

Devonian Reef-builders and the Development of the Fairholme Carbonate Reef Complex, Banff-Kananaskis Country, Alberta*

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Summary

The Fairholme Carbonate Complex is the southernmost and largest in an extensive stromatoporoid-dominated reef domain that developed in Alberta during Frasnian time. Its western margin, defined in the Kananaskis-Banff region, exhibits a major re-entrant 25 km wide named the “Shark Embayment.” A Devonian paleoclimatic model suggests that the western margin was subjected to seasonal oceanic upwelling of nutrient-rich and oxygen-poor waters that influenced the development of the carbonate buildups.

Three buildup margins exposed within the Kananaskis - southern Banff area define the western margin of the Fairholme Carbonate Complex: Turbulent Creek headwaters, Fatigue Mountain, and Copper Mountain. Overlying the Flume (Swan Hills equivalent) carbonate platform at these margins, the Cairn (Lower Leduc/Cooking Lake) platform ramp extends, and gradually thins in a basinward direction; it was a distally-steepened carbonate ramp, composed of three transitional facies:

- (i) A shallow, upper ramp stromatoporoid platform interior;
- (ii) A mid-ramp coralline facies;
- (iii) A black, organic-rich Perdrix/Duvernay basin.

The subsequent Peechee (Upper Leduc) buildup developed into a more steeply sloping, rimmed carbonate margin, which periodically shed reefal blocks and debris flows downslope and into the (uppermost) Perdrix and Mount Hawk (Ireton) basin. The western Peechee margin trends roughly northwest-southeast but forms a major re-entrant in the Spray Lakes Reservoir/Mount Shark area, approximately 25 km wide, called the “Shark Embayment.” The northern margin of the Shark Embayment is well defined at Turbulent Creek headwaters and Fatigue Mountain.

Only the northern extent of the western margin of the Fairholme Complex within the study area shows the presence of Arcs (Nisku) strata prograding over Mount Hawk (Ireton) basin fill. Mount Hawk sediments did not completely infill the late Frasnian basin adjacent to buildup margins in the Shark Embayment and to the south, preventing the progradation of the Arcs Member. Consequently, a large depression developed by the end of Frasnian time, subsequently infilled by westerly(?) -derived siliciclastics of the Sassenach Formation (Graminia equivalent).

Stromatoporoids were widespread and abundant calcareous benthos living in shallow, tropical, oligotrophic, and agitated marine environments. Five stromatoporoid assemblages, defined in the Flume and Upper Cairn succession, are correlated with RM conodont zones. Stromatoporoids exhibit mostly domical, but also bulbous, laminar, and dendroid growth forms that were genetically prescribed and only slightly modified by environmental factors. Evidence suggests that Paleozoic stromatoporoids eventually developed into mixotrophic organisms (containing symbiotic algae) enabling them to construct large carbonate buildups, but they were also vulnerable to the devastating effects of paleoceanic upwelling of nutrient-rich waters.

Introduction

During the early part of Late Devonian (Frasnian) time, central and western Alberta and eastern British Columbia were the site of an extensive reef domain ([Figure 1](#)). The eastern and central parts of this reef domain are now entirely in the subsurface, but the western part is well exposed in a series of thrust sheets along the eastern side of the Canadian Cordillera. The Fairholme Carbonate Complex is the southernmost and largest of four major Frasnian reef complexes. It stretches from the U.S. border to the headwaters of the North Saskatchewan River; a strike distance of approximately 330 km (205 miles). The interior portion of the Fairholme Carbonate Complex is magnificently exposed where the Bow River has carved its valley through the Front Ranges of the Alberta Rocky Mountains. The margin of the Fairholme Complex is only partly exposed along the Front Ranges to the northeast of the Bow Valley (e.g., Burnt Timber Embayment; McLean and Mountjoy, 1993), and is bordered eastward by the Ireton Basin in the subsurface. The north and northwestern margins of the complex border a narrow, elongate, northeast-trending area of basin strata, the Cline Channel, which separates the Fairholme Complex from the Southesk-Cairn Complex. The southeastern portion of the Fairholme Complex extends into central Alberta (the "Southern Alberta Reef Complex") in the subsurface where it changes to a more restricted, evaporitic facies. The western margin is exposed in the Main Ranges and trends northwesterly, roughly along the Alberta/British Columbia border. The Upper Devonian outcrops west of this margin are rare and dominantly basinal (open ocean?) strata of the Sassenach Depression (Mallamo and Geldsetzer, 1991).

