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Introduction

Over the years, several authors have attempted paleogeographic reconstructions of the foreland basin succession of the Western Canada Sedimentary Basin. Given the limited data available, particularly in earlier years, many are surprisingly accurate. Noteable contributions to our understanding of foreland basin paleogeography include those of Nelson (1970), Williams and Stelck (1975), Jackson (1984), Smith et al. (1984), and Stott (1984). The intent of this chapter is to build on these earlier efforts utilizing the vast database available to chapter authors, in concert with recent concepts of sequence stratigraphy. The product includes 14 paleogeographic maps of the major sandstone bearing units in the foreland basin succession and an accompanying brief geological description of each. It is hoped that this will provide the Atlas user with a geographic depiction of the major sandstone systems along with a basic understanding of environments of deposition, regressive or transgressive trends, and sediment dispersal patterns.

Understandably, there are limitations to this approach. In transgressive and regressive sequences, sandstones are diachronous from one area to another, presenting the problem of depicting sandstones of different ages on what would appear at first glance to be a chronostratigraphic map. In lieu of the nearly impossible task of constructing a myriad of chronostratigraphic slices for each formation, the author has chosen to depict most zones at their peak of regression or transgression, thus allowing the mapping of all sandstones and/or environments of deposition developed along the way. Unconformities and lowstand disconformities present another problem. With differential beveling from one area to another, sediments beneath the unconformity will be of different ages in different areas, even though they may be depicted on the same map. Consequently, all maps should be viewed with the understanding that they do not depict an instant in geological time, but rather demonstrate geological processes and patterns of deposition over the time period of the interval mapped.

The text accompanying each paleogeographic map includes a brief lithological description of the interval mapped and a short geological summary, including discussions on environments of deposition, patterns of coastal advance or retreat, tectonics, sediment dispersal patterns and the effect of sea-level fluctuations on the system.

Detailed analyses of the zones described in this chapter are presented in subsequent chapters by other authors. The reader is encouraged to consult these chapters for additional information.

Basal Nikanassin/Morrissey/Swift/Success (S-1) Interval (Fig. 17.1)

Upper Jurassic strata of Alberta and eastern British Columbia record the early stages of the Columbian Orogeny. The transformation from a wide, stable, continental shelf to a rapidly subsiding foredeep trough took place in late Oxfordian to Kimmeridgian time (Poulton et al., *this volume*, Chapter 18). Pre-orogenic, Lower Jurassic strata are characterized by thin platform limestones and phosphates (Nordegg) and organic-rich shales (Poker Chip Shale) with many disconformities. The Middle Jurassic is represented by shales and sandstones, which suggest only a hint of orogenic activity in southwestern Alberta (Grey Beds of the Fernie Formation) (Poulton et al., *this volume*, Chapter 18).

The first clear evidence of orogenic activity is found in lower Upper Jurassic strata, marked by the westerly derived sediments of the Passage Beds in southwestern Alberta (Rapson, 1965), and the Upper Fernie sandstones and shales and the basal Nikanassin Formation in northwestern Alberta and northeastern British Columbia (Poulton, 1984; Stott, 1984). The widespread hiatus that terminates most of the Middle Jurassic in Western Canada probably represents the beginning of downwarping and deposition associated with the earliest stages of foreland basin subsidence east of a rising Columbian orogenic belt (Poulton et al., *this volume*, Chapter 18). Initially, the trough was narrow and elongated northwest-southeast, parallel to the present-day Rocky Mountains. It broadened substantially during Cretaceous time.

The basal unit of the foreland basin succession is the discontinuous glauconitic sandstone of the Green Beds/Niton B zone, a transgressive deposit resting unconformably on pre-orogenic Middle and Lower Jurassic strata (Losert, 1990; Poulton et al., 1990). This unit is capped by the widespread deeper water shales of the upper member of the Fernie Formation (Poulton et al., 1990). As coarse clastics were shed from the rising Columbian Orogen to the west, the shales gave way to the coarsening-upward shoreface and shoreline sandstones of the Passage Beds and Morrissey Formation of southwestern Alberta (Gibson, 1985), the Transition Beds of northeastern British Columbia, and the basal Nikanassin Formation of northwestern Alberta (Stott, 1984; Poulton, 1984).

Along with Late Jurassic foredeep deposition, shoreface sandstones were accumulated in southern Alberta (Swift Formation) (Hayes, 1983) and in southern Saskatchewan (Success-S1 Member) (Christopher, 1984). Although detrital mica in these sandstones suggests distal orogenic detritus (Poulton et al., *this volume*, Chapter 18), these sands were probably, for the most part, derived from positive areas in the United States and the craton to the east.

Kootenay/Nikanassin/Minnes Interval (Fig. 17.2)

During Late Jurassic and Early Cretaceous time, continued uplift associated with the Columbian Orogen provided abundant sediment to the foredeep trough, resulting in fluvial deposition over much of its preserved length. The youngest strata of this time period (Minnes Group) are entirely fluvial except for a small area in northeastern British Columbia, where mixed fluvial/marine to totally marine clastics are preserved (Stott, 1967, 1969).

In southwestern Alberta, the Mist Mountain Formation is a nonmarine sandstone, shale and coal-bearing unit representing a low-relief floodplain. It is capped by the Elk Formation, a conglomerate-rich, uplands sequence (Gibson, 1985). North of the North Saskatchewan River, the coeval Nikanassin Formation is dominated by floodplain deposits in the west, grading to shoreline and estuarine sandstones near its eastern erosional limits. In the east, the presence of quartzarenites rather than lithic sandstones implies an easterly, cratonic source (Stott, 1984). Likewise, the equivalent Monteith Formation in northeastern British Columbia contains fluvial-deltaic lithic sandstones, shales and coals in the west and shoreline to estuarine quartzarenite sandstones in the east, suggesting that both western and eastern provenances are represented in preserved strata in this early, narrow, foredeep trough (Stott, 1984).

The Minnes Group is entirely fluvial in northeastern British Columbia south of the Sukunka River where it becomes, in part, the Gorman Creek Formation. In similar fashion to the Kootenay Group of southwestern Alberta, it contains floodplain shales, fluvial channel sandstones and coal in its lower part, which grade to uplands fluvial channel sandstones and conglomerates in its upper part. North of the Sukunka River, the Minnes Group changes from a cyclic succession of coarsening-upward shoreline sandstones and floodplain deposits near the river, to marine sandstones and mudstones at the northern limits of preserved strata (Stott, 1967, 1969).

Paleocurrent indicators in southwestern Alberta and southeastern British Columbia indicate northerly transport (Hamblin and Walker, 1979; Gibson, 1985). In addition, the change from uplands deposition in the south (Elk Formation) to marine deposition in the north (Minnes Group) points to basin axial fill from south to north. This would suggest that shoreline sequences become progressively younger from south to north. This south-to-north variation in timing of coarse clastic sedimentation in the early foredeep trough indicates progressive northward advance of orogenic uplift in Late Jurassic to Early Cretaceous time (see discussion by Poulton et al., *this volume*, Chapter 18).

Not included in Figure 17.2 are the discontinuous, Upper Jurassic to Lower Cretaceous deposits of the "Detrital" or Deville Formation (southern Alberta), the J2 and J3 sandstones (Gilby and Medicine River fields, west-central Alberta), and the S2 sandstones of southern Saskatchewan. Their local, erratic distribution suggests preservation in ancient incised valley systems (Poulton et al., *this volume*, Chapter 18).

Cadomin/Gething/Ellerslie/Dina Interval (Fig. 17.3)

Sedimentary deposition continued in the early, narrow foredeep trough until at least the end of Valanginian time (Minnes Group). During Hauterivian and Barremian time however, a major drop in base level resulted in significant erosion across the entire foreland trough. Toward the end of Barremian time, the loading of the western edge of the craton with thrust sheets associated with allochthonous terrane accretion renewed major subsidence in the foredeep and initiated deposition of the Lower Cretaceous Mannville Group (Cant and Stockmal, 1989; Hayes et al., *this volume*, Chapter 19).

The oldest sediments of the Mannville Group and its equivalents are the sandstones and conglomerates of the Cadomin Formation. These deposits are entirely continental, representing a series of coalescing alluvial fans and river deposits that flanked the eastern margin of the Cordilleran uplift (McLean, 1977). Streams flowed east from the Cordillera to join a major basin axial drainage system (Spirit River Valley) (McLean, 1977) that flowed northwestward to the Boreal Sea in extreme northeastern British Columbia and the Northwest Territories. Sediments of the Spirit River Valley were confined to the east by a major escarpment of outcropping Jurassic sediments (Fox Creek/Taber Escarpment) (McLean, 1977). Farther east, two additional major paleodrainages were developed: the Edmonton valley system in southern and north-central Alberta (McLean and Wall, 1981), and the Assiniboia valley system in Saskatchewan (Christopher, 1984). These major drainages first incised the underlying strata during the Hauterivian to Barremian hiatus, and then, with rising base level during late Barremian and Aptian time, accumulated significant thicknesses of fluvial deposits. Major delta complexes formed at the mouths of each of these river systems. The Spirit River and Edmonton drainages combined to form the Sikanni Chief Delta in northeastern British Columbia (Stott, 1973), and the Assiniboia River system developed the Fort McMurray Delta in northeastern Alberta (Flach, 1984). For a time, the Edmonton drainage appears to have been diverted northeastward through a gap in an adjacent highland (see below) to form the Keg River Delta in northwestern Alberta. In northern Alberta, extreme northeastern British Columbia and the Northwest Territories, coeval marine shales are found seaward (north) of these three major delta complexes. Located between the foreland basin drainage systems were a series of highlands that resisted erosion during the Hauterivian and Barremian hiatus. These highlands consist of strata ranging in age from Late Jurassic to Devonian (Hayes et al., *this volume*, Chapter 19; Christopher, 1984). Although all highlands were eventually buried by the combination of subsidence and continued deposition in the foredeep, some persisted as late as Early Albian time (see Figs. 17.3 - 17.6).

Calcareous/Ostracod/Cummings Interval (Fig. 17.4)

Strata of this interval consist primarily of thin, coarsening-upward successions of shales, siltstones and lenticular sandstones with locally occurring thin limestones representing deposition in a low-energy, brackish, subaqueous environment (Finger, 1983; James, 1985). Evidence of tidal activity is also common (Wanklyn, 1985; Banerjee and Davis, 1988).

As relative sea level rose with continued basin subsidence, the deltas and floodplains of the Cadomin/Gething interval were progressively inundated from the north. Tide-dominated embayments advanced southward along the Edmonton and Assiniboia valley systems, reworking the fluvial sands within. At the peak of the transgression, illustrated in Figure 17.4 (Early Albian time), most of Alberta and Saskatchewan were under water. Only the erosional highlands remained emergent, along with the western half of the Peace River Arch area, where a strong sediment supply from the Cordillera maintained the area above sea level (Gething Formation).

