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Facies Asymmetry in a Highstand Symmetrical Delta, Viking Formation, Crossfield Area, Alberta, Canada

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Summary

The Lower Cretaceous Viking Formation produces hydrocarbons from shallow-marine deltaic sandstone in the Crossfield area. Sedimentological and ichnological analyses indicate that the Viking Fm in the study area comprises four discrete depositional sequences. The highstand system tract of Sequence 3 constitutes the main reservoir interval at Crossfield, comprising stacked shallow-marine successions that record progradation of a mixed-process (wave-dominated, river-influenced) delta. Facies mapping reveals significant along-strike variations as a function of the relative importance of fluvial energy, fairweather waves, and storm wave processes on the preserved facies. Owing to the minimal influence of tidal processes, a modified process classification scheme is employed, wherein evaluation of the interplay of processes operating in the depositional environment is focused on fluvial sediment influx, fairweather wave processes, and storm wave processes.

Facies successions of the prodelta and delta front display pronounced variation along depositional strike, characterized by greater proportions of erosionally amalgamated HCS towards the northern part of the study area. South of the distributary channel deposits, the delta-front intervals appear to have been partially sheltered from storm energy and are markedly heterolithic, characterized by thinner tempestites intercalated with fairweather wave-generated bioturbated mudstone and mudstone drapes interpreted as fluid mud from river-derived hypopycnal (buoyant) plumes. Facies successions of prodeltaic intervals, however, demonstrate a progressive increase in fluvial influence (e.g., fluid mud layers, hyperpycnites) towards the distributary channels. As well, beds recording fairweather wave energy, which comprise mainly pervasively bioturbated sandy mudstone, and storms responsible for deposition of micro-HCS and HCS are evenly distributed on either side of the distributary channels. This arrangement clearly demonstrates that from a process perspective, the highstand delta was symmetrical.

This study demonstrates that careful mapping of paleoenvironments within discrete system tracts is essential for their accurate depositional characterization. Specifically, under shallow-water, high-energy conditions, spatial changes in some facies successions may be a function of a preservational bias; a taphonomic control that preferentially removes beds generated by other processes (*i.e*., fluvial and tidal) operating in the system and gives the false impression of deltaic asymmetry. Rather, successions that favour a more complete record of deposition (*e.g*., prodeltaic intervals) are superior for characterizing the actual distribution of depositional processes affecting the delta. Correspondingly, along-strike variations in the *preservation* of facies in high-energy delta fronts cannot be taken to be indicative of *process-driven* delta asymmetry.

Study Area and Dataset

The study area is located in the western part of south-central Alberta, Canada, extending from Townships 24–31 and Ranges 25W4 to 4W5 (Fig. 1). The polygon of the field area encompasses roughly 5000 km^2. The southern limit of the study area is located approximately 20 km north of the city of Calgary, and the northern limit lies 120 km south of the city of Edmonton. The available data encompass 1,415 wells that intersect the Viking Formation. Of these, 54 wells contain cores, which total 1,264 m of interval. An integrated sedimentological, ichnological and sequence stratigraphic analysis was undertaken on the Viking Fm in the study area, and highlighted 4 discrete sequences (Díaz, 2020). The study focused on the highstand systems tract of Sequence 3 as it constitutes the main Viking reservoir interval in the Crossfield area.