Buildup Development of the Fairholme Carbonate Complex

Lithostratigraphic units of the Fairholme Group are characterized in terms of a Rocky Mountain (RM) Conodont Zonation (Klapper and Lane, 1989). In the western part of the study area, the Flume (uppermost Swan Hills equivalent) carbonate platform began to onlap the westernmost slope of the West Alberta Ridge (WAR) as early as latest Givetian time (*norrisi* Zone). To the east, the Flume platform did not onlap and begin to cover the crest of the WAR until the succeeding RM Zone 1. The overlying Upper Cairn Member (Lower Leduc or Cooking Lake equivalent, containing a unique coral biofacies) and Perdrix (Duvernay) Formation range from the uppermost RM Zone 1 to Zone 4b. The Peechee Member (Upper Leduc) is difficult to date, but is probably within Zones 5a to 5b; the overlying Grotto Member (lower? Nisku) is no younger than Zone 5b. The Arcs Member (Nisku) is within Faunal Intervals (F.I.) 6 - 7, and the Ronde Member (Blueridge) is within Faunal Interval 8 which includes the Frasnian-Famennian boundary near its top. The Mount Hawk (Ireton) ranges from Zone 4b/5a to F.I. 8.

The Flume carbonate platform consists of intertonguing stromatoporoid biostromes alternating with interbeds of *Amphipora* floatstone-rudstone and microbial laminites. The biological assemblage can be described as oligotrophic and may have been adapted to a lower nutrient

environment (Mallamo and Geldsetzer, 1991). The cyclic nature of the Flume lithologic unit, comprised of meter-scale shallowing-upward parasequences, has been attributed to be repeated high-frequency oscillations of relative sea level (McLean and Mountjoy, 1994). Their data suggest that these parasequence stacking patterns were allocyclic (extra-basinal) rather than autocyclic (intrabasinal); episodic tectonic and sedimentary loading causing differential subsidence, along with glacio-eustasy was invoked to explain the development of these sequences.

The Upper Cairn Member is characterized by a unique and distinct deep-water carbonate ramp facies, herein termed the “Upper Cairn coral biofacies” (Figure 2). It is distinguished from the underlying stromatoporoid biofacies that is typical of the Upper Cairn Member in most other localities in Alberta. Lithologies of the deeper water coral biofacies within the interior of the complex yielded a significantly greater amount of conodonts than does the stromatoporoid biofacies. This allowed for a more refined dating of depositional episodes within the carbonate platform and correlation with basinal units. The coral biofacies occurs over an extensive area and is recognized in this study in equivalent subsurface strata to the east in the Foothills Belt.

A new configuration of the Peechee buildup margin in this area is palinspastically mapped (Figure 3), revealing an east-northeast-trending, 25-km wide re-entrant in the Mount Shark area of Kananaskis Country, herein name the “Shark Embayment.” Peechee paleogeography shows a rapid southwestward progradation of this unit across 10's of kilometers over the deeper water Upper Cairn coral biofacies.

The western buildup margin of the Fairholme Complex began as a distally-steepened ramp during deposition of Upper Cairn. Subsequently, the Peechee-Arcs-Ronde margin developed a steep slope and a rapidly deepening basin to the west. Limestone, shale, and buildup-derived debris clasts of the Perdrix and Mount Hawk formations had only partly filled the basin. Thus, water depths probably exceeded 300 m by the end of Frasnian time since siliciclastics of the Sassenach Formation infilled the basin in early Famennian time, and are up to 274 m adjacent to the buildup margin.

