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# Valley Incision During Transgression: A Contrarian View of Structurally-Controlled Gravel Barriers in the WCSB

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The Western Canada Sedimentary Basin (WCSB) is a rather unique depositional setting in that it has remained a comparatively low accommodation depocenter through most of its stratal record. Accommodation and sedimentation were intimately linked to and influenced by deep rooted faults and antecedent basement terrains. Accommodation rates varied across the WCSB at any given time, but appear to have been positive for most of the stratal record. They became negative producing type 1 and 2 sequence boundaries only during brief orogenic events. A low, but positive accommodation rate through Aptian to Albian time expressed itself by large and rapid shifts in paleoshoreline position within Bullhead and Fort St, John Groups.

The area underlain by the Ksituan basement terrain, bounded to the north by the Great Slave Lake Shear Zone and to the south by the Snowbird Tectonic Zone (STZ), is a region of historical differential subsidence throughout the Paleozoic and Mesozoic. It contains the Devonian Peace River Arch and the later Permo-Carboniferous Dawson Creek Graben Complex (DCGC) (Barclay et al, 1990). Williams (1958) first noted that “forces that caused the collapse of the Arch in Paleozoic time remained active, but were more moderate and subdued during the Mesozoic”. Renewed subsidence through early Cretaceous time in this region was associated with re-activation of structures associated with the DCGC. The STZ acted as a structural hinge providing more than 200 m differential accumulation of the Aptian Bullhead and Albian Fort St. John groups within the re-activated graben region to the north. The Fort St. John Group consists of a series of stacked transgressive-regressive (TR) cycles comprising an overall progradational deltaic succession. Differential subsidence across the STZ into the reactivated DCGC constrained both the maximum transgressive and highstand depositional limits of each deltaic TR cycle. Isopach maps of the Bullhead and Fort St. John groups illustrate the influence basement subsidence and downwarping had on sediment accommodation and the nature of the depositional system.

The Fort St. John group in the Peace River area is noted for stacked reservoir opportunity within gravel-rich deposits of the various Falher, Notikewin and Cadotte members across townships 65 to 75 W6M (Fig.1). Pate (1988) and Cant (1988) suggested rapid subsidence of the Peace River Arch controlled the transgressive-regressive limits of the Spirit River Group. Structural control on the position and distribution of gravel-rich deposits within the Spirit River Group has been recognized by Pate (ibid) and Nodwell and Hart (2006). The conglomerate deposits have been assigned a deltaic (Leckie, 1986, Hobbs, 2004; Arnott, 1993) and/or barrier strandplain interpretation (Leckie, 1986, Rouble, 1994, Caddel, 2000, Armitage et al, 2004, Nodwell and Hart, 2006,). In either scenario, the various shorelines were fed by gravel-rich distributary channels (Zonneveld and Moslow, 2004; Roubel and Walker, 1997; Casas and Walker, 1997) or deeply incised channels (Caddel, 2000).

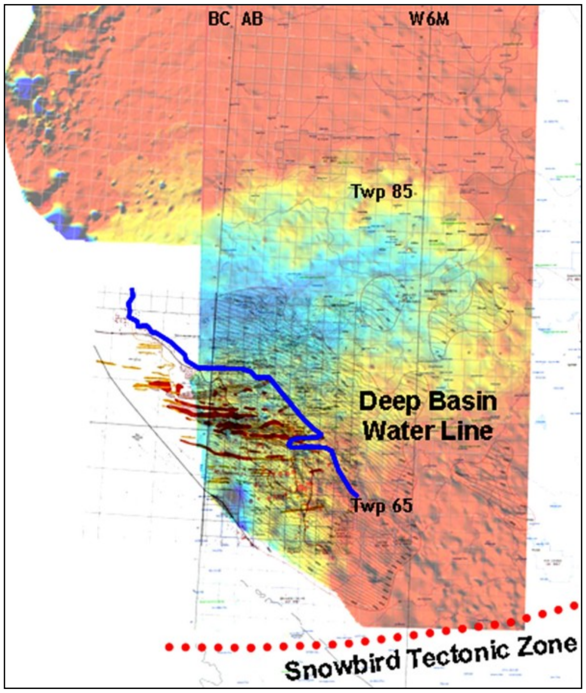

Figure 1: Distribution of gravel-rich barrier shoreline deposits (Sherwin, 2005) within the Deep Basin juxtaposed on an isopach map of the Spirit River Formation (red = thin, blue = thick). The Snowbird Tectonic Zone defined the southern limit of marine deposition

