Cassiar Terrane may have been a subaerially exposed part of the rim. In the Barkerville Terrane there is evidence to indicate that the marine setting proximal to the rim had sedimentary deposits and volcanics.

A Late Permian drop in sea level exposed the rocks of that age to erosion, and in places the uppermost Paleozoic strata were completely stripped away. This low sea-level stand also established the initial setting for Triassic sedimentation. Gibson (1974) identified the basal Triassic strata along the ancestral continental margin (Fig. 7.14) as repesenting deltaic and tidal flat deposits, suggesting a lowstand shoreline. Gibson and Barclay (1989) interpreted the entire Triassic succession along the length of the cratonic margin of that time as comprising at least three transgressive/regressive cycles. Each contains rocks typical of a marine shelf setting ranging from distal deep shelf waters to proximal shoreline (Edwards et al., *this volume*, Chapter 16). The distal deposits are characterized by carbonates and fine-grained siliciclastics, and the proximal deposits by deltaic, tidal flat and barrier bar siliciclastic complexes and typical sabkha evaporites (Starlight and Charlie Lake).

The sediments that accumulated on the eastern platform during this subinterval reflect the aridity of climatic conditions of that time. They were predominantly redbeds, dominated by mud and silt and local sand bodies (Cumming, 1956: Barchyn, 1980). Displacive anhydrites are also common within the sequence. The deposits generally suggest continental sedimentation, but some of the thin, yet more continuous, lithostratigraphic units have led Barchyn (1980) to invoke marine sedimentation for their origin.

The rifting of Pangea along the eastern perimeter of the North American proto-continent initiated convergence on the western margin. This event terminated the more or less trailing-edge depositional conditions that had prevailed since the proto-continent was formed some 600 million years before, and initiated foreland basin sedimentation.

Summary and Conclusions

Throughout most of the evolutionary history of the cratonic platform, the passive margin prevailed as a site of sediment accumulation. On the platform, an assortment of sediment distribution patterns, related to cycles of transgression and regression, punctuated its history. The inaugural Cambrian inundation was from the west. Following a regression and second transgression, this time from the southeast, the cratonic platform entered into a lengthy phase of carbonate sedimentation (Late Ordovician to Silurian), predominantly on the eastern portion.

The third inundation (Devonian), from the northwest, spread deeply into the interior of the cratonic platform through a southeast-trending embayment. Through time the seaway expanded into a ramp and then to a reef-dominated shale basin with a broad carbonate-evaporite marginal shelf in the eastern platform. Collision of the western continental margin with the Antler allochthon during the latest Devonian and earliest Carboniferous initiated sedimentation in narrow shelf-to-basin facies belts that followed the depositional strikes of a series of basins and troughs in the western platform and along the passive margin in the west.

In the last phase of the evolution of the cratonic platform (Late Carboniferous-Permian and Triassic), marine sedimentation was again restricted to the passive margin while the platform underwent erosion and continental sedimentation.

In conclusion, the geological history of the cratonic platform can be summarized as two periods of continental margin sedimentation separated by cratonic inundations from the west, southeast, and northwest. The amount of craton submerged during any one transgression was controlled by an assortment of arches, including the Peace River/Athabasca, the Severn-Sioux, the West Alberta Ridge, Montania, the Sweetgrass/North Battleford and the Central Montana Uplift.

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