Examples of Late Jurassic to Lower Cretaceous incised valley paleodrainages in structurally controlled low to intermediate accommodation foreland basin settings - the Basal Quartz & McMurray Formations, Western Canada Sedimentary Basin

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ABSTRACT

The Western Interior Foreland System forms a major north-south depositional zone west of a major tectonic fold-thrust belt developed as part of the convergent margin of North America (Catuneanu, 2004). DeCelles and Giles (1996) proposed a widely accepted zonation for foreland basin systems consisting of **wedge-top, foredeep, forebulge and backbulge depozones** (Figure 1).

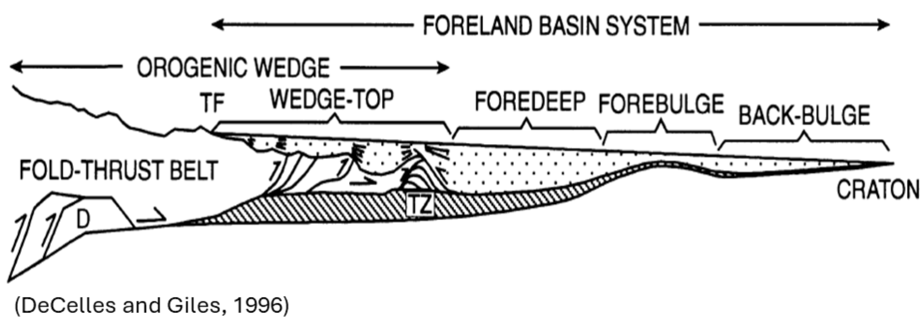

Figure 1: Schematic cross-section depicting a foreland basin system. Wedge-top, foredeep, forebulge and back-bulge depozones shown at approximately true scale. Topographic front of the thrust belt=TF. The foreland basin system is shown as coarse stipple; the diagonally ruled area indicates pre-existing miogeoclinal strata. A schematic duplex (D) is depicted in the hinterland part of the orogenic wedge, and a frontal triangle zone (TZ) and progressive deformation (short fanning lines associated with thrust tips) in the wedge-top depozone also are shown. (DeCelles and Giles, 1996)

As described by DeCelles (2012), the **Foredeep** is commonly not filled to the crest of the forebulge **("underfilled" state);** the forebulge is exposed and forms a topographic drainage divide between foredeep and backbulge depozones. Depending on base level, the backbulge region may also experience erosion and unconformity development. When the **Forebulge** is buried by sediment **("overfilled" state)** derived from the fold-thrust belt and/or the craton, the foredeep and backbulge merge. Although aggradation occurs on the forebulge crest, the rates of accumulation are very low, and sediments are intensely weathered and condensed. When the foredeep is underfilled but the **Backbulge** depozone is filled to crest with sediment derived from either the craton or out-of-plane pathways, sediments may spill into the foredeep from the backbulge depozone (Horton, 2022) (i.e. the "McMurray FM conundrum").

An <u>overfilled</u> foreland basin (OFB) system consists of all four depozones whereas an <u>underfilled (UFB)</u> is characterized by erosion focused on the flanking thrust belt and craton regions, with potential erosion, sediment bypass or severely limited sediment accumulation across the forebulge region, hence lacking a well-defined wedge top and backbulge area.

The WCSB is an ideal area for examining the changes between low and high accommodation settings in a Foreland Basin (Zaitlin et al., 2002). The Jurassic-Cretaceous Foreland Basin of the WCSB is part of the WCSB Super Basin and is considered one of the premier hydrocarbon provinces of North America. The WCSB is characterized by multiple conventional and unconventional stacked reservoirs and source rocks organized into:

- A lower **Underfilled** foreland basin (UFB), with the main reservoir units associated with the Jurassic to Lower Cretaceous Nordegg, Poker Chip, Rock Creek, Fernie-Nikinassin, Mannville (and stratigraphic equivalents); and
- An upper **Overfilled** foreland basin (OFB) consisting of the Joli Fou, Viking, SWS, Cardium and Belly River (and stratigraphic equivalents).

The organization of the WCSB-FB reservoirs into UFB to OFB settings, and a detailed understanding of both the depositional environment and sequence stratigraphic framework are among the first hierarchical steps to better understand conventional and unconventional targets. The UFB is characterized by restricted marine and marginal marine mixed carbonate and clastic deposits (sourced from the south and east; overlain by clastic dominated fluvial to marginal marine deposits. Accommodation increases to the north and northwest. Paleodrainage associated with the UFB is characterized by multiple paleodrainages oriented from south and southeast towards north and northwest, splitting around paleotopographic highs associated with erosional remnants preserved from the migration of peripheral forebulge events (Figure 2). Shorelines are dominantly oriented east-west and are organized into falling stage, lowstand, transgressive, and highstand parasequences and parasequence sets. The shorelines are segmented along strike into compartments due to multiple point sources of sediment from the multiple south to north oriented fluvial and fluvial deltaic systems occurring along the length of the shorelines.