Carmichael (1988) and Schmidt and Pemberton (2004) assigned gravel-rich deposits of the Notikewin Member to the transgressive systems tract. Similarly, Rouble (1994) and Casas and Walker (1997) interpreted Falher conglomerates as transgressive deposits fed by south-north oriented channels. Taking a contrarian view, Caddel (2000) Caddel and Moslow (2004), Armitage at al (2004) and Arnott (1993) attributed channel incision, gravel deposition and overall shoreline progradation to a relative base level fall, placing the deposits into a (forced regressive) lowstand systems track.

Overall architecture, spatial geometry and stratal position of the gravel-rich deposits within the Fort St. John Group are inconsistent with tectonic uplift or eustatic base-level fall as explanations for the marked shift in grain size from fine sand at the distal highstand position to gravel and coarser sand in the overlying proximal early highstand position. Gravel-rich deposits within *all* of the members occur in a retrogradational position relative to the underlying T-R cycle and overlie delta plain/coastal plain facies. There is no lowstand wedge attached to any of the lowstand 'incised channels' and no apparent fluvial transfer of gravel downstream away from the proximal highstand positions. Schmidt and Pemberton (2004) illustrated valley-fill conglomerates of the Notikewin T-R cycle in T67 W6M incised into coastal plain deposits of the Falher A more than 210 km landward of the maximum highstand limit for the Falher A cycle. Caddel, (2000) and Caddel and Moslow (2004) showed gravel-rich deposits of Falher C channels on Bullmoose Mountain, N.E. BC incised into retrogradational shoreface deposits the Falher C and coastal plain deposits of the underlying Falher D. Similarly, Armitage at al, (2004) illustrated gravel-rich Falher C parasequence directly overlying coastal plain deposits of the underlying Falher D T-R cycle. Falher D conglomerates, in turn, were shown by Wadsworth et al (2003) to overlie coal and rooted mudstone delta plain deposits at Mt Speiker, N.E. BC. Lastly, Zonneveld and Moslow (2004) described Falher F channelized gravel-rich channel fill incised into fine grained sandy HCS deposits directly overlying coal and rooted mudstones of the Falher G. From this location at Holtslander Ridge, N.E. BC, gravel-rich Falher G shoreface deposits grade laterally to the north (paleoseaward) into a distal shoreface sandstone facies association.

Overall thickness, architecture and geometry of the Fort St. John Group over the DCGC are consistent with a large fluvial delta complex on the scale of the highstand Mississippi River Delta. Similarly, the architecture, spatial geometry and stratal position of the gravel-rich shoreline deposits are consistent with a large wave-dominated transgressive/early highstand estuary complex of the style and scale of the coast of Nayarit, Mexico. In both examples, volume of sediment and scale of the depositional system indirectly reflect the scale of the drainage system feeding the coastline. The (Spirit River) alluvial system feeding the Fort St. John group must have been of similar magnitude to those rivers feeding the Nayarit and Gulf of Mexico coastlines (i.e. considerably more than several hundred kilometres in length).

The long profiles of all long rivers generally approach an upward-concave shape that is maintained in a quasi-equilibrium form over long geomorphic time (Sinha and Parker, 1996). One key characteristic of all equilibrium profiles is a predictable downstream fining of the bedload sediment, culminating in shoreline deposition of fine-grained distributary mouth bars. Equilibrium is maintained along the fluvial profile by rapid aggradation or degradation of a river bed. Both can occur in response to any change in discharge rate, upstream sediment supply, river slope or sinuosity, channel slope (e.g. faulting or tectonic tilting), and/or base level anywhere along the length of the profile. A critical aspect of downstream fining of the fluvial profile is the transition from a gravel bed to a sand bed. These transitions involve a change in bed composition from unimodal gravels through bimodal sediment to exclusively sand substrate. They occur in a wide range of channel types, environments and settings; occur over a few tens of kilometres; and are often associated with the break in slope along the profile (Smith and Ferguson, 1995). With an appreciation for fluvial morphodynamics, it follows that export of gravel bedload to any marine shoreline must be a disequilibrium signature.