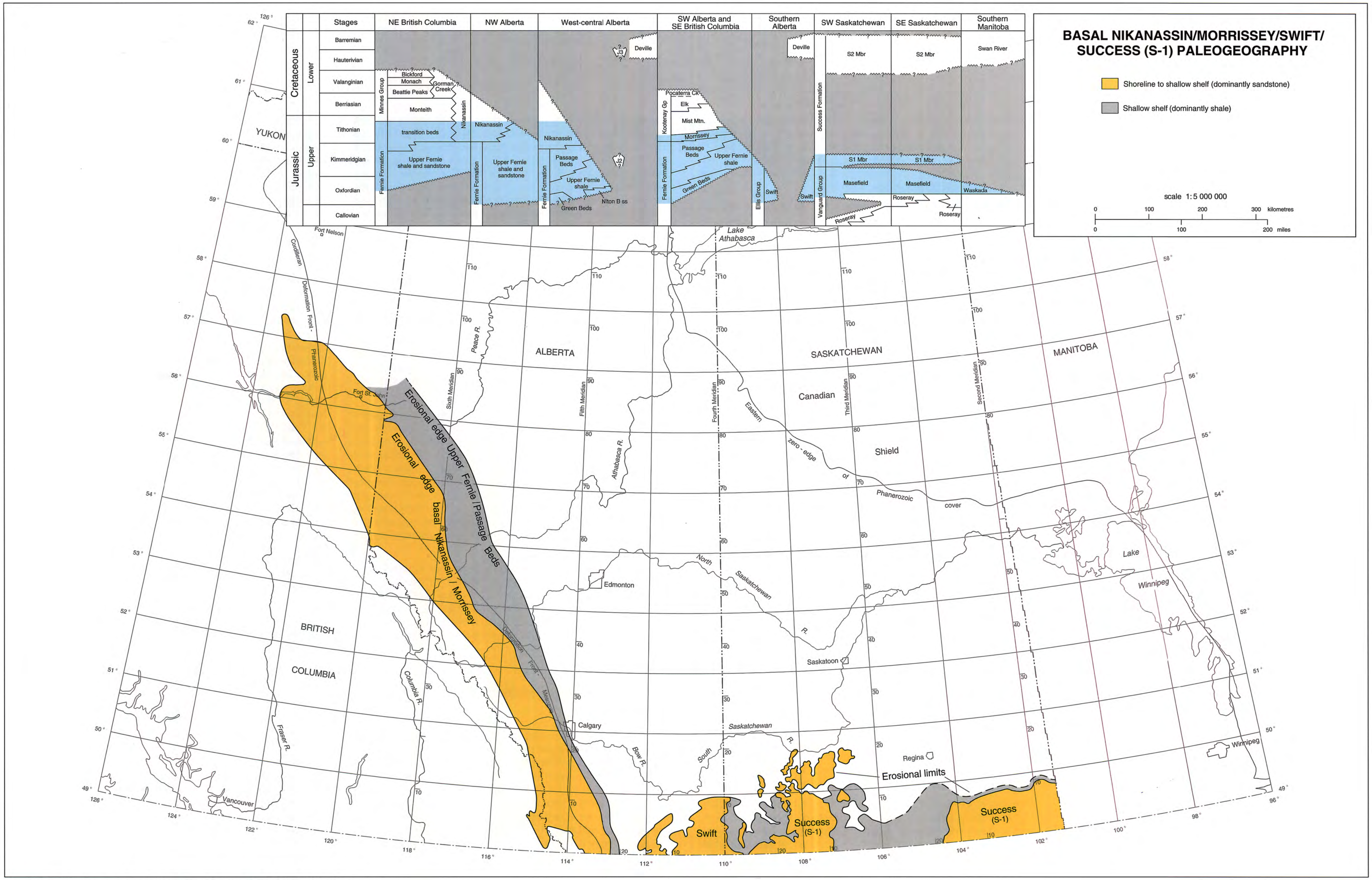

Figure 17.1 Paleogeography of the basal Nikanassin/Morrissey/Swift/Success (S-1) interval.

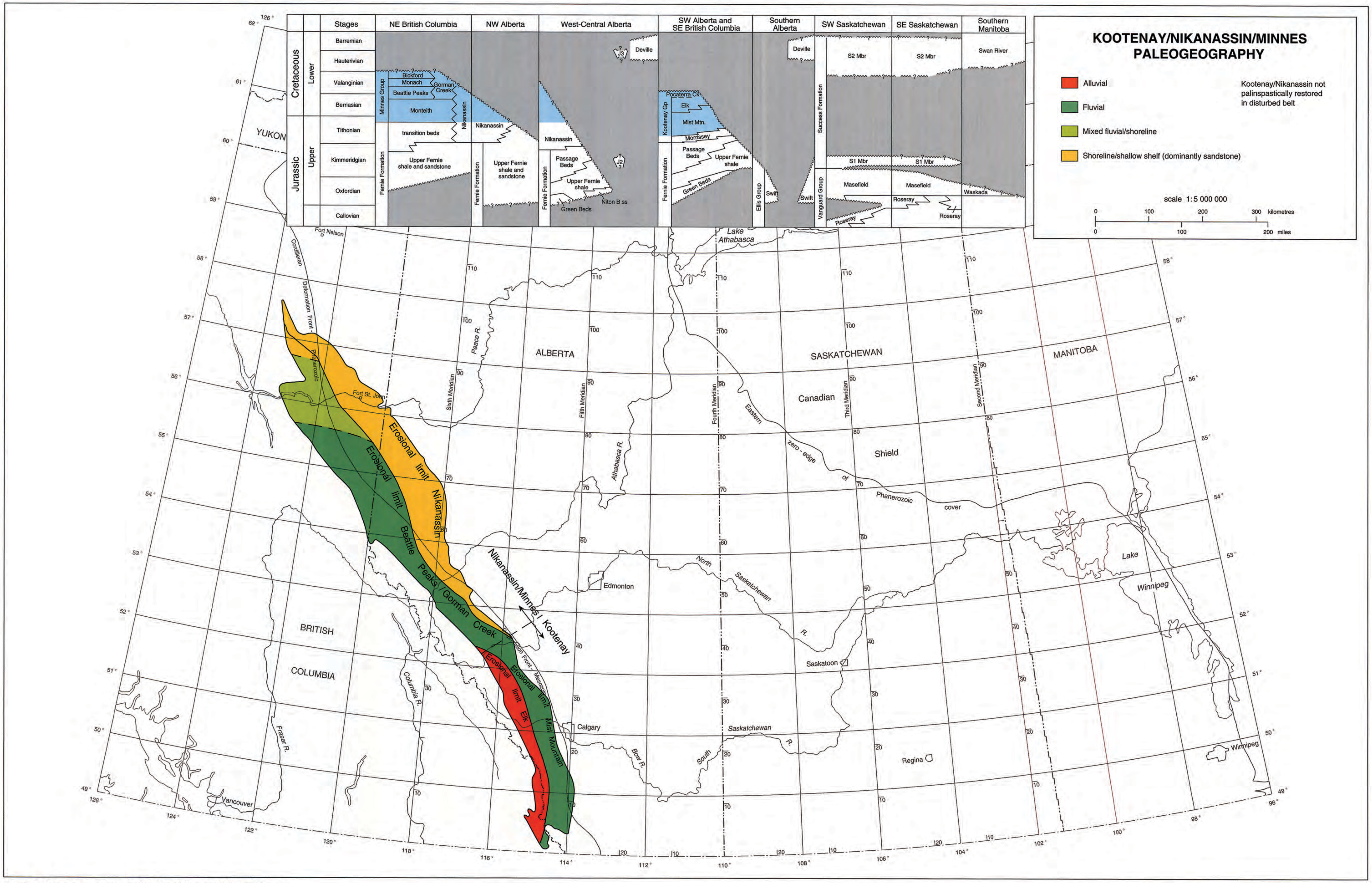

Figure 17.2 Paleogeography of the Kootenay/Nikanassin/Minnes interval.

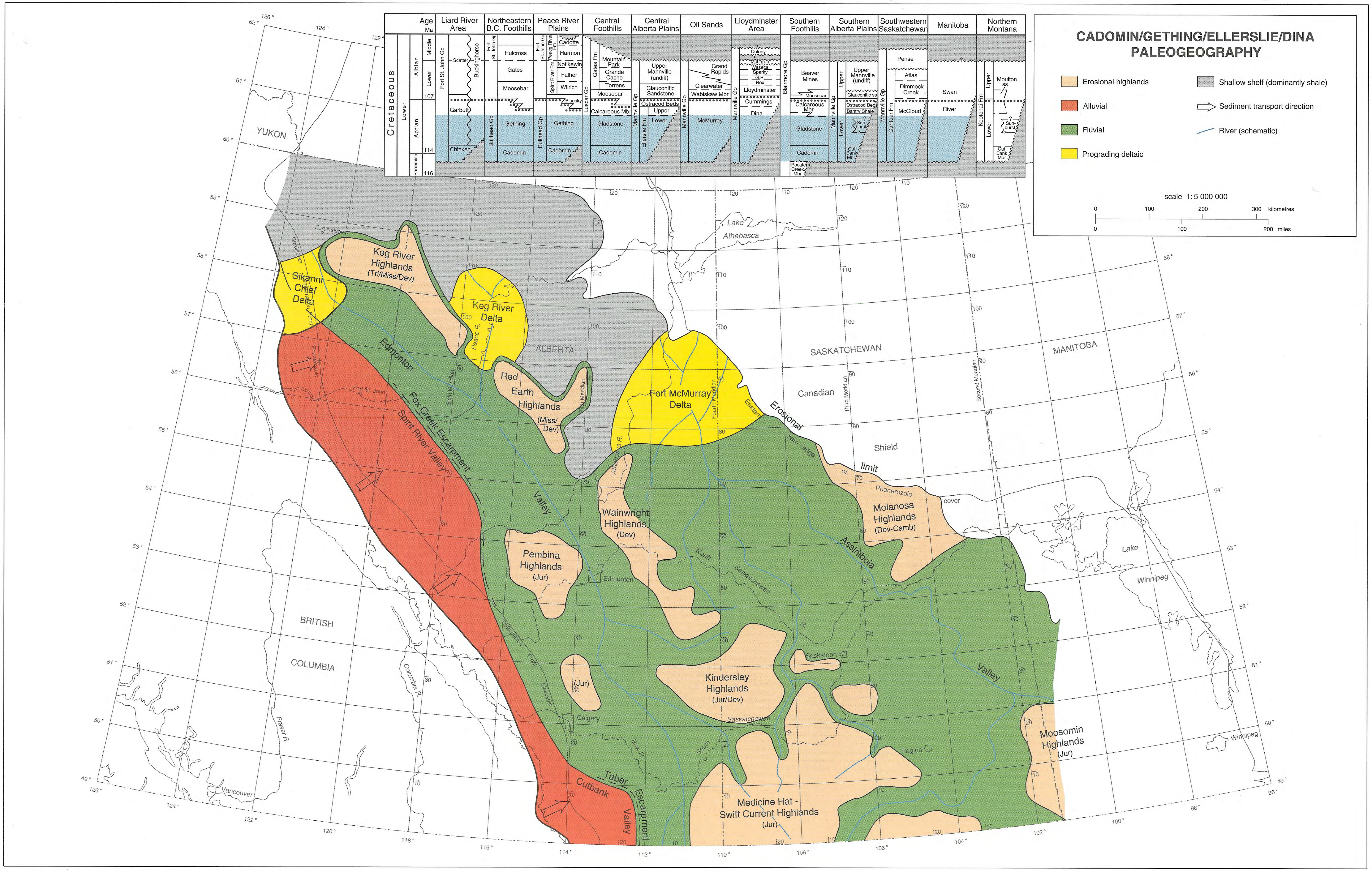

Figure 17.3 Paleogeography of the Cadomin/Gething/Ellerslie/Dina interval.

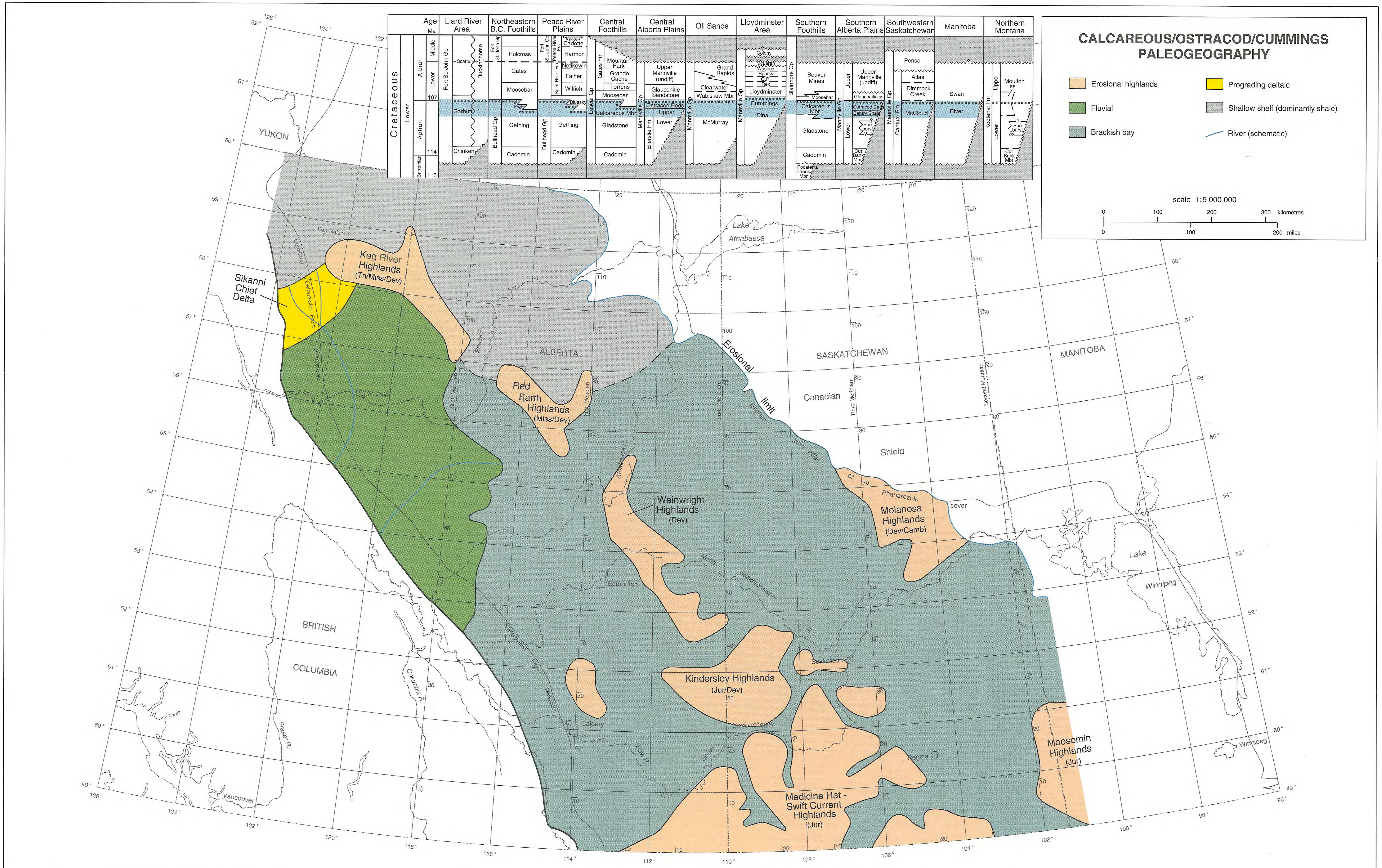

Figure 17.4 Paleogeography of the Calcareous/Ostracod/Cummings interval.