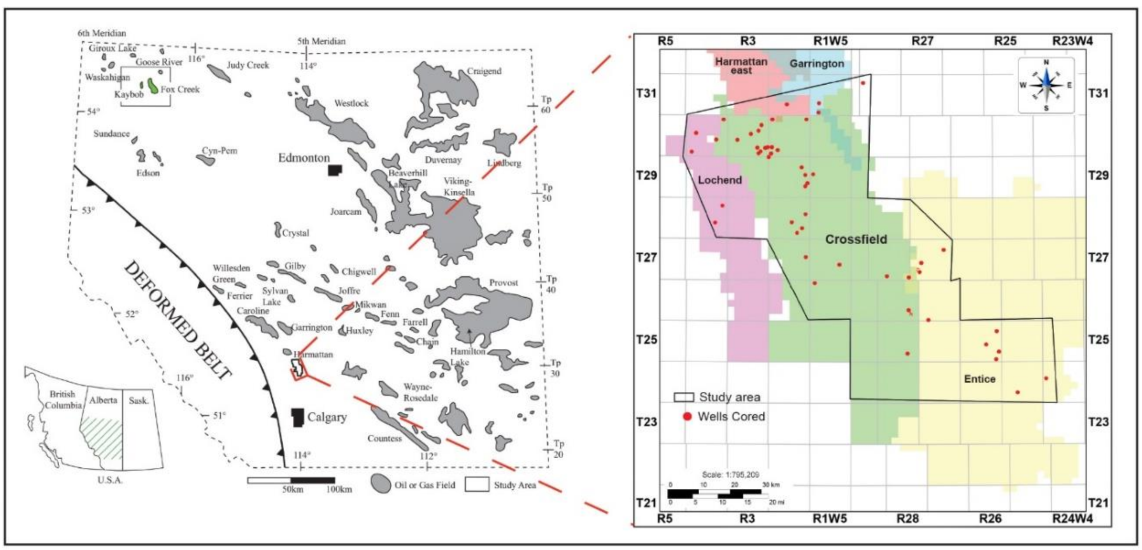

Figure 1: Regional map of central Alberta, Canada, showing the location of the major Viking fields (modified from Pattison, 1991; MacEachern et al., 1999). The map to the right shows the study area, main producing fields, and the location of cored wells that penetrate the Viking Formation.

Along-Strike Depositional Process Variations in the Delta Succession of the Highstand System Tract of Sequence 3

Delta successions of the highstand system tract in the Crossfield area are overwhelmingly wave-dominated with variable but locally significant fluvial influence. There is no clear evidence of tidal influence preserved in the facies. Ainsworth et al. (2011) proposed a ternary plot diagram, which seeks to characterize the relative importance of fluvial, wave and tidal processes on the facies characteristics of all siliciclastic coastal environments. All facies successions in the study interval plot along the left to lower left margin of the Ainsworth et al. (2011) diagram (Fig. 2A), and this indicates that changes observed along depositional strike in the HST delta complex are a function of the relative importance of wave vs. fluvial processes. However, facies mapping of the interval reveals that significant along-strike variations in facies successions are not only a function of the relative importance of fluvial energy, but the relative importance of fairweather wave vs. storm wave processes. In order to predict along-strike variations in delta successions of the HST, the

WAVE classification scheme of Ainsworth et al. (2011) is modified to exclude tidal energy, with the resulting ternary diagram comprising 3 apices: fluvial (F), fairweather waves (FW), and storm waves (ST; Fig. 2B). The same three-letter coding style proposed by Ainsworth et al. (2011) is employed within the modified scheme to characterize facies variations that are related to the different processes (i.e., fluvial, fairweather waves and storm waves) operating in the study area to explain variations in successions that are otherwise strongly wave dominated.