Stromatoporoid Paleobiology

Stromatoporoids were the main organisms responsible for the development of large Devonian reef complexes which now form major hydrocarbon reservoirs of western Canada. Stromatoporoids were widespread and abundant calcareous benthos living in shallow, tropical, agitated marine environments. Within the Upper Devonian Fairholme Carbonate Complex, stromatoporoids exhibit mostly domical, but also bulbous, laminar, and dendroid growth forms that were genetically prescribed and only slightly modified by environmental factors, such as sedimentation. Eleven of the 32 species identified in this study show some plasticity in their growth form. The large boring *Topsentopsis* is common within these stromatoporoid skeletons, exhibiting geopetal structures. Some of these borings were made while the stromatoporoid was in “living position”. An increase in boring activity during Cairn time may be related to changes in nutrient supply or general energy conditions. Interactions with brachiopods and corals indicate that stromatoporoids were capable of encrusting other organisms at rates greater than the growth of these organisms.

By examining various criteria, there is evidence to suggest that at least some Paleozoic stromatoporoids were mixotrophic. Stromatoporoids have characteristics which:

- (i) Were prerequisites for symbiosis;

- (ii) Promoted symbiosis;
- (iii) Resulted from symbiosis.

These characteristics include:

- Thin, exposed tissue,
- High calcification and growth rates,
- Photosynthetic fractionation of isotopic carbon,
- Restricted habitats to shallow, tropical, oligotrophic marine waters,
- Density bands,
- Similar evolutionary scenarios with mixotrophic scleractinian corals.

The inference that stromatoporoids were mixotrophic may be able to explain their evolution and extinction patterns, the regular growth rhythms in their skeleton, and their dominating reef-building capabilities during Silurian and Devonian times.

Paleoceanography and Its Influence on Reef Complexes and Reef-builders

Using modern oceanographic principles and Devonian paleogeography, a paleoclimatic model can be described to predict global atmospheric circulation and oceanic surface currents ([Figure 4](#)). A general easterly trade wind pattern occurred over the Laurussia continent that was transversed by the equator during Givetian/Frasnian times. In January, the easterly trade winds prevailed over the northern part of Alberta; southerly winds blew over the southern part of Alberta. In July, a local low-pressure system developed which caused westerly and northwesterly winds to prevail over northern Alberta; easterly trade winds blew over southern Alberta.

Mid- to late Frasnian basin-filling fine sediment (Mount Hawk and Lower Ireton) was transported by prevailing easterly trade winds westward from Laurussia highlands (in the northeast and east part of the continent) towards the Alberta Basin. The dispersal pattern and extent of transport of basin-filling sediment was limited and subsequently modified by easterly- and northeasterly-flowing paleocurrents ([Figure 4](#)). In addition, easterly flowing currents may have transported Perdrix/Mount Hawk basin-fill sediment from western exotic source areas.

Zones of wind-driven upwelling are postulated on and around Laurussia, based on prevailing atmospheric circulation patterns. Coastal or one-sided upwelling was the most common type of upwelling that developed in both seasons, especially along the northern and southern coasts of the Laurussia continent. Symmetrical upwelling developed in the equatorial region off the west coast of Laurussia adjacent to the southwestern region of Alberta in January. Within the Frasnian reef domain of central Alberta, upwelling occurred immediately adjacent to the western margin of the Fairholme Carbonate Complex proximal to the Shark Embayment ([Figure 4](#)).

The combined effect of oceanic upwelling and rapid rising of relative sea level was detrimental to mid-Frasnian stromatoporoid reef-builders. Upwelling events introduced cooler, oxygen-poor and nutrient-rich waters from depth to the surface and over the shallow carbonate shelf, triggering phytoplankton blooms. An increase in organic matter and turbidity and the depletion of oxygen and light created inhospitable living conditions for the stromatoporoids, greatly inhibited their growth. Overall carbonate accumulation rates decreased and the rising of relative sea

level outpaced carbonate platform growth, resulting in an overall deepening-upward lithologic succession of shallowing-upward carbonate sequences (Upper Cairn stromatoporoid biofacies) overlain by deeper water carbonates (Upper Cairn coral biofacies) and black shales (Perdrix).