The transition from brackish to marine waters within the Ostracod seaway is gradual from south to north, as demonstrated by increasingly saline fauna in central and northern Alberta (McLean and Wall, 1981). The system appears to be fully marine north of the Keg River and Red Earth highlands. There is evidence of at least one major lowstand toward the end of Ostracod deposition when much of the basin may have become temporarily emergent. Ostracod/Gething incised valleys are present at Aitken Creek, British Columbia (Aitken Creek-Bluesky Oilfield, 94-A-13, Blk. L), Peace River, Alberta (Peace River Oil Sands Deposit; Tp 85, R 18W5), Edson, Alberta (Edson-Bluesky Gas Field; Tp 53, R 18W5) (Hardy, 1989), Lanaway, Alberta (Lanaway-Ostracod Oilfield; Tp 36, R 3W5) and Bellshill Lake, Alberta (Bellshill Lake Oilfield; Tp 41, R 12W4). Although the precise age relations of these valley systems are still uncertain, they all preceed the transgression of the Moosebar/Clearwater Sea (Fig. 17.5).

Lower Upper Mannville (Glauconitic/Bluesky) Interval (Fig. 17.5)

Strata of this interval record the transgression of the Moosebar/Clearwater sea southward across much of Alberta and Saskatchewan. Sediments are diachronous (older in the north, younger in the south) and generally represent the early stages of the transgression, namely, either highly glauconitic, transgressive marine shoreline to shoreface sandstones or progradational marine shoreline sandstones representing temporary pauses in the overall transgression, such as in the Elmworth and Pembina barriers. In Alberta, the Moosebar/Clearwater Sea advanced as far south as Edmonton where the northeast-southwest-trending Hoadley Barrier was established (Rosenthal, 1988). In Saskatchewan, shallow-shelf conditions extended at least to the USA border (Christopher, 1984). A progradational deltaic sequence caps Ostracod brackish bay sediments south of the Hoadley Barrier (Glauconitic Formation) (Rosenthal, 1988). Numerous incised valley deposits are present in southern Alberta, commonly with evidence of tidal reworking (Wood and Hopkins, 1989). The abundance of incised valley deposits suggests that the Moosebar/Clearwater transgression was highly episodic and interrupted by periods of sea-level lowstand and valley incisement (Putnam, 1982; James, 1985; Rosenthal, 1988; Wood and Hopkins, 1989).

Middle Upper Mannville (and equivalents) Interval (Fig. 17.6)

The first indication of a change in provenance in the foreland basin is seen in southern and central Alberta, where interbeds of volcanic/feldspathic sandstone are found within the quartzose sandstones of the Glauconitic Formation (James, 1985; Rosenthal, 1988). A major influx of Cordilleran-derived sediment followed, pushing shorelines northward and transforming much of Alberta and Saskatchewan to a floodplain environment (Mellon, 1967; Christopher, 1984). Fluvial channel sandstones, siltstones, shales and coals are common in the floodplains of southern Alberta and southwestern Saskatchewan. Prograding, coarsening-upward shoreline deposits are generally deltaic and wave dominated in eastern and western Alberta and western Saskatchewan (Leckie and Walker, 1982; Putnam, 1982; Cant, 1984; Smith et al., 1984; Christopher, 1984; Leckie, 1986a; MacDonald et al., 1988). In general, sandstones contain significant volcanic and feldspathic grains indicating an unroofing of volcanic and/or metamorphic terranes in the Cordillera (Mellon 1967). Fluvial quartzose sandstones derived from the craton are found in eastern Saskatchewan (Christopher, 1984). Shoreline sandstones of the Grand Rapids Formation in northeastern Alberta, although slightly lithic, have a high quartz content (Christopher, 1984) suggesting a significant contribution from the craton in that area. Gravelly shoreline deposits in west-central Alberta (Falher Member) are rich in chert, indicating continued erosion of chert-rich Paleozoic sediments in the Cordillera. Seaward of the Falher-Grand Rapids shoreline, some shallow-shelf sandstones are found. These grade in a northward direction to deeper marine shales (Cant, 1984; Leckie, 1986a). Near the Northwest Territories border in the Liard Basin of northeastern British Columbia, a series of coarsening-upward, glauconitic sandstones in the Scatter Formation (Bulwell Member) are correlated with the Falher Member farther south (Stott 1982; Leckie et al. 1991). They are interpreted as shallow-shelf deposits with a Cordilleran source.

Upper Upper Mannville (and equivalents) Interval (Fig. 17.7)

It is difficult to accurately reconstruct basin paleogeography during upper Upper Mannville deposition because this depositional cycle was followed by a significant period of erosion (post-Mannville unconformity) (Fig. 17.7). Assuming varying amounts of sediment removal from one area of the basin to another (Koke and Stelck, 1985), strata immediately below the truncation surface have considerable variability in age across the basin. Consequently, Figure 17.7 should be used only to determine the depositional environments of strata below the post-Mannville unconformity rather than as a depiction of basin paleogeography prior to unconformity time. In the area of the Peace River Arch, additional post-Mannville strata are preserved beneath the post-Mannville unconformity as a result of mild downwarping (Harmon and Cadotte members). Thus the paleogeography of upper Upper Mannville equivalents in this area (Notikewin Member) is more accurate than in areas of Mannville sediment removal due to post-Mannville erosion (Fig. 17.7).

In general, however, it can be said that fluvial conditions prevailed over much of southern and central Alberta while shorelines continued to prograde northward in northeastern Alberta (uppermost Grand Rapids Formation), and west-central Alberta (Notikewin Member) (Smith et al., 1984; Leckie, 1985). In east-central Alberta, a shallow, brackish water shelf developed (Wightman et al., 1987; Beynon et al., 1988). In Saskatchewan, this brackish facies (Pense Formation) contains multiple coarsening-upward sandstone cycles in southern areas of the province (Christopher, 1984). A similar, restricted-marine facies was described by McNeil (1984) for Manitoba. In eastern Alberta, the deltaic sands of the Colony/McLaren separate the fluvial and brackish regimes. North of the Peace River Arch, upper Upper Mannville equivalent strata consist primarily of deeper water shales (Mellon, 1967; Stott, 1982). In the Liard Basin, lobes of stacked, coarsening-upward, shallow-shelf sandstones first noted in middle Upper Mannville equivalent strata appear to have prevailed until the end of Mannville equivalent deposition (Stott, 1982; Leckie et al., 1991).

Cadotte/Tussock Interval (Fig. 17.8)

In the area of the Peace River Arch, additional post-Mannville equivalent strata (Harmon, Cadotte) are preserved beneath the post-Mannville unconformity. This appears to have been caused by a mild downwarping of the arch subsequent to Mannville deposition. The Harmon shale is marine, representing a deepening subsequent to Notikewin deposition. Where preserved, the Cadotte is represented by a prograding barrier facies. Although not differentiated as such, the Cadotte barrier facies is present within the Boulder Creek Formation in the present-day British Columbia foothills (Leckie and Reinson, *in press*). In the British Columbia foothills, the post-Mannville erosional period is represented in part by a series of paleosols within fluvial sediments of the Boulder Creek Formation (Leckie and Reinson, *in press*). North of the Peace River Arch, beyond the northern limits of the Cadotte barrier, marine shales prevail and there appears to have been continuous deposition over the period of the post-Mannville unconformity (Stelck, 1991), suggesting that subaerial exposure associated with the unconformity terminated north of the Peace River Arch. In the Liard Basin, a pulse of coarsening-upward, shallow marine sandstone (Tussock Member) may correlate with the Boulder Creek Formation to the south (Stott, 1982; Leckie et al., 1991).

Bow Island/Viking/Paddy/Newcastle Interval (Fig. 17.9)

Deposition of sediments of the Viking Formation and its equivalents took place in a variety of environments including floodplain, estuarine, brackish bay, regressive and transgressive shoreline, and shallow marine.

Following a period of lowstand and basin-wide erosion in Middle to Late Albian time (post-Mannville unconformity), a major sea-level rise resulted in flooding of most of the Western Canada Sedimentary Basin (Joli Fou shale). In the early stages of this transgression, shoreline to shallow-shelf sandstones were developed in many areas of Alberta and Saskatchewan (Basal Colorado, Spinney Hill sandstones). Incised valleys cut on the Mannville floodplain in eastern Alberta were backfilled, then reworked by tidal currents (Colony channel sandstones). Similar incised valley deposits are found on the Peace River Arch (Leckie and Reinson, *in press*). Although the Joli Fou seaway appears to have stretched from the Gulf of Mexico to the Arctic, (Williams and Stelck, 1975), marine shales are not found on the Peace River Arch, which was positive at the time (Koke and Stelck, 1985). The Joli Fou seaway also skirted the western margin of the foreland basin where the overlying Viking Formation rests directly on the Mannville Group (Mellon, 1967). The Joli Fou equivalent Skull Creek Member also exhibits an onlapping relation in the Manitoba Escarpment (McNeil, 1984).

In southern and west-central Alberta, Viking strata consist of one or more coarsening-upward shale-to-sandstone cycles representing marine offshore to shoreface deposition (Leckie and Reinson, *in press*). This same sequence is found in southwestern and southeastern Saskatchewan (Kozial, 1988). In addition, transgressive shoreline to shallow-water, tide-dominated shelf sandstones and conglomerates are found in west-central Alberta (Leckie, 1986b). Similar deposits can be observed in the Bow Island Formation in southwestern Alberta. In northeastern Alberta, central Saskatchewan and southwestern Manitoba, Viking and equivalent strata consist primarily of marine shale and siltstone. In the present-day Alberta and British Columbia foothills, Viking strata are transitional with continental floodplain sandstones, siltstones and carbonaceous shales (Leckie and Reinson, *in press*). In the area of the Peace River Arch, the equivalent Paddy Member consists primarily of brackish-bay shales and thin, coarsening-upward sandstones with a major prograding barrier sequence separating Paddy bay sediments from marine shales farther north (Smith et al., 1984). Incised valley-fill deposits (estuarine) are found within the Paddy Member in northwestern Alberta and northeastern British Columbia (Leckie and Reinson, *in press*) and within the Viking Formation in west-central Alberta (Reinson et al., 1988).

Viking and equivalent clastics were derived primarily from the eroding Cordillera to the west, although the equivalent Newcastle Member in eastern Saskatchewan and Manitoba has an eastern source (McNeil, 1984). A major floodplain stretched along the present-day foothills from the United States border into northeastern British Columbia. Shorelines along the eastern margin of this floodplain prograded eastward into the basin. Shallow shelf conditions existed over much of the remainder of the foreland basin. On the north flank of the Peace River Arch a major prograding barrier sequence with sediments derived from the foothills area to the southwest sheltered the Peace River Arch area from the Boreal Sea, and relatively quiet-water brackish bay conditions developed. At least two sea-level lowstands occurred during Viking deposition (Reinson et al., 1988; Boreen and Walker, 1991; Leckie and Reinson, *in press*). During the lowstands, incised valleys were cut on the exposed shelf. These were backfilled and reworked by tidal currents during the next sea-level rise. Lowstand fluvial sands and gravels transported onto the shelf during late Viking deposition were reworked during the subsequent transgression into a series of transgressive shoreline and tide dominated shelf deposits (Leckie, 1986b; Downing and Walker, 1988). Following Viking and equivalent deposition, a major relative sea-level rise inundated the entire foreland basin (Colorado/Shaftesbury Sea), resulting in marine shale deposition over all of the preserved basin.

