

## **If the Shoe Fits: A Holistic Look at Viking Deposition in the Western Canada Sedimentary Basin**

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### **Summary**

High resolution mapping of isopach values for the Viking Formation and its equivalents from over 250,000 wells provides a perspective of the Viking depositional system not seen previously through conventional mapping techniques. When combined with historical published data, core observations and petrography, a picture emerges of a large submarine system that demarcates the structurally-driven regional transition from N-oriented sediment transport and deposition typical of the underlying Mannville Group to SE-oriented sediment transport and deposition typical of the overlying Upper Cretaceous deltaic successions (e.g., Dunvegan, Cardium, Muskiki, Belly River, Horseshoe Canyon etc.). Isopach trends and geometries indicate there are likely two Cadotte, two Paddy and three Viking successions separated both spatially and temporally. The multiplicity is related to inversion of the Peace River Arch and a rotation of the marine depocenter. This perspective accounts for many if not most of the inconsistencies between previous depositional, sequence stratigraphic and biostratigraphic models.

### **Introduction**

Sequence stratigraphic, depositional, and ichnological models for the Late Albian marine Viking formation in the Western Canada Sedimentary Basin espouse a paradigm of a shallow depositional shelf subjected to high frequency fluctuations in relative base level. The Viking formation comprises relatively thin sandy regressive successions that cover an area in excess of 80,000 – 100,000 km<sup>2</sup>. Viking sandstone reservoirs in west-central Saskatchewan and Alberta are unequivocally characterized as marine sand bodies enveloped in marine mudstones. Within the Viking Formation there is no unequivocal evidence for subaerial exposure, shallow water deposition or wave ravinement anywhere.

The Viking Formation hosts a variety of oil and gas reservoirs within traps that range from purely structural in the west to purely stratigraphic in the east. Provost, the largest oil field to date, was discovered in 1946. Within ten years, eight of the top ten largest Viking oil fields and all of the top ten largest Viking gas fields were discovered and delineated (Reinson et al, 1994).

The groundwork for the current structural, stratigraphic and biostratigraphic understanding of the Viking formation was largely established prior to 1960, early in its exploration history. Gammel (1955) and De Weil (1956) advocated a shallow water forced shoreline regressive model for Viking sand deposition related to mountain uplift in conjunction with volcanism. Gammel (ibid) further proposed that Viking sand distribution could have been influenced by antecedent structure and seafloor topography. Citing features like cross-bedding, current bedding, ripple-marks, and recurrence of pebble beds, Roessingh (1959) interpreted the Viking sands as shore to off-shore sediment deposited during repeated minor transgressions and regressions. He concluded the water depth during Viking deposition could not have been very great at any time.

Williams (1958) recognized structural inversion of the Peace River Arch (PRA) depocenter immediately post Cadotte deposition, but prior to Upper Cretaceous time. Stelck (1958) used foraminiferal biostratigraphy to loosely correlate the Paddy sandstone over the inverted PRA to both the Joli Fou and Viking formations to the south and east. He further suggested the Paddy sands represented a shoreline phase of the upper part of the Joli Fou and lowermost Viking. The correlation of Paddy and Viking formations was reaffirmed by Oliver (1960) using electric log correlations, cuttings and core to demonstrate an unconformity truncating the Cadotte sand and underlying Harmon shale. He considered the Viking Formation to be partially equivalent to the Paddy, and the northern Joli Fou shale depositional limit as an onlap onto truncated Cadotte.

Of all the early authors, only Beach (1955, 1956) took a contrarian view of Viking deposition. Based on the regional distribution and fine-grained nature of the sediments, he concluded that the Viking was likely deposited by high density, low velocity currents, or turbidity currents and further proposed a tsunami origin for gravel deposition at Viking-Kinsella, Joarcam, Joffre, Kessler and Pendant d'Oreille fields.

Very few papers on the Viking formation were published through the 1960's and 1970's, but with the aggressive promotion of sequence stratigraphy in the 1980's, study resumed and focused primarily upon sequence stratigraphic correlation of submarine disconformities within the Viking. Many of these incorporated concepts generated for the younger Cardium formation that also experienced a similar academic revival. The resultant shallow water sequence stratigraphic models for the Viking Formation provided the framework for a plethora of ichnological studies that continued into the 1990's.