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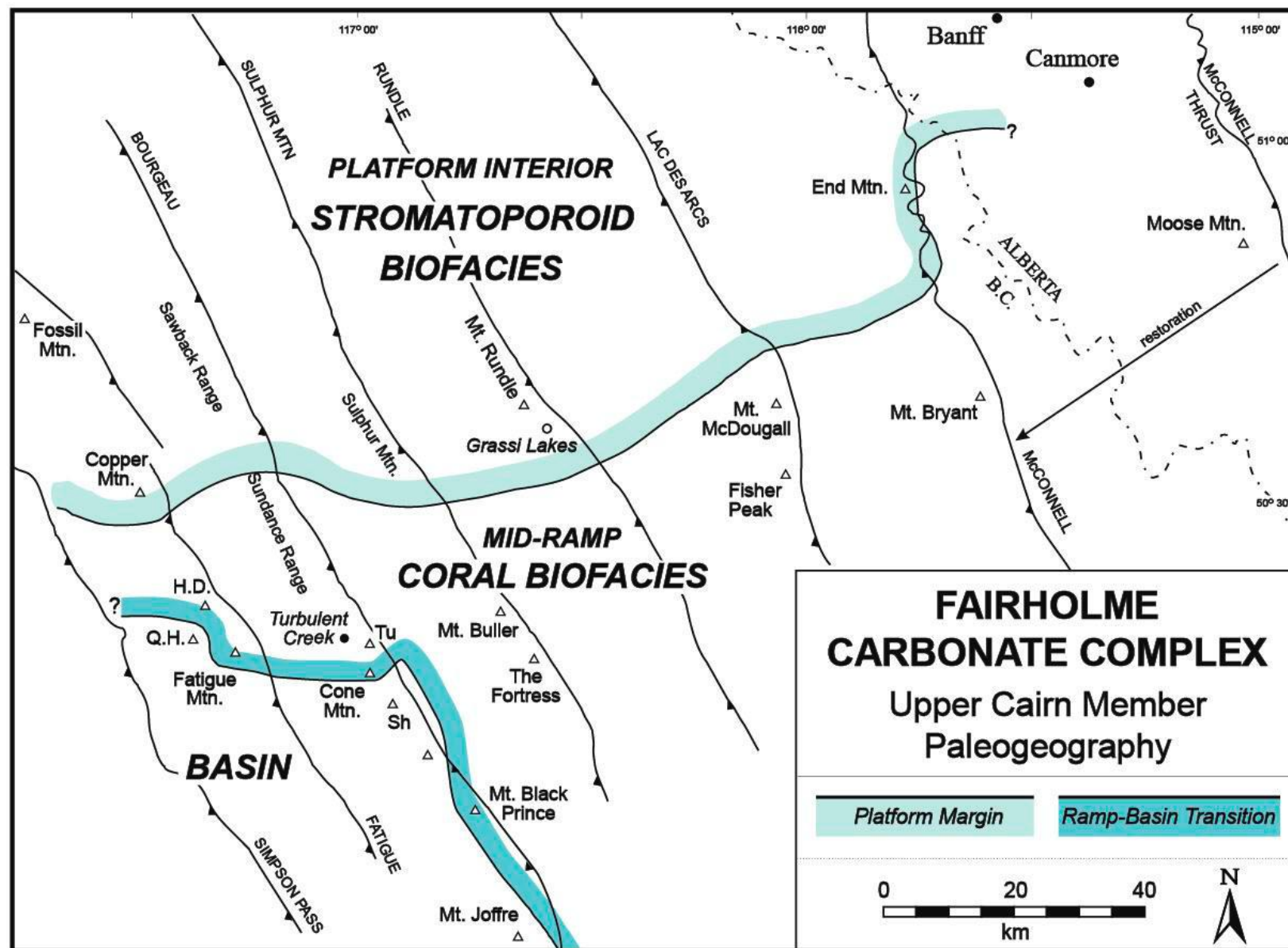