Dunvegan Interval (Fig. 17.10)

Sediment distribution patterns in the foreland trough changed dramatically in Late Cretaceous time. Upper Jurassic and Lower Cretaceous sediments appear to have come from the south and west with little coarse clastic input north of the Peace River Arch. Fill was basin-axial from southeast to northwest. Upper Cretaceous sequences, in general, indicate a sediment supply from the west or north with fill from the northwest. This supports the concept proposed by Poulton et al. (*this volume*, Chapter 18) that the centre of maximum Cordilleran uplift and erosion moved north with time, reaching the northern Yukon in the Late Cretaceous. Dunvegan strata clearly indicate this trend. In the Liard Basin adjacent to the Yukon/Northwest Territories border, Dunvegan strata consist primarily of coarse sandstones and conglomerates representing an uplands fluvial sequence. Southeastward of this succession and extending into northwestern Alberta, the Dunvegan Formation is made up of non-marine shales and carbonaceous shales, siltstones and fining-upward fluvial channel sandstones, with some paleosols, representing deposition in a floodplain to coastal plain environment (Bhattacharya and Walker, 1991). Farther southeastward, the Dunvegan Formation grades to deltaic shoreline and shoreface deposits represented by coarsening-upward river and wave dominated delta-front sandstones, fining-upward riverine and estuarine channel-fill sandstones and inter-distributary bay shales and carbonaceous shales. The fauna of this succession range from brackish to marine. Beyond this facies, the Dunvegan Formation passes seaward into marine shales of the Shaftesbury and Kaskapau formations (Bhattacharya and Walker, 1991). There appears to have been at least one major lowstand during Dunvegan deposition, correlating with the incision of the Simonette channel (Bhattacharya and Walker, 1991). The Dunvegan deltaic complex was ultimately terminated by an apparent global rise in sea level that culminated in the deposition of the overlying Kaskapau shale (Bhattacharya and Walker, 1991).

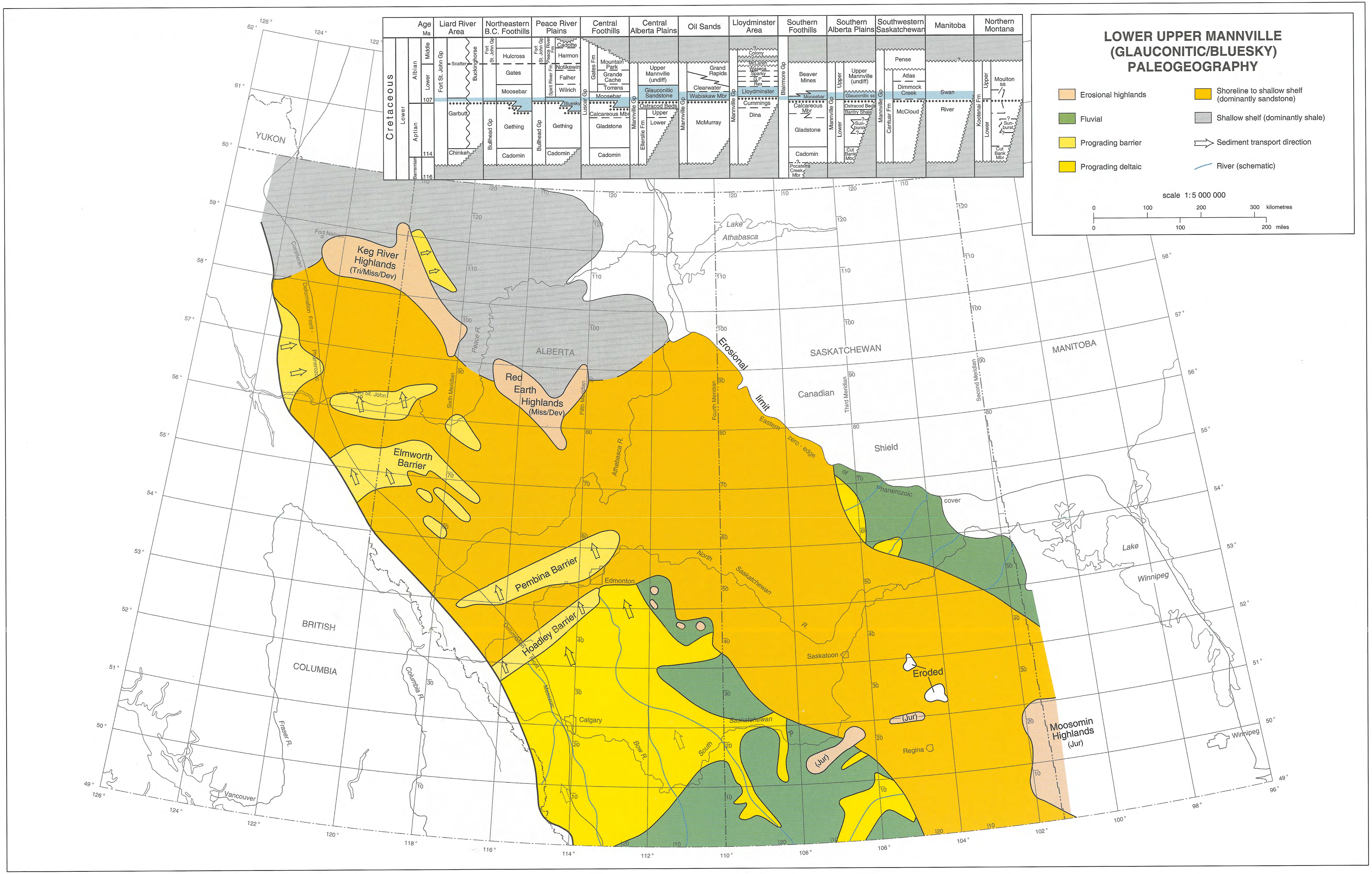

Figure 17.5 Paleogeography of the lower Upper Mannville (Glauconitic/Bluesky) interval.

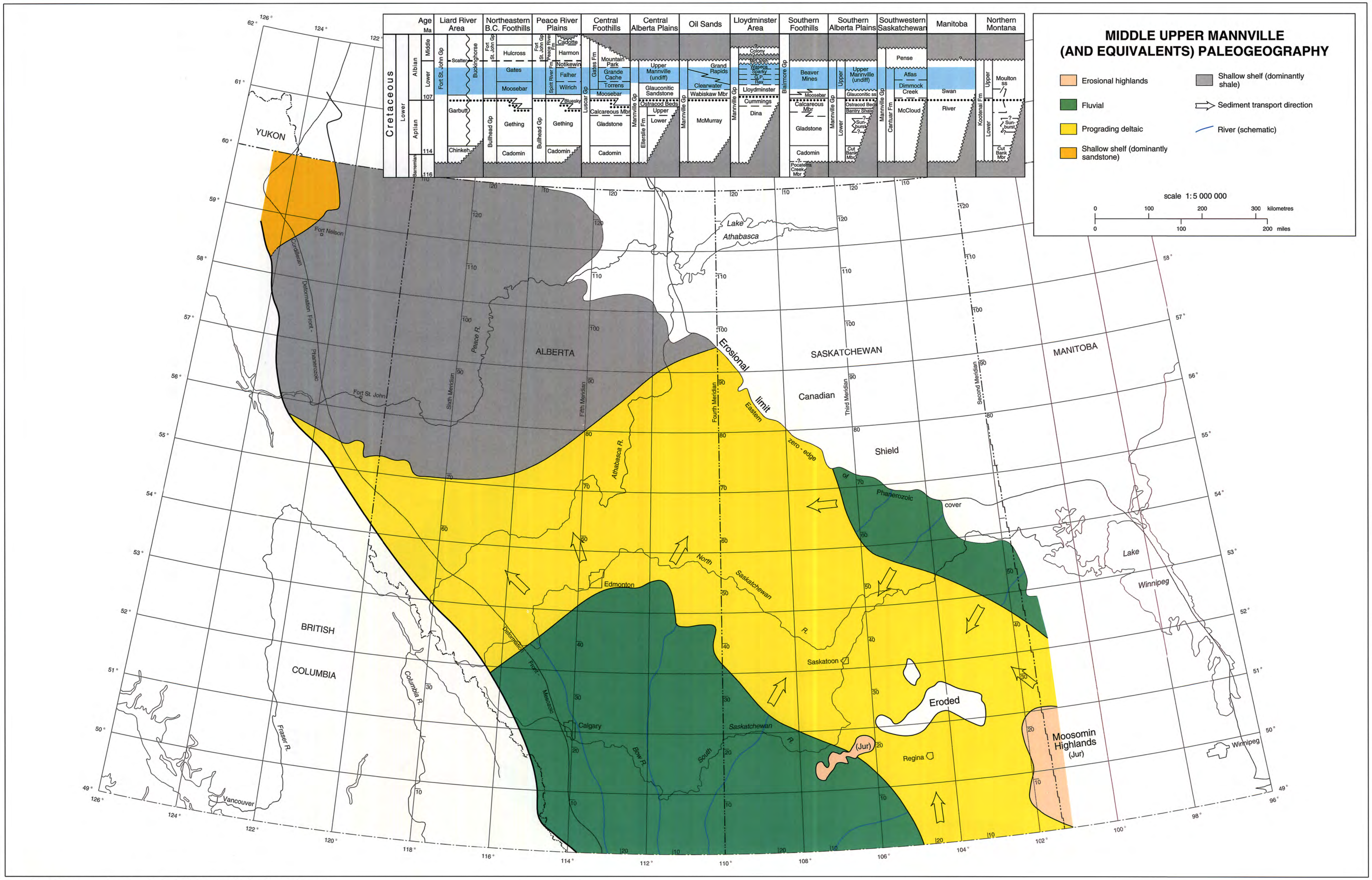

Figure 17.6 Paleogeography of the middle Upper Mannville (and equivalents) interval.

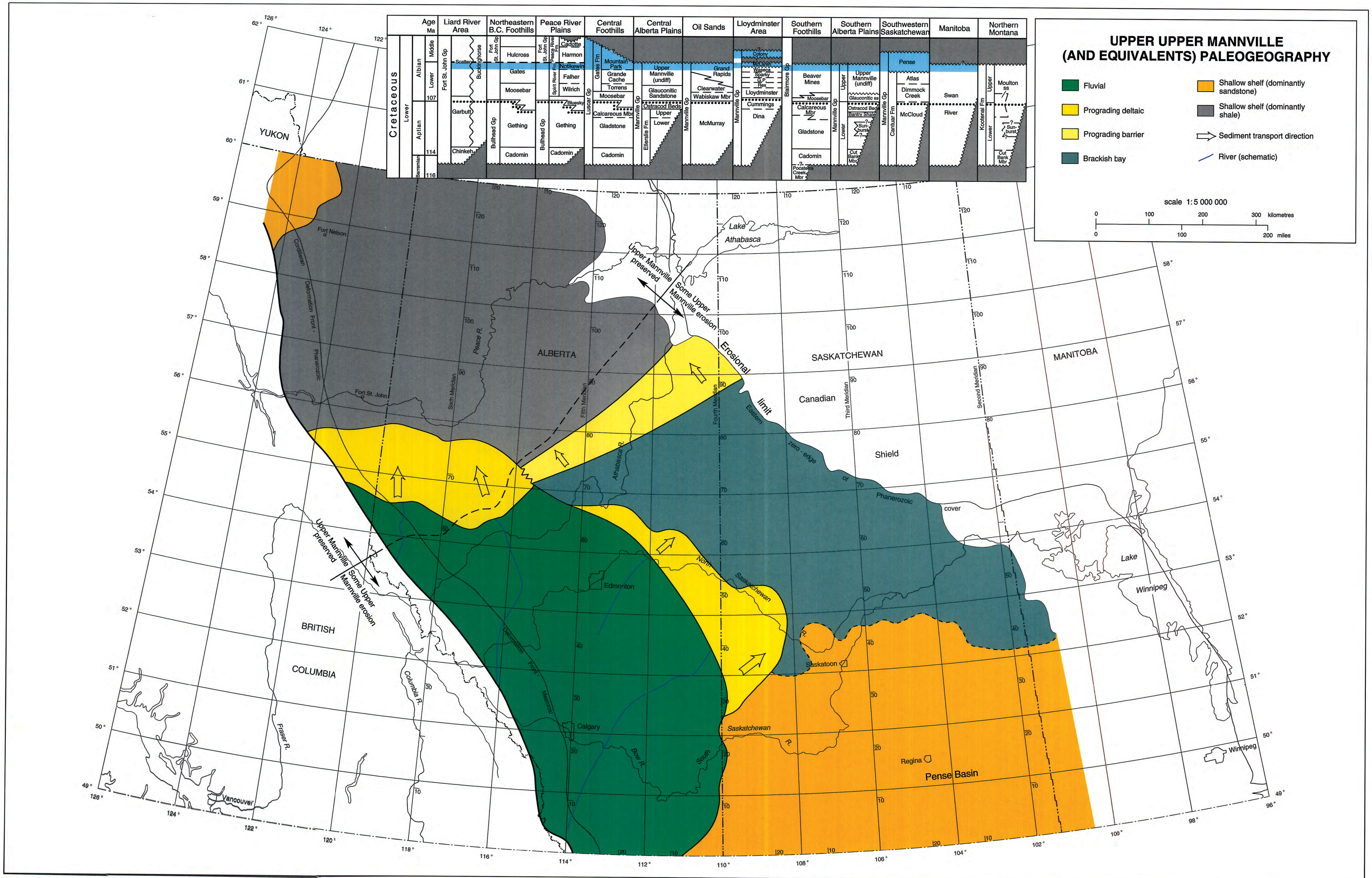

Figure 17.7 Paleogeography of the upper Upper Mannville (and equivalents) interval.

