A Revised Stratigraphic Architecture and History for the Horseshoe Canyon Formation (Upper Cretaceous), Southern Alberta Plains

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Summary

A revised stratigraphic architecture and history for the paralic to continental, Upper Cretaceous Horseshoe Canyon Formation (HCFm) in the southern Alberta plains highlights the combined influences of changes in relative sea level and tectonism. Whereas the stratigraphic architecture in the lower one-half of the formation appears to have been influenced mostly by changes in relative sea-level, the upper one half is stratigraphically more complex, indicating significant tectonic and climatic influences. These differences help explain variations in hydrocarbon potential throughout the formation.

Stratigraphy

In the stratotype area, near Drumheller, the composite HCFm section is 265 m thick and comprises two-thirds of the Edmonton Group (Figure 1). In subsurface, the HCFm thickens and becomes older to the north and west at the expense of the marine Bearpaw Formation. To the south and east, the HCFm thins and becomes younger, interfingerng with upper portions of the Bearpaw Formation. It spans six million years and ranges from Late Campanian (~73 Ma; magnetochron 32r) to Late Maastrichtian (~67.0 Ma; magnetochron 30n), with an average sedimentation rate of 4.5 cm/ka.

In this revised stratigraphy, the HCFm consists of five informal sub-units (1-5) that are defined largely by the presence/absence of coals, grain size, and sandstone stacking patterns.

Unit 1 (160 m)

Unit 1 includes the marine-to-nonmarine interfingering transition with the Bearpaw and is characterized by vertically-aggrading and weakly progradational parasequences. In the stratigraphic nomenclature of Hamblin (2004) it encompasses the Strathmore and Hoodoo tongues, and the lower 2/3 of the Midland tongue. The amount of stratigraphic and sedimentological work that has been conducted in Unit 1 during the past 20 years exceeds the rest of the published work on other parts of the Edmonton Group combined.

In outcrop, the numbered coal horizons (#s 0-9) are recognized (Gibson, 1977). The 0-5 coal swarm is informally referred to as the Drumheller coal zone, whereas the 6-9 coal swarms make up the Weaver coal zone.

A regionally extensive bentonite rich zone occurs in association with a ~25 m thick interval that includes the closely spaced 6 and 7 coal swarms. This zone is interpreted as a chronostratigraphic datum, and all measured sections and well logs in this study are hung on it. East-west cross sections below the datum (lower one-half of the HCFm), show a broadly tabular package that thickens only weakly to the west (source direction). This lower interval is characterized by marine-to-nonmarine transitions, as well as isolated lenticular channel sandstone bodies, fine grained sandstone, well-developed coal seams, and laterally extensive carbonaceous mudstones, all of which indicate moderate-to-high accommodation, and an overall trend toward vertical aggradation, with very little channel stacking. This interpretation is consistent with the large abundance of articulated dinosaur remains and bonebeds in the overbank settings that dominate this interval.

In contrast, the stratigraphic interval above the bentonite datum (up to the #10 coal), is strongly wedge shaped, thickening to the west and indicating an increase in sediment supply and, perhaps, subsidence. An interpretation of increased sediment supply is supported in outcrop by localized occurrences of medium grained sandstones, rare lenses of extrabasinal pebbles, and increased occurrences of stacked paleochannels. We infer the duration of this increased sediment supply as being about 1 million years.

Unit 2 (40 m)

Unit 2 shows a reduction in bed thickness, has few organic horizons, and records a significant marine transgressive event. Unit 2 rests on the 9 coal zone (top of the Weaver Coal Zone) and includes most of the "Drumheller Marine Tongue" (including the #10 coal) -- a 30 m thick unit that records fundamental changes in depositional style in the Horseshoe Canyon Fm. The transition up into Unit 2 is marked by a dramatic reduction in bed thickness and paleochannel size, and the widespread occurrence of ripple-laminated sandstones. Coals and carbonaceous shales are rare, and there are locally developed sand- and siltstone beds that are rich in brackish-water pelecypods. Unit 2 encompasses the uppermost and lowermost portions of Hamblin's (2004) Midland and Tolman tongues, respectively. Relative to other Upper Cretaceous shoreline successions in Alberta, Unit 2 records an atypical depositional history: a rise in sea level (the DMT) coincident with a reduction in both sediment supply and accommodation (enough to prevent the development of peat swamps and reduce occurrences of stacked sandstone bodies). In combination, these features indicate an absolute reduction in rates of subsidence. The near absence of coals, a reduction in sporo-pollen assemblage diversity, and the presence of vertisols suggest a seasonally dry climate at this time (Srivisatava, 1970; Hamblin, 2004).

