The Nature and Significance of Transgressive Surfaces of Erosion in the Viking Formation, Southeast Central Alberta*

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Search and Discovery Article #51070 (2015)
Posted March 20, 2015

*Adapted from extended abstract prepared in conjunction with a presentation given at CSPG/CSEG 2004 GeoConvention, Calgary, AB, Canada, May 31-June 4, 2004,

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Abstract

The transgressive surfaces of erosion (TSEs) in the Viking Formation of southeast central Alberta formed during periods of substantial marine flooding during Albian time (Cretaceous). These TSEs are a result of erosion during relative sea level rise and are commonly overlain by a pebble lag, conglomerate or coarse sandstone unit. Some wells contain several lags signifying multiple transgressive or erosional events that are usually laterally discontinuous between wells. A major transgression at the end of Viking time led to the deposition of a relatively continuous lag demarcating the top of the Viking Formation. This erosional surface is the most distinguishable due to its lateral continuity across the basin. Despite its continuous extent, this TSE varies in its erosional and ichnological character, as well as, in the nature of the overlying transgressive lag. In this presentation, a typical Viking core will be reviewed, and portions of several other cores will be presented displaying the variety of transgressive erosional features seen in the study area.

Study Area

The study area is located in southeast central Alberta within townships 25 to 40 and ranges 13 to 24 (Figure 1). This region includes the fields of Wayne-Rosedale, Cessford, Chain, Fenn West, Fenn Big Valley; parts of Mikwan, Nevis, Red Willow, Provost, and Hussar fields; and the townships between these fields. Twenty-six selected cored Viking intervals have been logged over the study area.

Stratigraphy and Paleogeography

The Viking Formation represents a regressive package between the underlying transgressive Joli Fou Shales and the overlying transgressive Westgate Shales (Figure 2). Rapid sediment accumulation and subsequent relative sea level fall resulted in progradation, the formation of unconformities at incised valleys and deposition of isolated coarse sediment bodies in a basinward position (Cant and Stockmal, 1989). Accordingly, the Viking is part of a wedge of coarse clastics that thickens toward the Cordilleran Orogenic belt and thins towards the east into the foreland basin.

The marine deposits of the Viking are predominantly non-reservoir siltstones and shales with infrequent reservoir quality sandstone units. These deposits comprise the regionally extensive coarsening upward shelf-to-shoreface parasequences of the highstand systems tract (Pemberton et al., 1992). Mikwan, Fenn and Chain fields are located within the study area and contain some of the discrete sandstone reservoir units, which are considered sharp-based shorefaces at variable stratigraphic levels (Burton and Walker, 1999).

An extensive TSE underlying the Westgate Shales demarcates the top of the Viking Formation. This basin wide TSE, called the VE4 (Viking Erosional surface 4) was documented by Walker (1995) and is overlain by a coarse lag that is centimeters to 5m in thickness. The lag thins and fines basinward, and is underlain by a *Glossifungites* surface delineated with occasional *Skolithos* and *Thalassinoides* (Walker, 1995). Walker (1995) concluded that the VE4 surface was formed by subaerial erosion and subsequent transgressive modification with the coarse lag attributed to marine erosion.

Preliminary Observations and Interpretations

Nature of the Uppermost Viking TSE

Analysis revealed four variations of the TSE that characterizes the top of the Viking Formation. (1) The simplest case is a pebbly or sandy lag overlying an erosional surface. In some cases, sideritization of a thick zone has taken place beneath the erosional surface, which may reflect significant hiatus associated with the surface. A variation of this type of TSE is characterized by the presence of multiple lags overlying the erosional surface (Figure 3A). (2) Other lags within the Viking overlie a surface delineated by the *Glossifungites* ichnofacies typified by *Skolithos* burrows (Figure 3B). In some cases, *Glossifungites* suites are within a sideritized unit, in other cores there are multiple *Glossifungites* surfaces. (3) In instances where the *Glossifungites* ichnofacies is not present, evidence of firmground conditions may still be seen (Figure 3C). (4) In some cores, the transgression is expressed as a more gradational change in deposition or a sharp-based transition from the underlying units (Figure 3D). With each type of TSE, the overlying transgressive lag varies in grain size from fine sand to pebbles, and in thickness from a thin lag to tens of centimeters. The matrix to clast ratio is also variable and can change within a single lag.

Minor erosional or hiatal surfaces can also be characterized by a pebbly or sandy lag and/or a *Glossifungites* suite. However, these surfaces do not have the same stratigraphic significance as the uppermost Viking TSE, which is overlain by thick transgressive shales. These minor erosional surfaces may represent higher frequency transgressive events, local erosional events or storm scouring.

Typical Viking Core: 07-20-037-23W4

A typical Viking core was selected to demonstrate the relationship of the regional Viking parasequences to the uppermost TSE and other erosional or hiatal surfaces (Figure 4). The regional Viking deposits in core 07-20-037-23W4 are characterized by three coarsening upward packages with variable thickness, sedimentology and ichnology. The uppermost parasequence is truncated by an erosional surface with an overlying pebbly lag, and is subsequently overlain by massive shales.