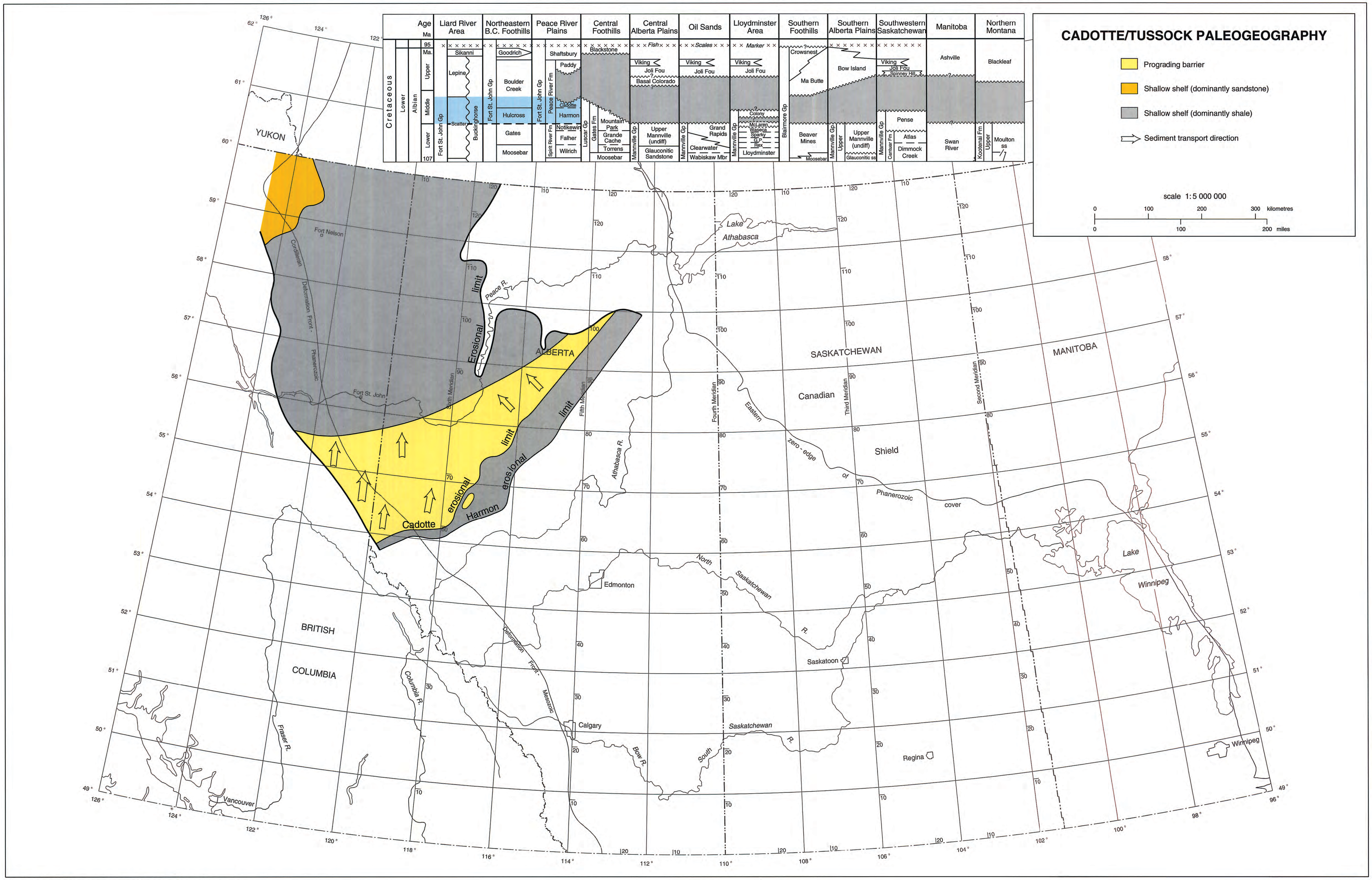

Figure 17.8 Paleogeography of the Cadotte/Tussock interval.

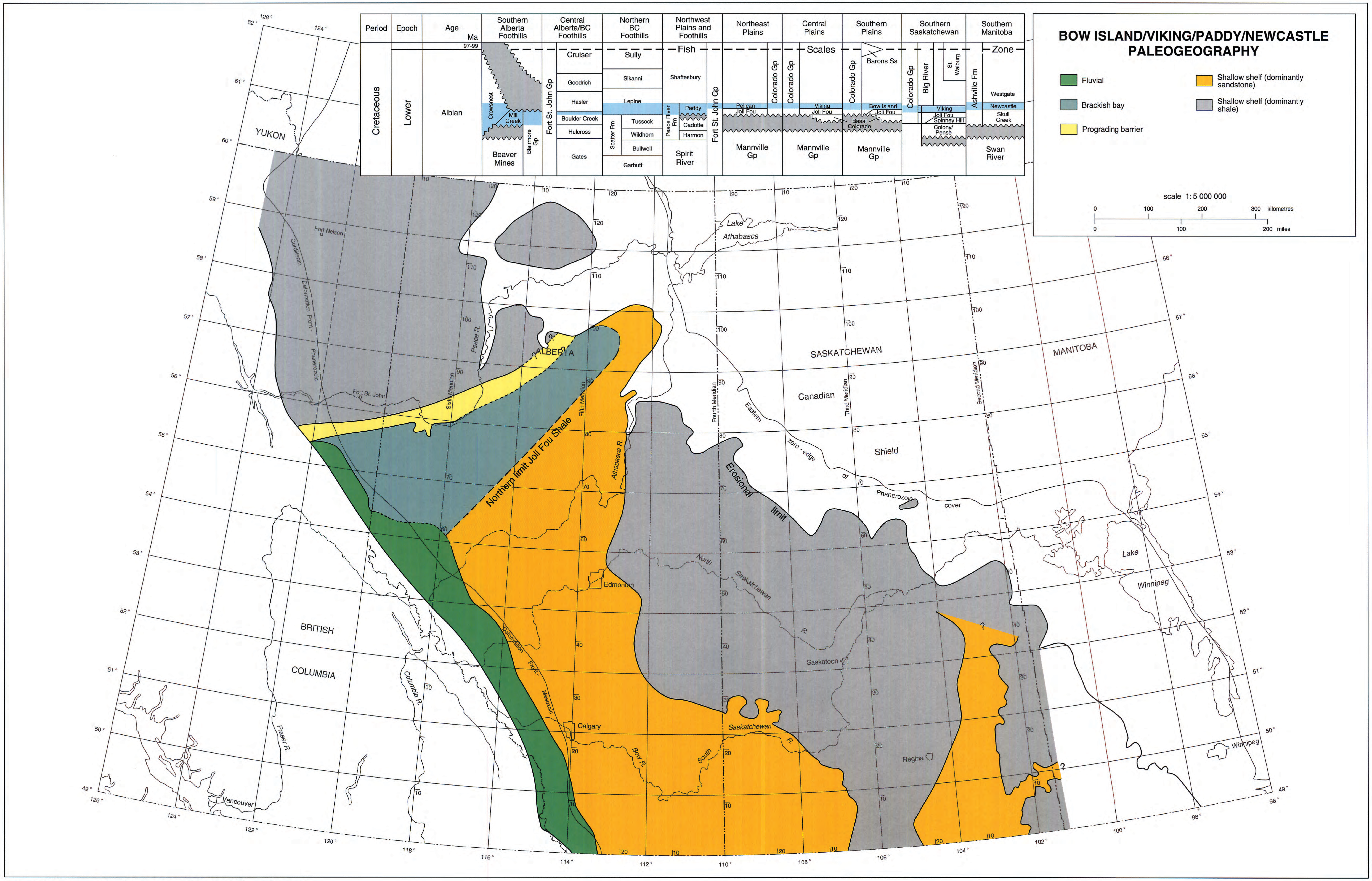

Figure 17.9 Paleogeography of the Bow Island/Viking/Paddy/Newcastle interval.

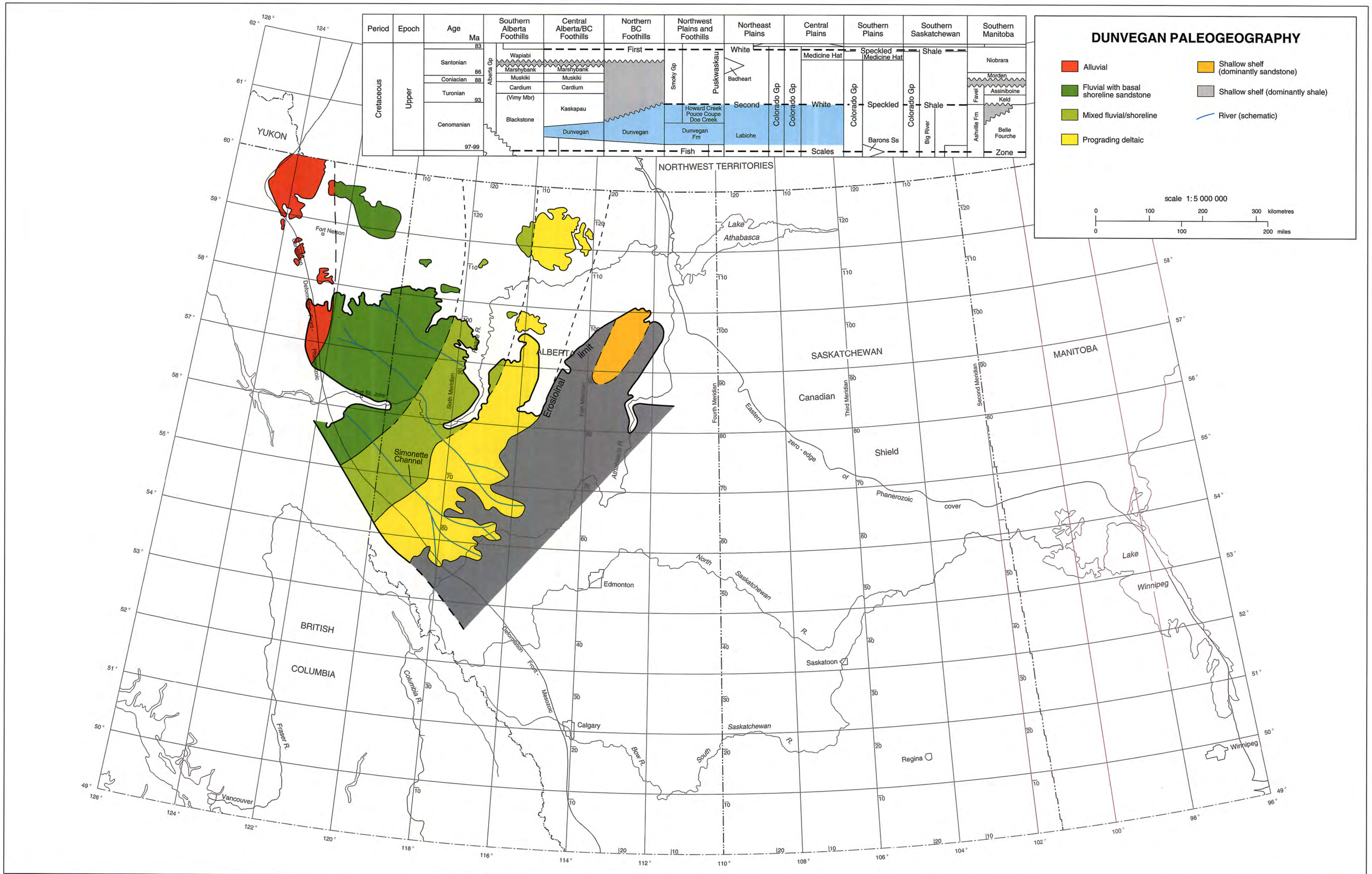

Figure 17.10 Paleogeography of the Dunvegan interval.