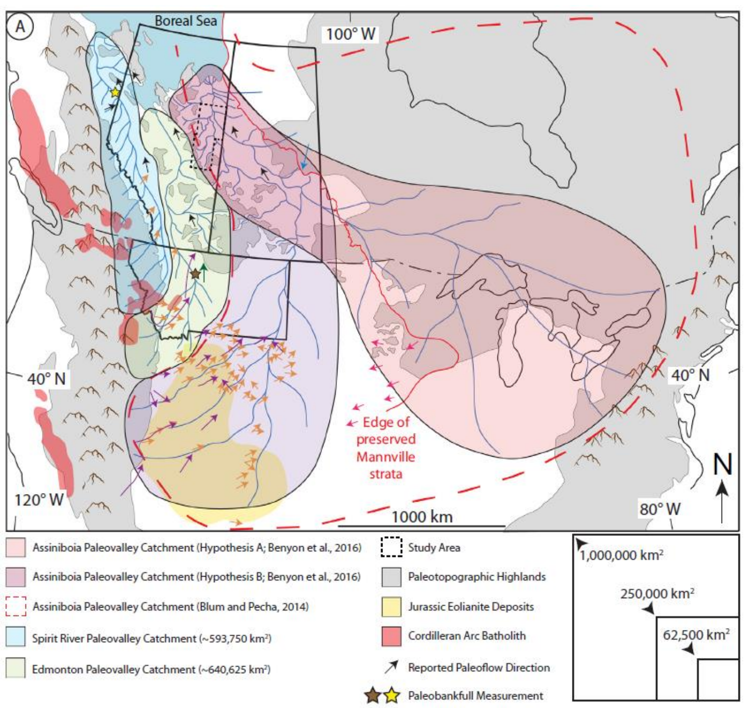

Figure 2: (A) Aptian paleogeographic map. Regions inferred as relative paleotopographic highs are shown in gray. Areas of general deposition are depicted in white. Locations of Cordilleran arc batholiths are shown in red. Arrows represent compiled paleocurrent indicators. Catchment areas for the Spirit River and Edmonton paleovalley channel systems are shown in blue and green. Several proposed catchments of the Assiniboia paleovalley channel system are presented. (from Horner et al., 2019).

The transition between UFB and OFB deposits is marked by a reorganization of paleodrainage and associated shoreline orientation. The OFB is characterized by clastic dominated fluvial to marginal marine fluvial, deltaic, estuarine, shoreface and shelf deposits sourced from the west. Paleodrainage associated with the OFB is characterized by fluvial and fluvial deltaic systems oriented from west to east. Shorelines are oriented north-south, parallel to the length of the foreland basin. Key reservoir targets are associated with the Dunvegan (fluvial, distributary and deltaic), Belly River (channels, shorefaces) and Cardium/Second White Specks.

During the Jurassic-Early Cretaceous (*UFB*), fluvial systems consisted of axially draining rivers of continental-scale and low slope. During times of maximum transgression of the Cretaceous Seaway, occurring on the Turonian and Campanian, the western North American foreland basin was characterized by smaller-scale, steeper gradient sand and gravel bedload rivers, dominated by transverse drainages in the rising Cordillera. This created several smaller river-delta systems along the coast, such as the Dunvegan, Ferron, Frontier, Lance and Cardium formations.

Late Jurassic to Lower Cretaceous fluvial to fluvial-estuarine incised valley reservoirs host among the most prolific hydrocarbon successions in the WCSB. Production includes conventional oil and gas reservoirs of the Basal Quartz to the unconventional ''supergiant'' heavy oil deposits of the McMurray Formation. A series of studies were undertaken on WCSB incised valley systems, and several unique formation-specific problems were identified and addressed to effectively exploit these resources. Arguably, the most significant problem is the difficulty of mapping incised valley trends and internal facies architecture developed in low to intermediate accommodation foreland basin settings across the WCSB (Figure 3).