Unit 3 (15 m)

Unit 3 is a thin but very prominent unit in outcrop and subsurface, provides an additional means of correlation independent of coal markers, and generally can be traced west to the 5th meridian. It consists of stacked shoreline sandstones (southward) and alluvial sandstones (northward) that are ubiquitously cemented with iron carbonate, and which form resistant benches or vertical cliffs in outcrop. This thin interval occurs in the middle of Hamblin's (2004) Tolman tongue. The laterally extensive and stacked architecture of this zone -- regardless of whether it comprises offshore, shoreline, or alluvial sediments -- indicates continued influence of the marine process in the type area in tandem with a decrease in accommodation, suggestive of a highstand systems tract.

Unit 4 (25 m)

Unit 4 remains non-coaly, but exhibits sub-equal paleochannel-overbank bed thicknesses and non-amalgamated channel deposits, encompassing the remainder of Hamblin's (2004) Tolman tongue. The combination of well separated fluvial sandstones and coarse grained volcanic ash, suggests a phase of overthrusting and mountain building to the west that resulted in increased rates of subsidence and a concomitant increase in accommodation -- all during withdrawal of marine influences to the east. Sediment supply remained low as indicated by a predominance of siltstone and very fine sandstone in the coarsest units.

Unit 4 is notably non-coaly indicating the persistence of the drier climate that was established in Unit 2. Vertebrate fossils are abundant and dominated by broken elements and rare articulated skeletal remains. Dramatic differences in the dinosaurian faunas between Units 1 and 4 include the replacement of *Edmontosaurus* by *Hypacrosaurus*, the absence of centrosaurine dinosaurs, and reduced representation of all ceratopsian dinosaurs.

Unit 5 (25 m)

Unit 5 comprises the uppermost 25 m of the HCFm, is the uppermost coaly interval of the Formation consisting of coal zones 11 and 12 (Carbon and Thompson swarms, respectively), and corresponds to Hamblin's (2004) Carbon tongue. The unit is also characterized by thick, multistoried fine-to-medium grained alluvial sandstone bodies with localized lags of extraformational pebbles and cobbles. These features clearly indicate a tectonically-influenced increase in sediment supply coupled with a return to a wetter climate, and a decrease (initially) in accommodation. Unit 5 is also marked by a notably extreme decrease in the preservation of vertebrate fossils and the appearance of the palynological biostratigraphic marker, *Manicorpus gibbus*.

Whitemud-Battle (10 m)

The Whitemud Formation comprises mature HCFm sediments, indicating an extreme reduction in accommodation and sediment supply. The unit is probably best included in the HCFm as originally proposed by Hamblin (2004). The Whitemud-Battle contact is a significant unconformity characterized by channel-scale relief, and intense rooting and weathering on the Whitemud. Channel fills at the base of the Battle Formation yield palynomorphs previously unrecognized in the area, very rare dinoflagellates, and cold temperature resistant microtaxa. Most of the Battle consists of altered volcanic ash with thin siliceous (weathered) zones. Cool-temperature, sediment-starved paludal/lacustrine environments dominated the ancient Whitemud and Battle landscape.

Discussion

The Horseshoe Canyon Formation represents a significant progradational sedimentary phase that culminated in the draining of the epeiric Western Interior Seaway from southern Alberta. Data presented here indicate, however, that this history was influenced episodically by volcanism, tectonic adjustments and climate change (Figure 1). Similarly complex patterns have been recognized in the underlying Belly River Group (Eberth and Hamblin, 1993) and, given that the Edmonton Group clastic wedge reflects a major phase of accretionary tectonics and resulting continental sedimentation in the Western Canada Sedimentary Basin, it is not surprising that complex influences were at work during Horseshoe Canyon "time" as well.

From a stratigraphic perspective, the most important results of this study are as follows:

1) A laterally extensive bentonite-rich zone occurs in Unit 1 and serves as a new stratigraphic datum in the Plains region.
2) The peculiar co-occurrence in Unit 2 of a reduced sediment supply, less accommodation, and a general absence of coals, all during a relative rise in sea-level, indicate that rates of subsidence were decreasing or even negative in Plains region, most likely due to a forebulge rise in response to overthrusting and mountain building (to the west). This interpretation requires that the DMT transgressive event be accepted as eustatic in origin.
3) The co-occurrence in Unit 2 of evidence for seasonal dryness and tectonic uplift suggests that drier climates likely were driven by the regional uplift and, possibly, an enhanced rain-shadow effect.
4) The return to wetter climates in Unit 5 co-occurs with a dramatic increased influx of alluvial sediments, suggesting tectonic quiescence and foredeep rebound to the west. However, the notable rarity of vertebrate fossils in this interval remains unexplained and extremely unusual for an interval with abundant, stacked alluvial sandstones. Given the overall cooling trend during the Maastrichtian, however, under-representation of vertebrates may simply reflect decreasing diversity due to changes in climate.