Cardium Interval (Fig. 17.11)

The Cardium Formation (Turonian to Coniacian) was deposited along the western margin of the foreland trough at a time when Cretaceous global sea level was close to its all time high (Cenomanian and Turonian). Sediments were derived from the active Cordillera to the west. In eastern areas, the Cardium Formation consists primarily of a coarsening-upward sequence of bioturbated marine mudstones and hummocky cross-stratified sandstones indicating deposition in a storm-dominated, open-marine, offshore to shoreface environment (Wright and Walker, 1981; Krause and Nelson, 1984; Plint et al., 1986). To the west, the Cardium Formation includes a coarsening-upward, prograding shoreface-to-shoreline sequence of bioturbated mudstones and hummocky cross-stratified sandstones (lower shoreface), high angle, cross-stratified sandstones (upper shoreface) and parallel laminated, rooted sandstones (foreshore and backshore). This is capped by a coastal plain sequence of mudstones, fluvial channel sandstones and paleosols (Stott, 1963; Plint and Walker, 1987). Several fluctuations in relative sea level occurred during Cardium deposition (Plint et al., 1986). At least one sea-level fall appears to have been major, resulting in subaerial exposure and erosion of a significant portion of the shelf (the E-5 surface of Plint et al., 1986). During this lowstand and the early stages of the subsequent sea-level rise, coarse sands and gravels were transported by rivers across the exposed shelf to the lowstand coastline where they were reworked and redistributed by waves and currents along the shoreface. In addition, shoreface erosion by wave scouring during stillstands in sea-level rise resulted in further beveling of the E-5 surface and concentration of shoreface gravels at the bevels (Bergman and Walker, 1987, 1988; Walker and Eyles, 1988, 1990; Leggitt et al., 1990; Arnott, 1991).

Milk River/Chungo/Chinook Interval (Fig. 17.12)

A significant influx of Cordilleran-derived sediment in southwestern Alberta during early Campanian time pushed Milk River/Chungo shorelines northeastward into the foreland trough. In the southern Alberta foothills and plains, sediments consist of a series of offlapping, coarsening-upward shale-to-sandstone cycles representing marine offshore to shoreface to foreshore deposition (Meijer Drees and Myhr, 1981). Shoreface sandstones are dominated by hummocky cross-stratification indicating deposition on a storm-dominated shelf (Lerand, 1983; Rosenthal and Walker, 1987; Cheel and Leckie, 1990). A major tidal inlet complex occurs at Writing-On-Stone Provincial Park in southern Alberta, indicating the presence of tidal processes along an otherwise wave-dominated shoreline (Cheel and Leckie, 1990). Shorelines were oriented west-northwest/east-southeast and prograded northeastward to a point close to the Mount Yamnuska outcrop in the Alberta foothills (Lerand, 1983) and near the common junction of the Alberta-Saskatchewan boundary and the 49th parallel. A capping coastal plain sequence consisting of shales and carbonaceous shales, fluvial channel sandstones, siltstones and coals can be found in the outcrops of the southern Alberta foothills and in the outcrops and subsurface of the southern Alberta plains (Meijer Drees and Myhr, 1981; Rosenthal and Walker, 1987).

Seaward (northeast) of the Milk River shoreline sequence, a large area of bioturbated, thinly interlaminated, sharp-based silty sandstones and shales are found more or less centered over the Sweetgrass Arch (Alderson Member). Deposits similar to this sandier-upward sequence in the southern Alberta foothills are attributed to deposition at or below storm wave-base by storm-related density currents (Lerand, 1983; Rosenthal and Walker, 1987). A significant drop in relative sea level occurred following Milk River/Chungo deposition (Rosenthal and Walker, 1987; O'Connell et al., 1992). This was followed by a major relative sea-level rise with deposition of the marine shales of the Pakowki Formation/Nomad Member. A chert-pebble transgressive lag marks the ravinement surface associated with this transgression. Using palynology, Sweet and Braman (1990) suggested a younger age for Chungo outcrops in and north of the Bow River valley. They suggested that these northern sections are correlative with the disconformity (lowstand period) at the end of Chungo deposition described by Rosenthal and Walker (1987) and O'Connell et al. (1992). This implies that shoreface sequences north of the Bow River valley are lowstand deposits, laid down during a period of falling (or rising) sea level when southern areas of the province were subaerially exposed and possibly undergoing erosion and/or valley incision. O'Connell et al. (1992) extended the disconformity northeastward beneath the Alderson Member and described the Alderson as a lowstand deposit that onlaps the disconformity in a southward direction, indicating deposition during rising sea level. Using palynology, they suggested a late Campanian age for the Alderson. Sweet and Braman (1990) suggested a late, if not latest early Campanian age for the Chungo sections of the Bow River valley and northward, making them slightly older. McNeil and Caldwell (1981) documented an unconformity between the equivalent Santonian to early Campanian Niobrara Formation and the overlying Campanian Pierre Shale in the Manitoba Escarpment. This hiatus may correspond to the lowstand at the end of Chungo deposition described above.

Belly River (and equivalents) Interval (Fig. 17.13)

Following an early Late Campanian period of marine inundation (Pakowki/Nomad Sea), another major influx of clastic detritus from the Cordillera again pushed coastlines eastward across the foreland basin. At the peak of this regression in late Late Campanian time, Belly River coastlines had advanced at least as far east as Saskatoon, Saskatchewan, or approximately 106°W longitude. This regression was terminated by a major rise in relative sea level with the resultant transgression of the Bearpaw Sea westward across the Belly River floodplain to a point near Edmonton in central Alberta and to the western limits of foothills outcrops southwest of Calgary, Alberta (Stott, 1984). Belly River and equivalent sediments consist of a basal deltaic shoreline and shoreface succession overlain by coastal plain and floodplain deposits.

The basal sequence consists of a series of offlapping, coarsening-upward river and wave dominated delta-front sandstones with incising, fining-upward distributary channel sandstones (Iwuagwu and Lerbekmo, 1984; Wasser, 1988). The presence of hummocky cross-stratification in coarsening-upward sequences indicates a storm-dominated shoreface. Some evidence of tidal influence has been observed in distributary channel sandstones in south-central Alberta (R.A. Rahmani, pers. comm.). Shoreface sandstones of the Belly River prograding wedge can be found as far east as Regina, Saskatchewan. Beyond Regina, marine shales (Riding Mountain Formation) persist to the outcrop in the Manitoba Escarpment.

The overlying sequence consists of coastal plain and floodplain fluvial channel sandstones, overbank siltstones and shales and interdistributary bay shales, carbonaceous shales and coals. This continental wedge thickens from a zero edge near 106°W longitude to over 700 m in the southern Alberta foothills. Estuarine channel deposits have been described in uppermost Belly River (Judith River) sediments in outcrop in Dinosaur Provincial Park (Koster et al., 1987; Koster and Currie, 1987). These sediments probably represent the early stages of the transgression of the Bearpaw Sea.

Sandstones of the Belly River and equivalents clastic wedge are rich in volcanic rock fragments, suggesting that this progradational cycle was largely a response to coeval volcanism (or tectonic emplacement of older volcanic rocks) as well as thrusting in the Rocky Mountains (Mack and Jerzykiewicz, 1989). Mack and Jerzykiewicz (1989) suggested that the Omineca Crystalline Belt was the probable site of the volcanism. Sediment transport was primarily eastward or northeastward to the western margin of the foreland basin (Mack and Jerzykiewicz, 1989). Within the foreland basin, sediment transport appears to have been southeastward in Alberta, becoming more easterly in Saskatchewan (Eisbacher et al., 1974; Rahmani and Lerbekmo, 1975).

Horseshoe Canyon/Scollard/Paskapoo/ Ravenscrag Interval (Fig. 17.14)

The uppermost Cretaceous/Tertiary units depicted in Figure 17.14 include, in ascending order, the Maastrichtian Horseshoe Canyon/St. Mary River formations, Whitemud Formation, Battle Formation, Scollard/Willow Creek/Frenchman formations, and the Paleocene Paskapoo/Porcupine Hills/Ravenscrag/Turtle Mountain formations. Beyond the western limits of the Bearpaw marine shale, Figure 17.14 includes the upper portions of the Brazeau and Wapiti formations. Apart from the basal transitional sandstones of this sequence, which record the final retreat of the Cretaceous sea from Western Canada, (Blood Reserve, Eastend and Boissevain formations), this sequence is entirely non-marine.

The diachronous, lowermost Horseshoe Canyon sandstones and their equivalents represent the leading edge of this Late Cretaceous/Tertiary eastward-prograding clastic wedge. These coastline deposits consist primarily of coarsening-upward barrier and delta-front sandstones, dissected by fining-upward distributary channel sandstones (Shepheard and Hills, 1970; Nadon, 1988; Rahmani, 1988). The presence of hummocky cross-stratification in coarsening-upward sequences indicates a storm-dominated seaway (Nadon, 1988; Rahmani, 1988). Coastal tidal activity is indicated by the presence of estuarine deposits at Drumheller, Alberta (Rahmani, 1988) and fining-upward tidal inlet sandstones in southwestern Alberta (Nadon, 1988).

The remainder of the Horseshoe Canyon Formation and its equivalents consist primarily of fluvial channel sandstones, floodplain siltstones and shales as well as coals and carbonaceous shales. Lacustrine deposits characterized by shales, siltstones and coarsening-upward, fine-grained sandstones were described by Nurkowski and Rahmani (1984) along the Red Deer River in south-central Alberta.

The overlying Whitemud and Battle formations are widespread over Alberta and Saskatchewan. The Whitemud Formation consists of kaolinitic and bentonitic sandstone, siltstone and shale; the Battle Formation consists of highly bentonitic shale with interbeds of volcanic tuff. Mack and Jerzykiewicz (1989) interpreted the time period represented by the Horseshoe Canyon, Whitemud and Battle formations as a period of tectonic quiescence. The foreland basin at this time consisted of a low-relief floodplain with numerous rivers, swamps and large, shallow-water lakes. Rivers flowed southeastward across the basin (Rahmani and Lerbekmo, 1975; Eisbacher et al., 1974). Extensive volcanism to the west (Irish and Havard, 1968) and south (Binda, 1969) during the late stages of this time period gave rise to the bentonitic shales and tuffaceous beds (Kneehills Tuff) of the Battle Formation. Subsequent to deposition of the Battle Formation, a period of uplift and erosion resulted in the post-Battle disconformity.

Sediments of the Scollard Formation and its equivalents consist of a floodplain sequence of fluvial channel sandstones, siltstones and shales. The lower member (informal) is coarser grained and barren of coals. The upper member (informal) is finer grained and contains minor coal. Caliche deposits and redbeds, described in the equivalent Willow Creek Formation in southwestern Alberta by Jerzykiewicz and Sweet (1988) indicate more arid conditions in that part of the basin, perhaps due to a rain shadow caused by the Cordillera to the west. Mack and Jerzykiewicz (1989) related the lower, coarser grained member to a period of tectonic thrusting in the eastern Main Ranges or Front Ranges and the upper, coal-bearing member to a period of tectonic quiescence. The contact between the lower and upper members of the Scollard Formation is roughly coincident with the Cretaceous/Tertiary boundary event (Lerbekmo et al., 1987).