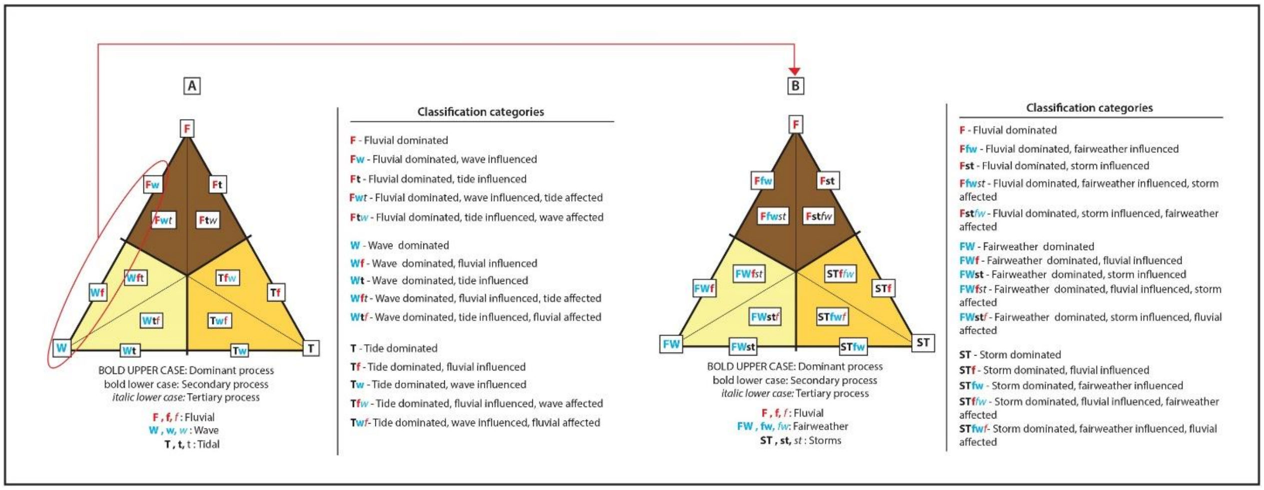

Figure 2: A) Classification scheme of Ainsworth et al. (2011). B) Modified process classification scheme used to evaluate the dominant processes acting in depositional environments where tidal processes appear to be very minor, fluvial processes are significant, and wave energy can be differentiated into fairweather shoaling and storm energy.

Facies Asymmetry in a Highstand Symmetrical Delta

The preserved record of delta-front facies associations reveals that storm waves were relatively stronger and/or impacted more frequently along the northern margin of the delta, and this is manifested in the predominance of thick and erosionally amalgamated HCS sandstone bedsets and rare preservation of fluvial- and fairweather wave-generated beds and bedsets. South of the distributary channel deposits, the delta-front intervals were more sheltered from storm energy, and are characterized by thinner and less erosionally amalgamated HCS and micro-HCS intercalated with fairweather wave-generated bioturbated mudstone and mudstone drapes interpreted as fluid mud derived from hypopycnal river discharge. By contrast, facies of the prodelta demonstrate a progressive and symmetrically distributed increase in fluvially influenced deposition (fluid mud layers, hyperpycnites) towards the distributary channels. Likewise, fairweather wave-generated bioturbated sandy mudstone and storm-generated micro-HCS and HCS are evenly distributed in prodeltaic intervals on either side of the distributary channels. This arrangement clearly indicates that from a process perspective, the delta of the highstand system tract was symmetrical.

The observed variations in the ichnological signature of the delta-front deposits along depositional strike cannot be regarded to record changing paleoecology. Rather, the resulting suites record changing *taphonomy*, which directly tracks the preservation potential of the physical sedimentological beds. Ichnological suites along the northern margin of the delta consists of the near exclusive preservation of post-storm opportunistic associations (e.g., *Cylindrichnus,* *Ophiomorpha,* and *Skolithos*), and is expressed by variable but low BI values. Fairweather beds containing common *Chondrites, Palaeophycus, Phycosiphon, Planolites, Teichichnus* and *Thalassinoides* are uncommon along the northern margin of the delta front, but are comparatively more abundant towards the south. This spatial distribution is interpreted to indicate that the southern margin of the delta was better protected from storms.

This study demonstrates that under shallow-water, high-energy conditions, spatial changes in facies may be the product of an incomplete record owing to autogenic erosion associated with storm events. Beds that were generated by fluvial and fairweather wave processes operating in the system were increasingly removed from the depositional record as a function of progressive shallowing into the delta front. Facies successions of the prodelta, however, yield a more complete record of beds and bedsets and therefore of the processes that operated in the study area (i.e., fluvial, fairweather waves and storm waves). This is because the prodelta setting resided in a distal position and was protected from extensive reworking by storm waves. Correspondingly, the spatial variation in the effectiveness of storm-induced erosion gives the false impression of deltaic asymmetry. As such, along-strike variations in the *preservation* of facies of high-energy delta fronts should not be taken to be indicative of *process-driven* delta asymmetry.

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