Ten facies were defined from this typical Viking core. Facies A is characterized by fissile, dark grey shale with indiscernible bioturbation. Because of the muddy nature of the deposit, there is a lack in contrast of the sediment that usually allows for ichnofossil identification. Likely, this shale is highly bioturbated as it would have been deposited in a low energy setting where abundant reworking could take place. Thus, this facies is interpreted as representing shelf mudstones.

Another fine-grained facies, facies B, is a massive shaley siltstone with abundant to pervasive bioturbation and less than 10% sand sized particles. Ichnogenera present in this facies include dominant *Helminthopsis*, *Planolites*, and *Chondrites*; secondary *Schaubcylindrichnus*; and rare *Zoophycos* and *Skolithos*. Due to the dominance by grazing and deposit feeders, this assemblage is thought to represent a distal *Cruziana* ichnofacies. The fine-grained nature of the sediment and distal *Cruziana* suite of traces indicates deposition in the proximal lower offshore.

Silty shale characterizes facies C, which is rarely to moderately bioturbated with less than 15% sand sized particles. Rare sand lenses and laminae are present with shale partings also noted. Biogenic structures include *Schaubcylindrichnus* and *Helminthopsis*. The identifiable traces indicate dominance by grazing and suspension feeders, but likely represent a distal *Cruziana* assemblage due to the fine grained nature of the deposit. Accordingly, the silty shale is interpreted as a lower offshore deposit.

Rare sandy laminae and lenses with planar to wavy laminations are found within the sandy siltstone of facies D. Most sand sized particles have been mixed into the siltstone by bioturbation, which is moderate to pervasive in this facies. Trace fossils include a dominance of *Helminthopsis* and *Planolites*; secondary *Chondrites* and *Schaubcylindrichnus*; occasional *Zoophycos*, *Skolithos*, *Diplocraterion*, and *Teichichnus*; and rare *Palaeophycus*. The diversity of traces and dominance by grazing and deposit feeders with a significant influence of suspension feeders suggests an archetypal *Cruziana* ichnofacies. Thus, the lithology and archetypal *Cruziana* assemblage indicate deposition in the distal upper offshore.

Interbedded sandy and shaley siltstone with low to moderate bioturbation corresponds to facies E. This facies has a common preservation of thin beds of fine sand, as well as, muddy laminations. The muddier intervals are frequently bioturbated to a higher degree while the sand laminations/lenses are often characterized by wavy laminations and less commonly by wave ripples. Trace fossils present in this facies include dominant *Helminthopsis* and *Planolites*; secondary *Schaubcylindrichnus*; and rare *Chondrites*, *Teichichnus*, *Skolithos*, and *Zoophycos*. It is important to note that the *Skolithos* burrows only occur in firmground assemblages. The traces within this facies represent a dominance of grazing and deposit feeders with secondary suspension feeders delineating a distal *Cruziana* ichnofacies. The interpretation of facies E is then similar to facies B – proximal lower offshore – but facies E may also represent a slightly higher energy setting somewhat nearer to the upper offshore.

Pervasively bioturbated homogeneous silty sandstone characterizes facies F. This deposit contains very rare sandstone lamina with vfU to fL sand and 30-40% silt content. The ichnogenera present are dominant *Helminthopsis* and *Planolites*; secondary *Chondrites*; lesser *Palaeophycus*; and rare *Zoophycos*, *Schaubcylindrichnus* and possibly *Cylindrichnus*. *Diplocraterion* and *Skolithos* are also present within this facies, but are found in association with a *Glossifungites* surface. Accordingly, the ichnofacies that describes this trace fossil suite would be archetypal *Cruziana* as there is an abundance of deposit and grazing traces with a diverse assemblage. The dominance of sand sized particles with the trace fossil assemblage suggests a proximal upper offshore depositional environment.

Facies G is composed of finely laminated to mixed silty sandstone with 35-50% silt particles and moderate bioturbation. Wavy and planar laminations are common within the fU to mL sands and a moderate abundance of muddy laminations occurs as well. The suite of traces includes dominant *Planolites* and lesser *Helminthopsis*. The low abundance and diversity of traces in this facies does not allow for ichnofacies designation. However, the presence in the vertical sequence and size of sand particles suggests a higher energy setting than the underlying facies F, which represents a proximal upper offshore setting. Based on the vertical succession, facies G possibly represents an upper offshore to transition zone deposit.

Coarsening upward faintly laminated sandstone is denoted as facies H, which is characterized by an unbioturbated fU to vcU sandstone. Small pebble stringers and dispersed small pebbles (max 5mm) are also found within the deposit. Sedimentary structures include faint cross bedding to planar laminations. Facies H was deposited in a high-energy environment and possibly represents a shoreface deposit.