The Paleocene Paskapoo Formation (Alberta) and its equivalent Ravenscrag Formation (Saskatchewan) are associated with the last thrusting event in the Cordillera (Mack and Jerzykiewicz, 1989). The Paskapoo contains numerous fluvial channel sandstones interbedded with overbank siltstones and shales, but is barren of coal except for the Obed coal zone in west-central Alberta. The Ravenscrag is similar except that it is rich in coal seams across most of southern Saskatchewan (Irvine et al., 1978).

Subsequent to Paskapoo/Ravenscrag deposition, a period of major uplift and erosion marked the end of foreland basin deposition.

SUMMARY

This chapter contains 14 paleogeographic maps of the major sandstone-bearing sequences of the foreland basin depicted either at peak transgression or peak regression. The intent is to provide the Atlas user with a geographic depiction of the major sandstone systems along with a basic understanding of environments of deposition, regressive or transgressive trends and sediment dispersal patterns.

The transformation of Western Canada from a wide, stable, continental platform to a rapidly subsiding foredeep trough took place in Late Oxfordian to Kimmeridgian time (Late Jurassic) as a result of allochthonous terrane accretion associated with the Columbian Orogeny. The initial sediments of the foreland basin succession include the Upper Fernie and Kootenay Group in southern Alberta, the Nikanassin Formation in west-central and northwestern Alberta and the Minnes Group in northwestern Alberta and northeastern British Columbia. Sediments shed from the rising Cordillera to the west during Late Jurassic and Early Cretaceous time quickly filled the early, narrow foredeep trough, resulting in fluvial deposition over much of its preserved length. Paleocurrent indicators point to a northerly transport direction and there is a change from uplands deposition in the south to mixed fluvial and marine deposition in the north suggesting a northward tilt to the foreland trough. This tilt was probably caused by more intense orogenic activity in the south during Late Jurassic time.

During Hauterivian and Barremian time (Early Cretaceous), a major drop in sea level resulted in significant erosion across the entire foreland trough (pre-Mannville unconformity). The earliest post-unconformity sediments include the alluvial fan and braided stream deposits of the Cadomin Formation (Barremian) and the fluvial deposits of the Lower Mannville Group (Aptian). Rivers flowed northward between a series of highlands to a boreal sea located in northern Alberta, extreme northeastern British Columbia and the Northwest Territories.

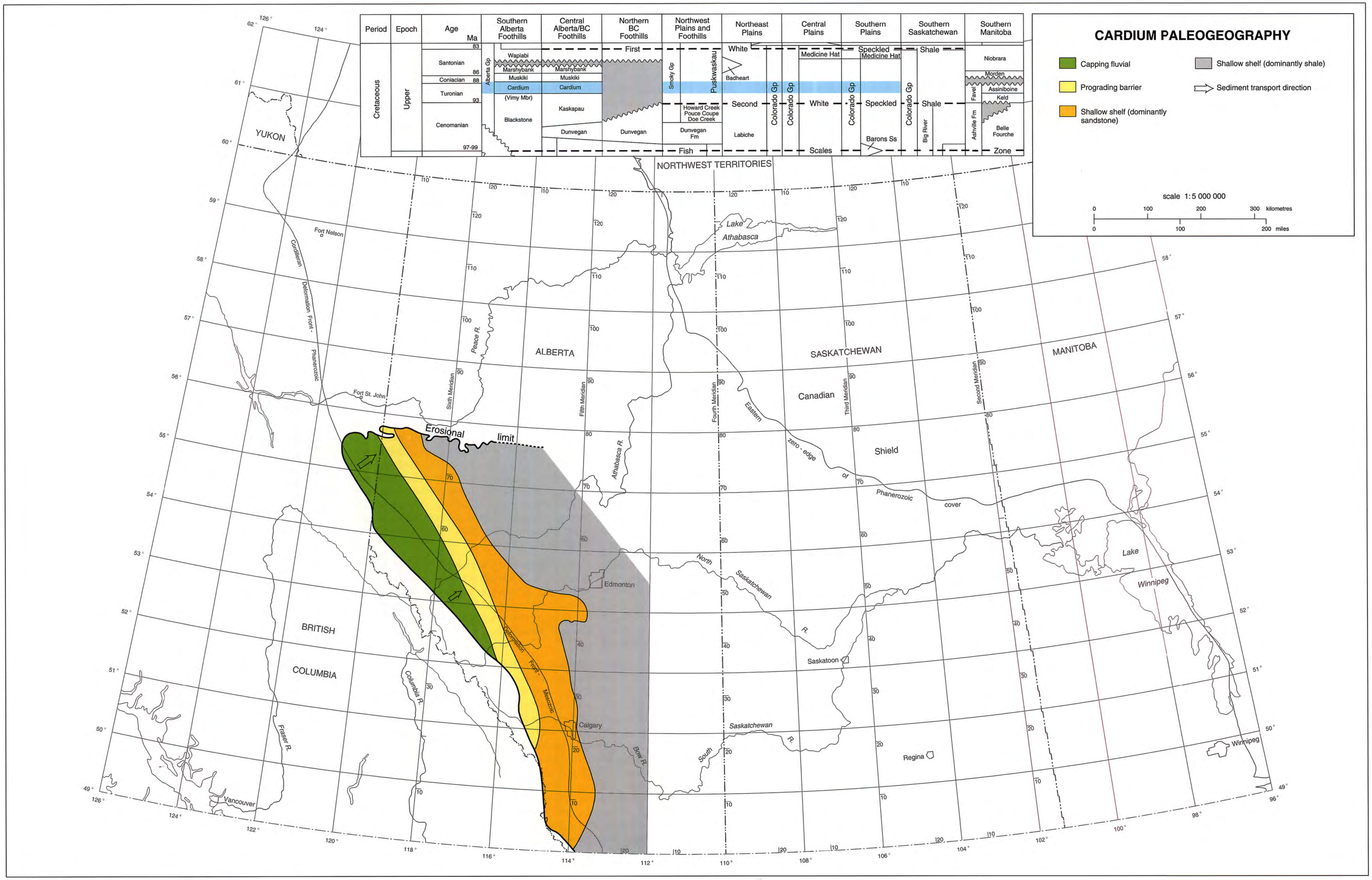

Figure 17.11 Paleogeography of the Cardium interval.

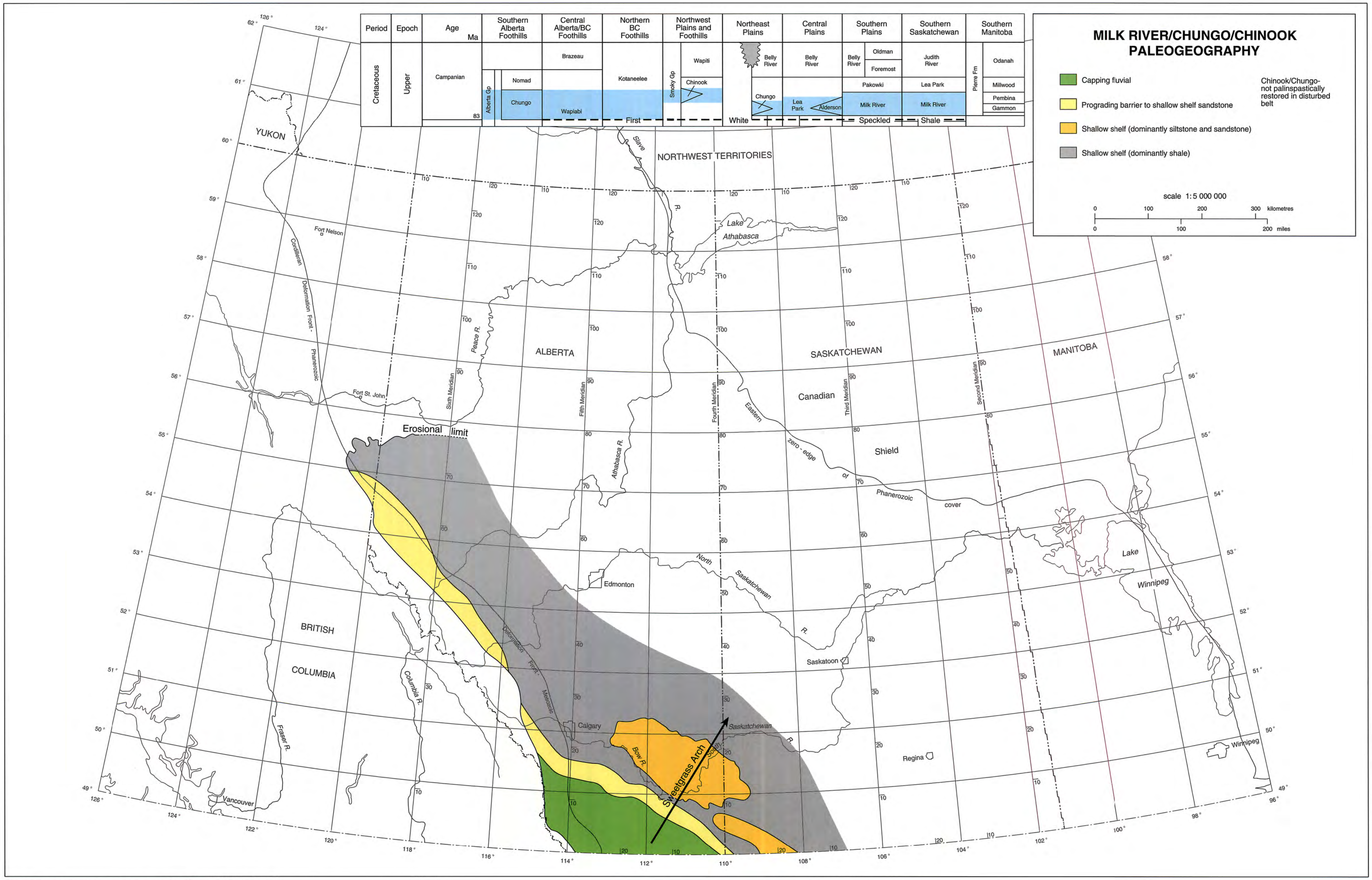

Figure 17.12 Paleogeography of the Milk River/Chungo/Chinook interval.

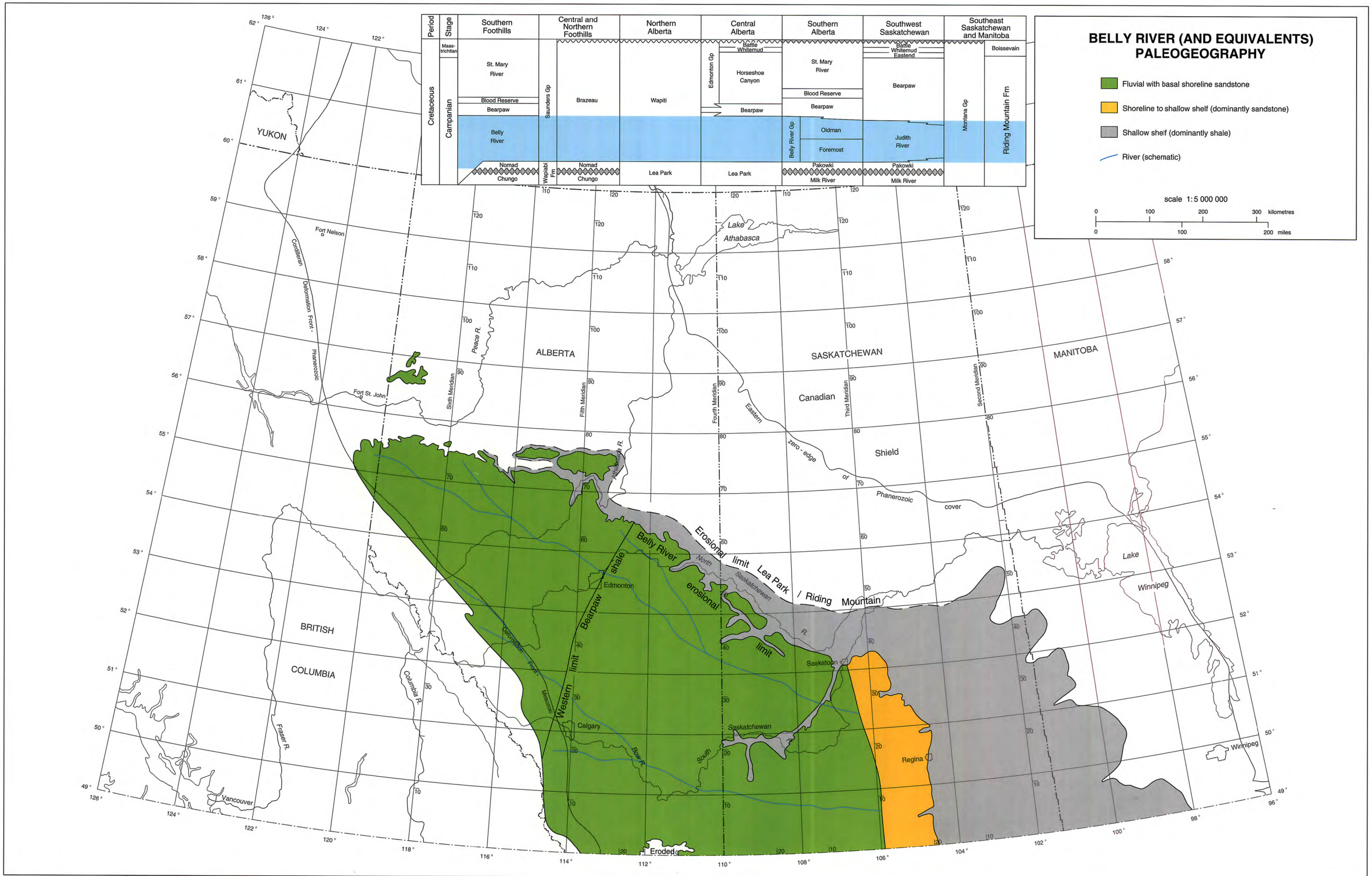

Figure 17.13 Paleogeography of the Belly River (and equivalents) interval.