Figure 2. Upper Cairn paleogeography of the Fairholme Carbonate Complex. This palinspastically-restored map of the study area shows the distribution of the stromatoporoid and coral biofacies, and the equivalent Perdrix "basinal" area (Mallamo, 1995).

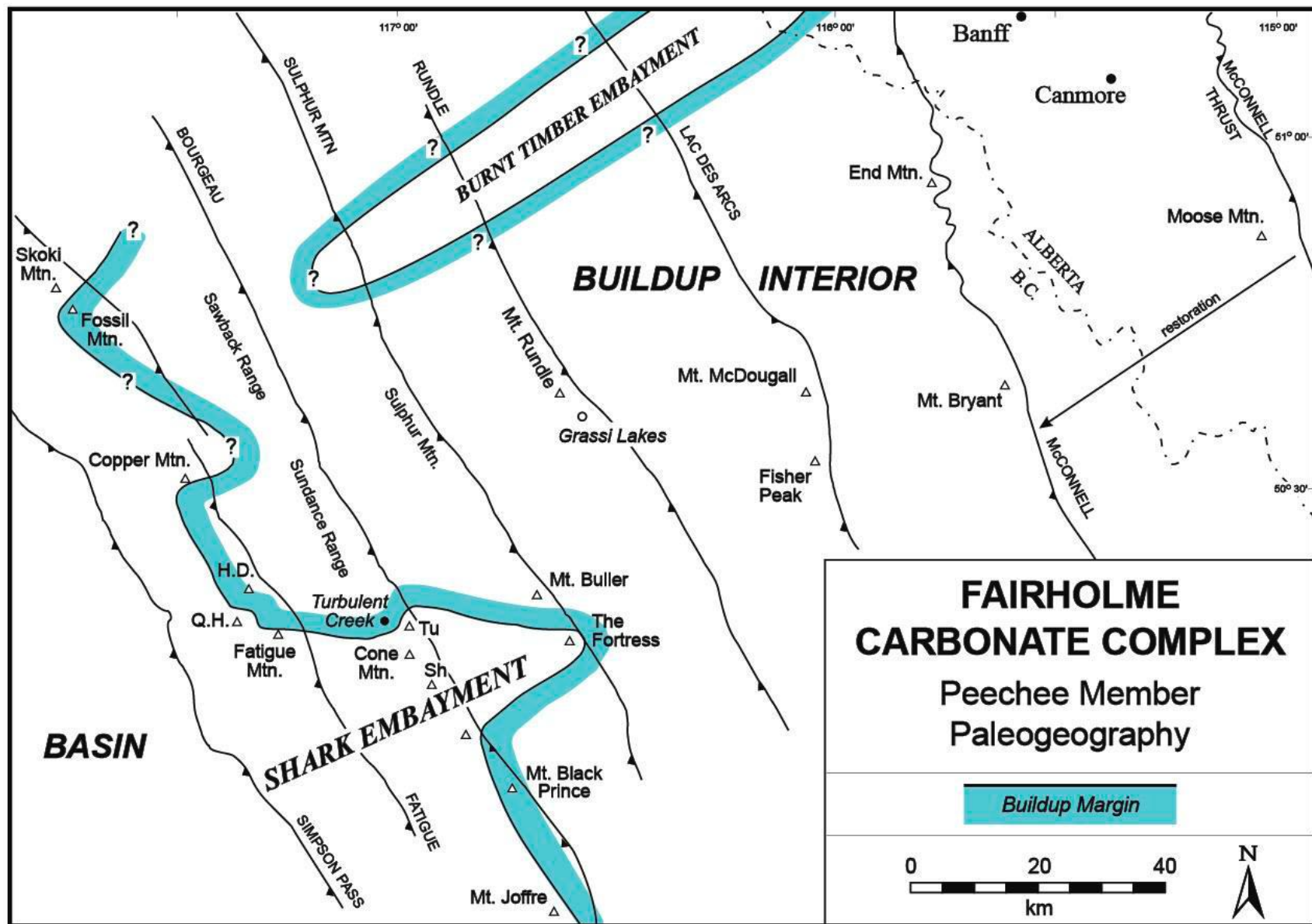


Figure 3. Peechee paleogeography of the Fairholme Carbonate Complex. The light shaded line marks the buildup margin separating the broad, very shallow buildup interior from the basinal setting (uppermost Perdrix and Mount Hawk formations) (Mallamo, 1995).

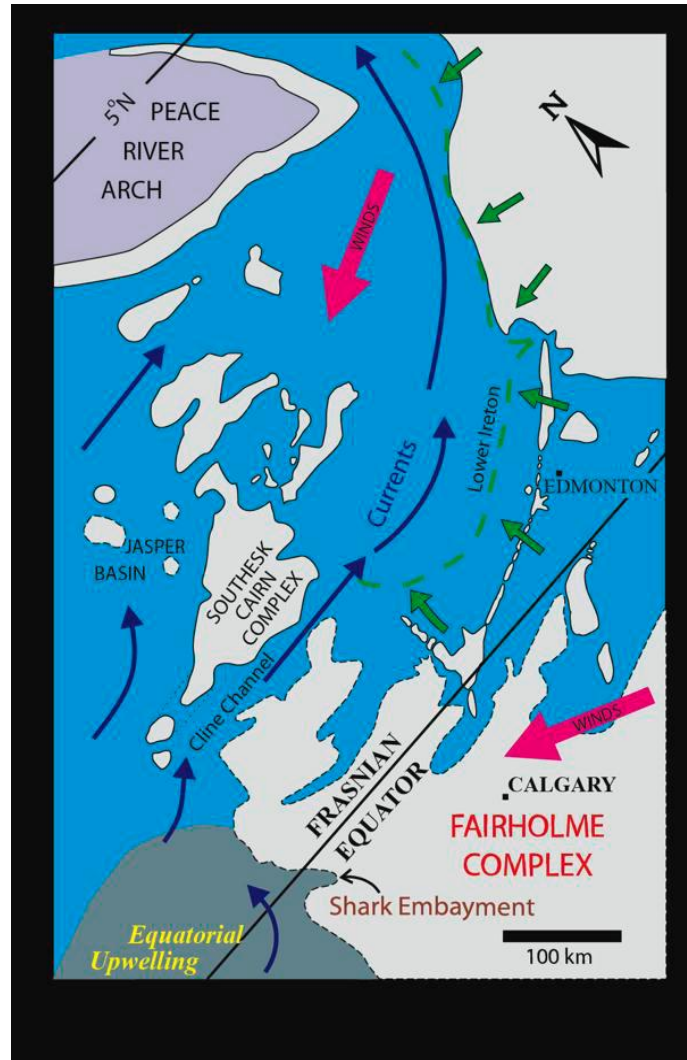


Figure 4. Paleoclimatic map of the Frasnian reef (Peechee/Leduc) domain of west-central Alberta in a Frasnian January (Mallamo, 1995). Large magenta arrows indicate prevailing easterly surface paleowinds; thin blue arrows are surface oceanic currents (Equatorial Counter Current) being deflected northward as they reach the western continental shelf of Laurussia. The grey area in the southern part of the reef domain indicates the zone of upwelling adjacent to the western margin of the Fairholme Carbonate Complex. The thick green arrows show the direction of Lower Ireton basin-filling sediment; the dashed line marks the lateral extent of the Lower Ireton (from Switzer et al., 1994), limited by the northeasterly-flowing paleocurrents through the reef domain (Mallamo, 1995).