Compilation of Viking Formation literature depicts a patchwork quilt of studies that focused largely on producing fields to the east and producing fields and/or outcrops to the west within the disturbed belt. A few regional studies attempted to correlate various studies, but most of these defaulted to the original depositional interpretations. Most currently popular forced regression and lowstand models for the Viking sands invoke storm-dominated shelf deposition involving a significant sea level drop. Estuarine valley fills dominated by tidal deposits and brackish water ichno-assemblages comprise an integral part of these models. Transgressive wave-incised shorefaces are a requisite element to account for the absence of down-stepping shorefaces and subaerial facies. The facies mosaic derived from these studies as depicted in paleogeographic maps for the Viking Formation (Reinson et al, 1994, Canadian Discovery, 2005) bears little resemblance to modern depositional systems in both scale and orientation (Figure 1).

To date, there is no single study that has examined the Viking depositional system as a whole. In the most recent and arguably most regional study, Roca et al (2006) allostratigraphically subdivided the Late Albian to earliest Cenomanian succession in western Alberta into five allomembers on the basis of regional unconformities and transgressive surfaces. They combined the Paddy, Joli Fou, Viking, Westgate and Fish Scales allomembers into an informal Lower Colorado allogroup. On the basis of allostratigraphic correlations, they concluded that the Paddy alloformation is older than most of the Joli Fou and all of the Viking alloformation, contrary to previous interpretations which suggested equivalence to all or part of the Viking and Joli Fou. They argue on the basis of correlations that the Paddy alloformation on the Peace River is bounded above and below by major unconformities. While extensive, their study focused on the western deposits and examined less than half of the Viking sand distribution.

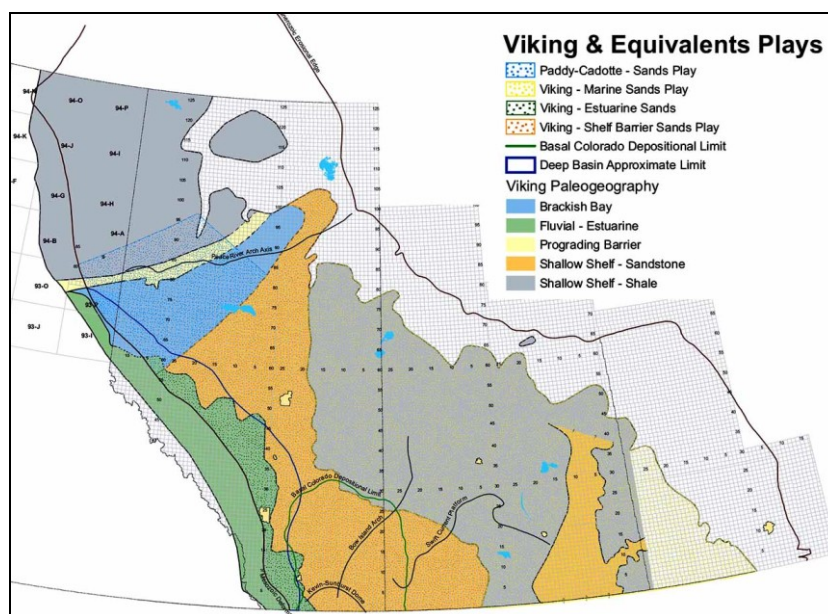


Figure 1: Generalized paleogeography of the Viking Formation and its equivalents together with the principal play types (from Canadian Discovery, 2005, modified from Reinson et al, 1994).

The Viking sandstones in south-central Alberta demarcate a structurally driven regional transition from N/NW-oriented sediment transport and deposition typical of the Mannville Group to SE-oriented sediment transport and deposition typical of the overlying Upper Cretaceous deltaic successions. The change coincides with structural inversion of the Peace River Arch and the more regional southerly transgression of the Mowry Sea that signals the Greenhorn sea level cycle. No foraminiferal zone has been established for the Viking Formation and its position straddles the zonal boundary between Joli Fou and Westgate assemblages. (Stritch and Schröder-Adams, 1998). Viking contains a foraminiferal assemblage from both the Joli Fou and Westgate, and both abundance and diversity vary significantly within the assemblage. A depositional hiatus and paleoenvironmental change at the top of the Viking Formation mark the onset of the Greenhorn transgression (ibid).