A process-based depositional model for valley incision and development of gravel-rich marine shorelines during transgression (Fig. 2) is presented using the Fort St. John Group as an example. Applying Occum's razor, most of what has been observed in the stacking and distribution of sediment packages within the Fort St. John Group can be explained by predictable autogenic response to tectonic tilting. <u>With an appreciation for the scale of depositional systems</u>, early highstand gravel barrier deposition can be modeled as a consequence of differential subsidence across the Snowbird Tectonic Zone. Rapid fluvial degradation and headward erosion to a gravel-sand transition several hundreds of km's landward would be a response to the more than 200 km shortening of the overall fluvial length caused by subsidence and marine transgression. Fluvial incision would culminate in deposition of a coarse grained, early highstand delta. Following re-adjustment of the equilibrium profile, the fluvial system would continue to feed progradation of a late highstand fine grained delta until the next tectonic event. Tectonic tilting across the SBTZ accounts for the multiple T-R cycles characteristic of the aggrading Fort St. John Group, but can also explain valley incision and grain size jumps (e.g., Cadomin Fm.) characteristic of the Lower Cretaceous alluvial successions in southern Alberta. There is no need to invoke, and really no evidence for complicated, high frequency fluctuations in sea level to explain the early Cretaceous stratal architecture within the WCSB.

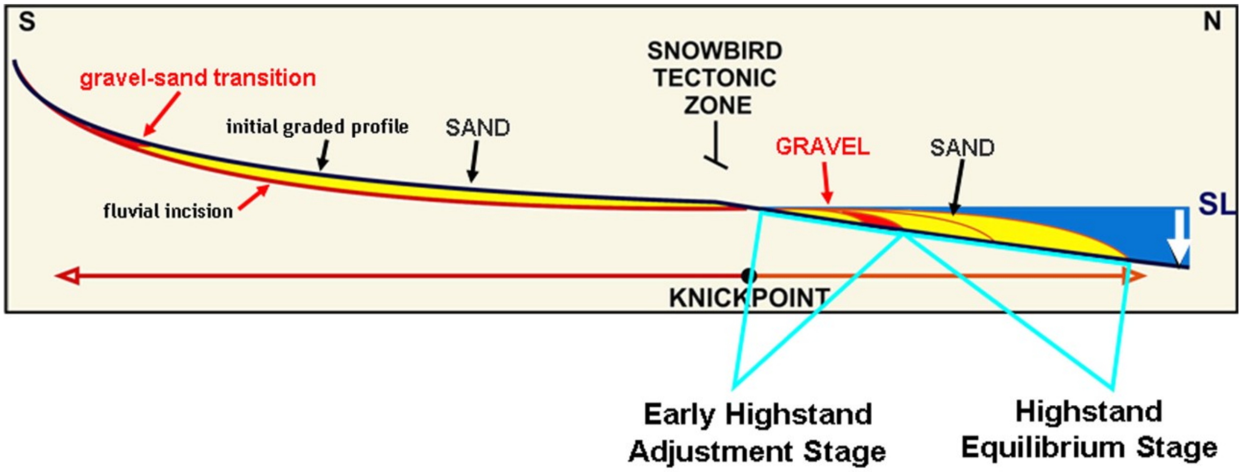

Figure 2: Schematic depositional model for early highstand barrier gravel deposition as a consequence of tectonic tilting across the Snowbird Tectonic Zone. Rapid fluvial incision and headward erosion landward to the gravel-sand transition culminates in deposition of an early highstand coarse grained delta. Following adjustment of the profile the system shifts back to an equilibrium profile that feeds progradation of a fine grained late highstand delta. Tectonic tilting across the SBTZ also accounts for the multiple T-R cycles characteristic of the aggrading Fort St. John Group.

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