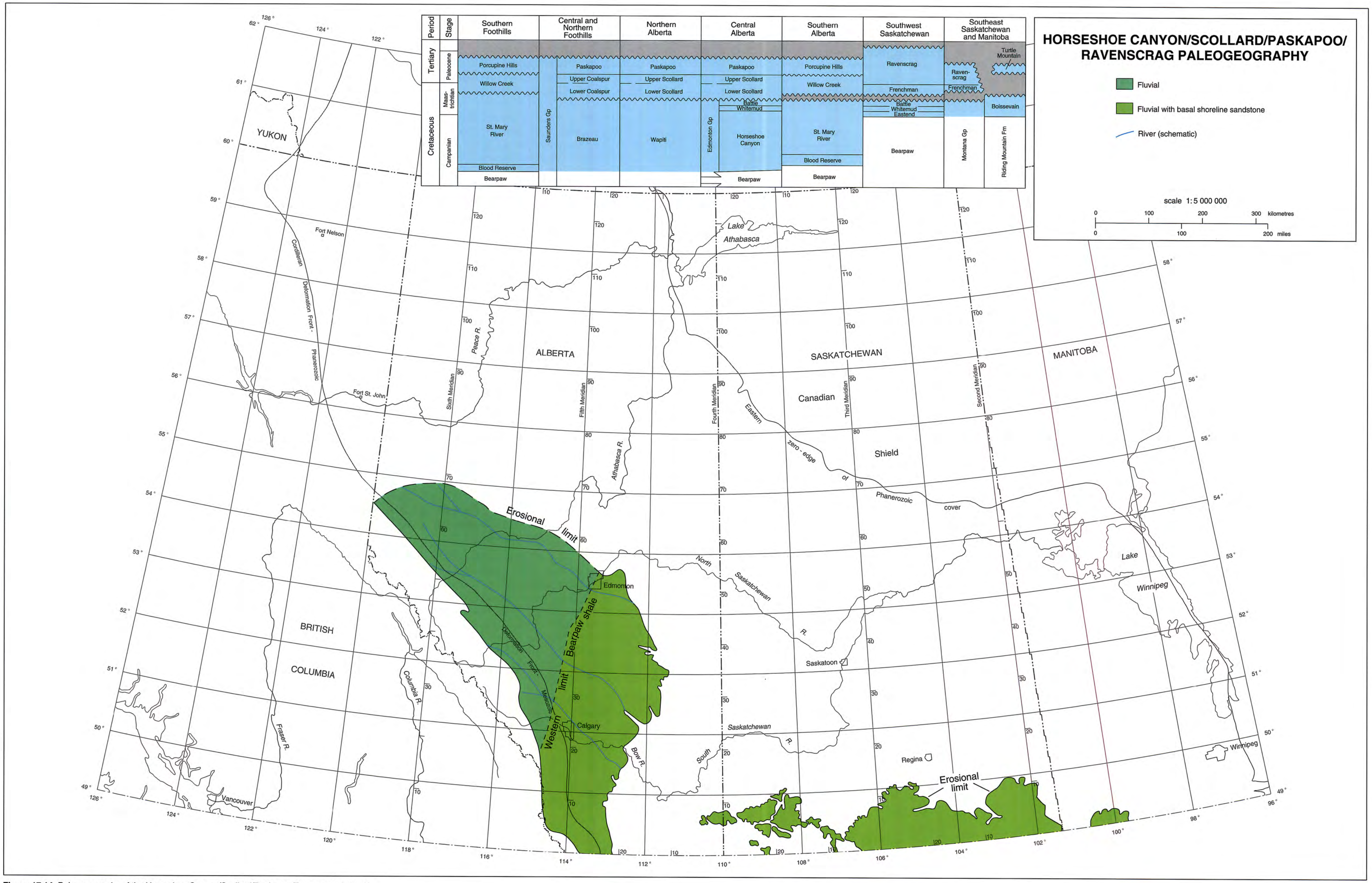

Figure 17.14 Paleogeography of the Horseshoe Canyon/Scollard/Paskapoo/Ravenscrag interval.

During Late Aptian time, a rise in relative sea level flooded most of the foreland trough. Areas that remained emergent include the erosional highlands and the western half of the Peace River Arch, where a strong Cordilleran sediment supply kept the area above sea level (Gething Formation). Sediments of this low-energy, brackish seaway include the Ostracod Beds/Calcareous Member of Alberta and the lower portion of the Cummings Member in Saskatchewan. At least one major sea-level lowstand occurred near the end of Ostracod/Gething deposition, resulting in emergence and valley incision over much of the Western Canada Sedimentary Basin.

In Early Albian time a major rise in sea level flooded much of Alberta and Saskatchewan, resulting in open marine conditions as far south as the Hoadley Barrier (Glauconitic Formation) in Alberta and the U.S.A. border in Saskatchewan. The early transgressive deposits of this flooding include the Bluesky Formation of northeastern British Columbia and northern Alberta, the Wabiskaw Member of east-central Alberta and the upper portion of the Cummings Member in Saskatchewan. The abundance of incised valley deposits associated with the Glauconitic Formation in southern Alberta suggests that this sea-level rise was highly episodic and interrupted occasionally by periods of lowstand.

At about this time renewed Cordilleran activity resulted in a major influx of Cordilleran sediment into the basin, pushing shorelines northward and transforming much of Alberta and Saskatchewan to a floodplain environment. These shoreline and floodplain deposits are found in the middle Upper Mannville of southern Alberta, the Falher Member of northern Alberta, the lower portion of the Grand Rapids Formation of northeastern Alberta and the Lloydminster, Rex, GP, Sparky and Waseca members of Saskatchewan.

During late Upper Mannville deposition, fluvial conditions prevailed over much of southern and central Alberta while shorelines continued to prograde northward in northeastern Alberta (upper portion of the Grand Rapids Formation) and west-central Alberta (Notikewin Member). In Saskatchewan, a shallow, brackish water shelf developed (Pense Formation). In eastern Alberta, the deltaic sands of the Colony/McLaren members separate the fluvial and brackish regimes.

Following this depositional cycle, a major sea-level lowstand resulted in exposure and erosion across much of the Western Canada Sedimentary Basin (post-Mannville unconformity). In the area of the Peace River Arch, mild downwarping resulted in the preservation of an additional depositional cycle beneath the post-Mannville unconformity. Marine shales of the Harmon Member represent a deepening subsequent to Notikewan deposition. The overlying Cadotte Member is represented by a prograding barrier facies.

Following the post-Mannville lowstand, a major sea-level rise flooded most of the Western Canada Sedimentary Basin (Joli Fou Formation). During the initial stages of this transgression, incised valleys cut during the lowstand were backfilled and reworked (Colony Member channel sandstones) while transgressive shoreline and shallow shelf sandstones developed over the Mannville floodplain (Basal Colorado/Spinney Hill sandstones).

At the peak of the Joli Fou transgression, all of the Western Canada Sedimentary Basin was inundated, with the exception of the Peace River Arch and a narrow floodplain adjacent to the Cordillera. During Viking deposition, shorelines along the eastern margin of this floodplain prograded eastward into the foreland basin, while shallow-shelf conditions developed over much of the remainder of the basin. On the Peace River Arch, the equivalent Paddy Member is represented by brackish bay sediments with a major prograding barrier sequence separating Paddy bay sediments from marine shales farther north. At least two sea-level lowstands occurred during Viking deposition. During these lowstands, fluvial sands and gravels were transported onto the exposed shelf, to be reworked during the next transgression either as valley-fill deposits or as transgressive shoreline to shallow shelf sandstones and conglomerates. Following Viking and equivalent deposition a major sea-level rise inundated the entire foreland basin (Colorado/Shaftesbury Sea).

Near the end of Albian time, sediment distribution patterns in the Western Canada Sedimentary Basin changed. Late Cretaceous sequences in general indicate a sediment supply from the west or north with fill from the northwest as opposed to the south-to-north fill of Late Jurassic and Early Cretaceous sequences. During Late Cretaceous Cenomanian time, one such major sediment pulse originating in the Yukon pushed southeastward into the Western Canada Sedimentary Basin (Dunvegan Formation). Uplands fluvial sandstones and conglomerates in northeastern British Columbia adjacent to the Yukon/Northwest Territories border grade southeastward first to floodplain sandstones and carbonaceous shales then to deltaic shoreline and shoreface deposits in west-central Alberta. At least one major lowstand occurred during Dunvegan deposition resulting in the incision of the Simonette channel.

The Cardium Formation (Turonian to Coniacian) was deposited along the western margin of the foreland trough at a time when global sea level was close to its all time high (Cenomanian and Turonian). Cardium strata grade from shoreline sandstones capped by floodplain shales and channel sandstones in the west to shoreface sandstones and shales in the east. Several fluctuations in sea level occurred during Cardium deposition, resulting in the transportation of coarse sand and gravel onto the exposed shelf during lowstand, to be reworked by waves and currents during the early stages of the subsequent sea-level rise.

A significant influx of Cordilleran-derived sediment in southwestern Alberta pushed shorelines northeastward into the basin during Campanian time (Milk River/Chungo formations). In the southwest, sediments consist of a series of offlapping shoreline sandstones capped by floodplain shales, channel sandstones and coals. To the northeast, seaward of the prograding barrier sandstones, a large area of thinly laminated sandstones and shales occur, representing shelf deposition at or below storm wave base (Alderson Member). Using palynology, recent authors have suggested that the Alderson Member and the Chungo sandstone north of the Bow River are lowstand deposits, laid down when southern areas of the province were subaerially exposed.

Following an early Late Campanian period of marine inundation (Pakowki/Nomad Sea), another major influx of Cordilleran detritus again pushed coastlines eastward across the foreland trough (Belly River Formation and its equivalents). At the peak of this regression, coastlines had advanced halfway across Saskatchewan. The Belly River Formation and its equivalents consist of a basal unit represented by offlapping deltaic shoreline sandstones overlain by a sequence of floodplain channel sandstones, shales, and coals. Progradation of the Belly River deltaic complex was terminated by a major sea-level rise and trangression of the Belly River floodplain by the Bearpaw Sea to a point about halfway across south-central Alberta. Estuarine channel deposits at the top of the Belly River probably represent the early stages of this transgression.

One final major sediment influx occurred in the foreland trough during Late Cretaceous Maastrichtian time and early Tertiary Paleocene time. This sediment pulse includes the beds of the Horseshoe Canyon, Whitemud, Battle, Scollard and Paskapoo formations and their equivalents. West of the limits of the Bearpaw transgression, this sequence consists of floodplain sandstones, shales and coals. East of the Bearpaw transgression, this sediment package consists of a basal barrier to deltaic shoreline sandstone overlain by floodplain sandstones, shales and coals. Some lacustrine deposits have been noted. Extensive volcanism in the west gave rise to the bentonitic shales and tuffaceous beds of the Battle Formation. One period of uplift and erosion is evidenced by the post-Battle disconformity. At the end of Paskapoo deposition a period of major uplift and erosion marked the end of foreland basin deposition.

For a detailed analysis of the zones described in this chapter, the reader is encouraged to consult subsequent chapters.

Acknowledgments

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