High resolution regional mapping of the Paddy/Cadotte-Viking-Bow Island isopach from ~280,000 wells throughout N.E. BC, Alberta and Saskatchewan provides a view of the Viking depositional system not seen previously with conventional mapping techniques (Figure 2). Oblique 3-D illumination and colour transformation of isopach contours integrated with historical data explains many, if not most, of the inconsistencies between various previous interpretations. Isopach trends and geometries indicate that there are likely two Cadotte, two Paddy and three Viking successions separated both spatially and temporally. The duplicity is related to inversion of the arch and a rotation of the marine depocenter to the SE.

The earliest Viking succession comprises prodelta deposits of the Bow Island delta prograding from SW to NE. Uplift of the PRA terminated Bow Island/Viking<sup>1</sup> deposition. South-oriented Paddy<sup>2</sup> valleys on the PRA incised into north-oriented Cadotte<sup>1</sup> shoreface and Paddy<sup>1</sup> delta plain deposits, feeding an E-W oriented sandy Cadotte<sup>2</sup> shoreline and an offshore, N-S oriented Viking<sup>2</sup> submarine turbidite fan complex (>>80,000 km<sup>2</sup>). Viking<sup>2</sup> turbidites incised into the Joli Fou or distally downlapped onto a radiolarian-rich phosphatic submarine hardground. Termination of fan deposition was marked by fan degradation, canyon incision and submarine erosion. The Viking Crystal field is but a small element within a large N-S oriented submarine incision that bisects the fan. Submarine erosion of the Bow Island delta shelf to the south by SE-oriented currents produced a sharp, >320 km long linear scarp. The scarp is mantled with coarse contourite deposits and terminates to the east with deposition of a >120 km long Viking<sup>3</sup> contourite spit or drift. Omission surfaces within the distal Viking facies are marked by traction carpet deposits containing reworked silicified radiolarian phosphatic hardground.

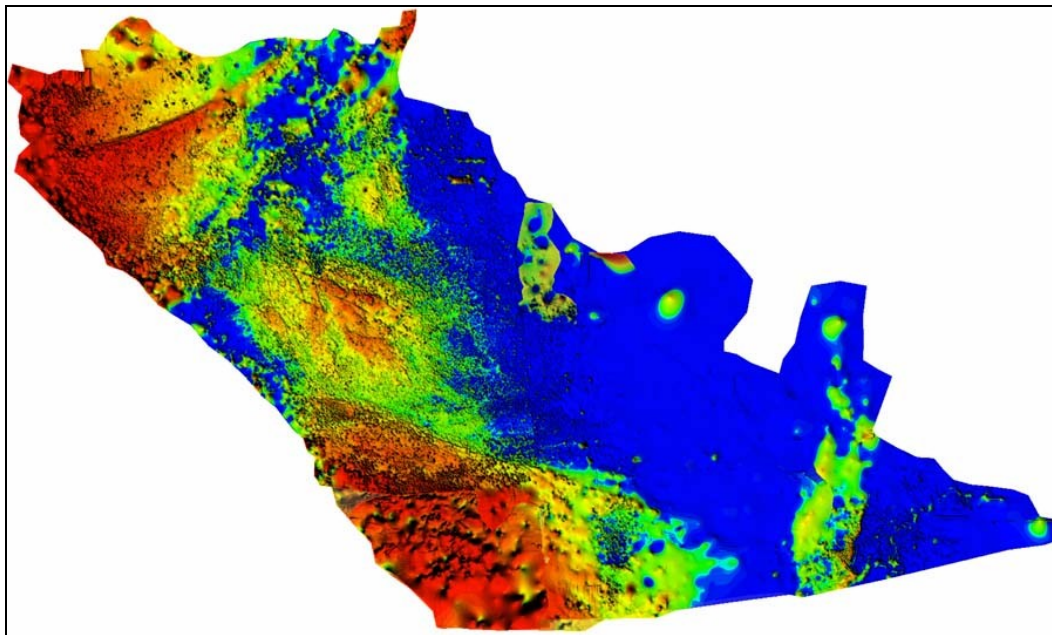


Figure 2: 3-D isopach map of the Viking Formation and its equivalent from 280,000 wells across Alberta and SE Saskatchewan with oblique illumination (from the south) and colour transformation of contour intervals.

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