There are three sandstone-rich zones that are of interest in terms of hydrocarbon potential: the top of Unit 1; all of Unit 3; and all of Unit 5. Unit 3 is in the middle of a non-coaly interval, is ubiquitously tight, and has the most limited potential of the three. The top of Unit 1 exhibits numerous large-scale paleochannel sandstones that tend to be stratigraphically isolated. Unit 3 includes stacked and laterally-extensive paleochannel sandstones in association with coal deposits, and probably has the best potential for further hydrocarbon exploitation.

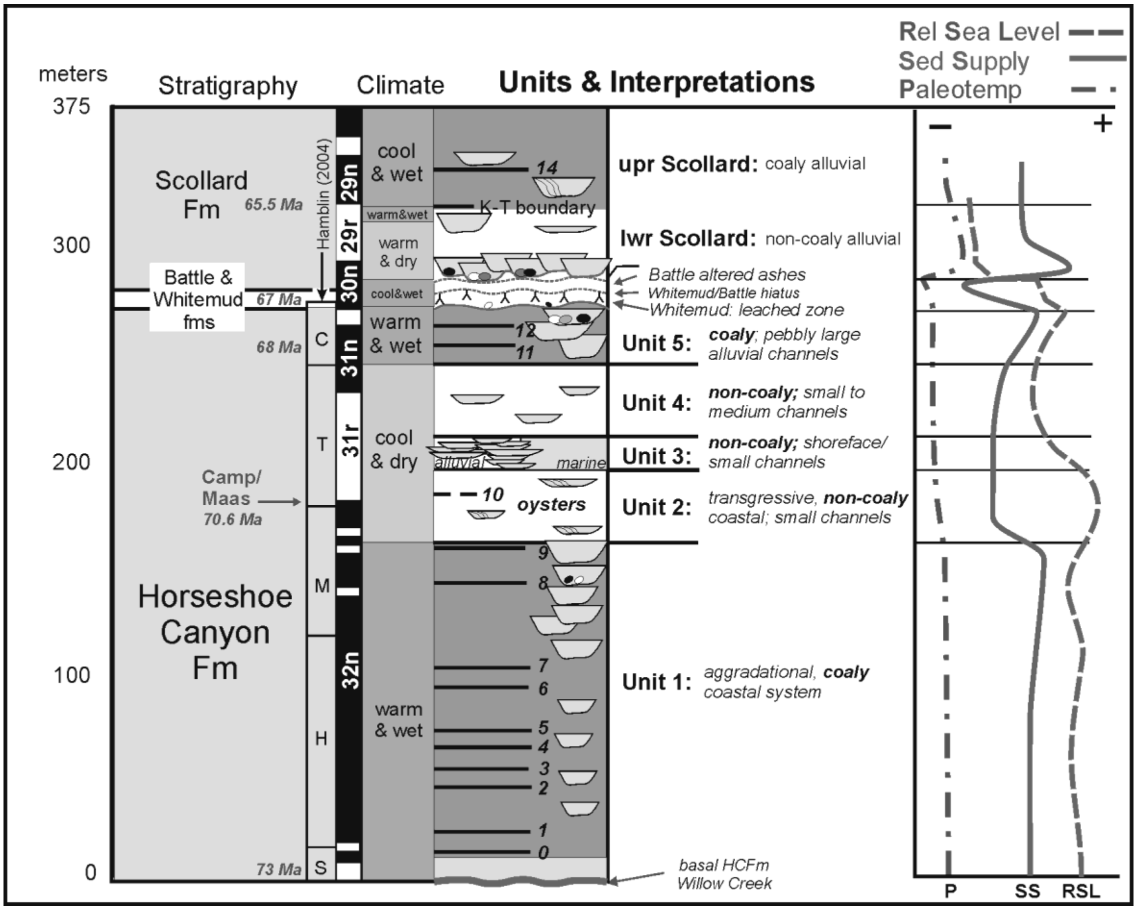

Figure 1. Summary of the stratigraphic revision of the Horseshoe Canyon Formation presented here. Paleomagnetic data from Lerbekmo and Braman (2002). All the curves (to the right) were derived from multiple sources, including this study. Radiometric ages are derived and inferred from a variety of published and unpublished sources.

References

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