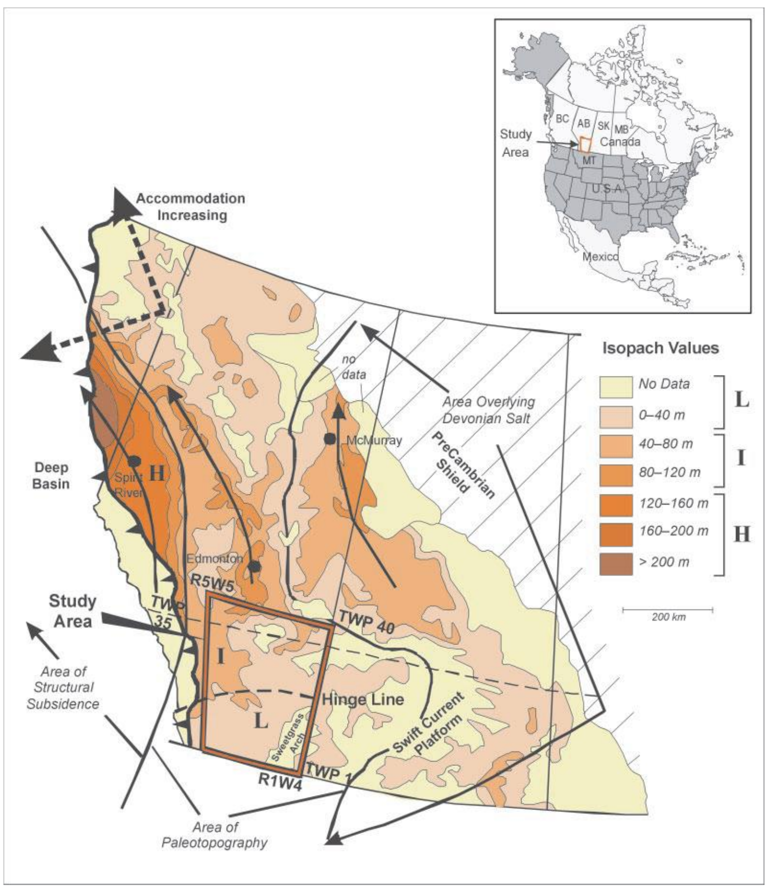

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Figure 3: Isopach map of the Lower Mannville Formation in the WCSB, approximately equivalent to Basal Quartz and Ostracod Member of this study (modified after Cant and Abrahamson, 1996). L = low accommodation area; I = intermediate accommodation area; H = high accommodation area. Arrows indicate paleodrainages of the McMurray, Edmonton and Spirit River systems. Heavy dashed arrows indicate NW and W direction of increasing accommodation. Inset map indicates study area in relation to North America (BC = British Columbia; AB = Alberta; SK = Saskatchewan; MB = Manitoba; MT = Montana). (modified from Zaitlin et al., 2002).

The Lower Cretaceous Basal Quartz (BQ) of Southern Alberta (Townships 1 - 40, Ranges 1W5-5W5; Figure 3) can be informally divided into seven mappable units (A Sandstone, composed of the Regional A, Carmangay, Mesa IV, Valley and Terrace; Horsefly, BAT, Ellerslie) (Zaitlin, et al. 2002). The study area is in an accommodation-limited setting characterized by the presence of multiple, closely spaced unconformities, and the general absence of marine deposits. Multiple levels of cyclicity exist in the BQ. There are two cycles of increasing-upward mineralogical and textural maturity, the first associated with the A Sandstone and the second associated with the Horsefly-BAT Ellerslie successions. There are multiple southward marine transgressive events, both on the unit scale and on the cycle scale, indicative of a backstepping stacking geometry.

The high-resolution subdivision of the BQ allows for the recognition of changing BQ paleodrainage through time.There is both a progressive spatial and stratigraphic change in incised valley organization, from thin and wide valley forms in the south and at the base of the cycles, to thicker, narrower, and more deeply cut systems toward the northwest and top of the cycles. In addition, there is spatial variation in tributary systems for the upper cycle, from no tributaries associated with the thin, wide valley forms associated with the Horsefly, to narrow and thin tributaries in the BAT south of the Vulcan Low, deeply cut complex tributary systems across the Vulcan Low, and linear deep tributaries north of the Vulcan Low for both the BAT and Ellerslie. The style of depositional fill also changes stratigraphically and spatially, from braided to coarse meandering “sheet” deposits south of the Vulcan Low associated with the Carmangay and Horsefly, and low accommodation Valley and Terrace and BAT north of the Vulcan Low; meandering deposits associated with the low accommodation Mesa IV, and higher accommodation Valley and Terrace, Horsefly and BAT; and fluvial-estuarine deposits associated with the Valley and Terrace, BAT and Ellerslie north of the Vulcan Low in higher accommodation setting.

The dominant control on the BQ depositional patterns is the interplay between eustasy and heterogeneous basement subsidence. The tectonic influences on sedimentation are most obvious in the sediments immediately overlying long-duration unconformities. Fluvial erosion on the unconformity surface amplifies the tectonic signal by accentuating the tectonically produced relief in a low accommodation setting. The accommodation-limited conditions occurring during BQ deposition resulted in sequence boundaries amalgamating on the interfluve, and it is only by detailed correlation and petrographic analysis that BQ units can be differentiated.

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