The sandstone of facies I is vfU to fL and is unbioturbated to abundantly bioturbated with some wave ripples preserved. Ichnogenera present in the bioturbated portion of this facies include dominant *Helminthopsis*, and lesser *Planolites*, *Palaeophycus*, and *Chondrites*. *Diplocraterion* at the top of the bioturbated unit may represent a palimpsest substrate associated with a deepening event. The unbioturbated portion of the facies overlies a bentonitic layer, and is succeeded by a deeper water facies. The bioturbated unit occurs at the top of a parasequence and is characterized by an archetypal *Cruziana* assemblage. Both sands of facies I possibly represent a transgressive or flooding sand deposit.

The final facies, facies J, in the typical Viking core consists of a conglomeratic deposit. This deposit contains rounded to subrounded pebbles, calcite cementation, fL sand to muddy matrix and a dominance of both clast and matrix. The pebbles are mostly dark chert and there is no evident bioturbation present. This facies is interpreted to represent a transgressive lag association with a major transgressive surface of erosion.

Description of the Vertical Succession

Based on the above facies interpretations, the parasequences can be interpreted in terms of a succession of depositional environments (Figure 4). The basal Regional Viking Parasequence 1 (RVP1) consists of two higher frequency coarsening upward units separated by thin sand. The basal unit is coarsening upward from shelf muds to distal offshore deposits, and then subsequently overlain by a thin sandstone related to a flooding event. This is followed by proximal offshore and then successive distal upper offshore deposits. The top of this parasequence is marked by a flooding surface with a *Glossifungites* ichnofacies characterized by sharp walled *Diplocraterion* and overlain by a transgressive sandstone. The top of this sandstone has an erosive nature and possibly represents a palimpsest substrate, as the *Diplocraterion* traces at the top of the sandstone appear to extend downwards from the erosive contact to the overlying parasequence.

The subsequent Regional Viking Parasequence 2 (RVP2) is also coarsening upward from shale through to sandstone. The interpreted depositional environments reflect a slow shallowing from the distal lower offshore to proximal lower offshore, distal upper offshore and then proximal upper offshore. The proximal upper offshore deposits are truncated by another *Glossifungites* assemblage with *Diplocraterion* and possible *Skolithos* burrows passively infilled with coarser sandstone and located within a thick siderite zone. The facies dislocation across this firmground is relatively insignificant; thus, this surface represents a minor amount of erosion and associated hiatus. The *Glossifungites* suite is followed by finely laminated to mixed silty sandstone possibly from the offshore to lower shoreface transition due to the coarse nature of sand sized particles. The top of RVP2 consists of faintly laminated sands with dispersed small pebbles possibly representing a shoreface deposit. RVP2 is then capped by a flooding surface, which is demarcated by a sharp contact to the overlying parasequence.

The final parasequence – Regional Viking Parasequence 3 – consists strictly of offshore deposits. The basal silty and shaley units reflect deposition in the distal upper offshore and distal lower offshore, respectively. This alternating strata is then overlain by proximal lower offshore to upper offshore deposits containing a *Glossifungites* assemblage demarcated by *Skolithos* traces. This firmground assemblage is located within a conformable succession; consequently, the surface represents a minor erosional event. The truncation of the RVP3 is characterized by a *Glossifungites* suite of *Skolithos* within a siderite interval and overlain by a transgressive lag, which defines the uppermost TSE in the Viking Formation. Overlying the transgressive lag is subsequent distal lower offshore and shelf deposits of the Westgate Formation.

Conclusions

In southeast central Alberta, a typical Viking core consists of Regional Viking Parasequences that are characterized by shallowing and coarsening upward units that were mainly deposited in the offshore. The parasequences have variable thickness, lithology and depositional environments. Overall, these parasequences show the progradational nature of the Viking deposits, which are truncated by a major transgression that formed the TSE at the top of the Viking. This uppermost transgressive surface of erosion is variable sedimentologically and ichnologically. Most often, the erosional surface is overlain by an inconsistent transgressive lag and often underlain by a sideritized interval. In some cases, the *Glossifungites* ichnofacies can also characterize the TSE. Other erosional surfaces, pebbly or sandy lags, siderite intervals and *Glossifungites* suites are present within the Viking; however, these surfaces do not represent the same stratigraphic significance as the regional TSE. A firmground or erosive surface emplaced within a conformable succession suggests only minor erosion and associated hiatus. Interpreting the significance of erosional surfaces requires the analysis of the sedimentology, ichnology and stratigraphy of the deposits.

Acknowledgements

The authors would like to thank Apache Canada Ltd. for providing financial support to this research project. We would also like to thank all of the members of the Ichnology Research Group (IRG) at the University of Alberta for their support, especially Scott Reid, Michelle Spila, Mike Hearn, Curtis Lettley, Sean Miller, Tom Saunders, Natalie Sirman, and Marilyn Zorn.

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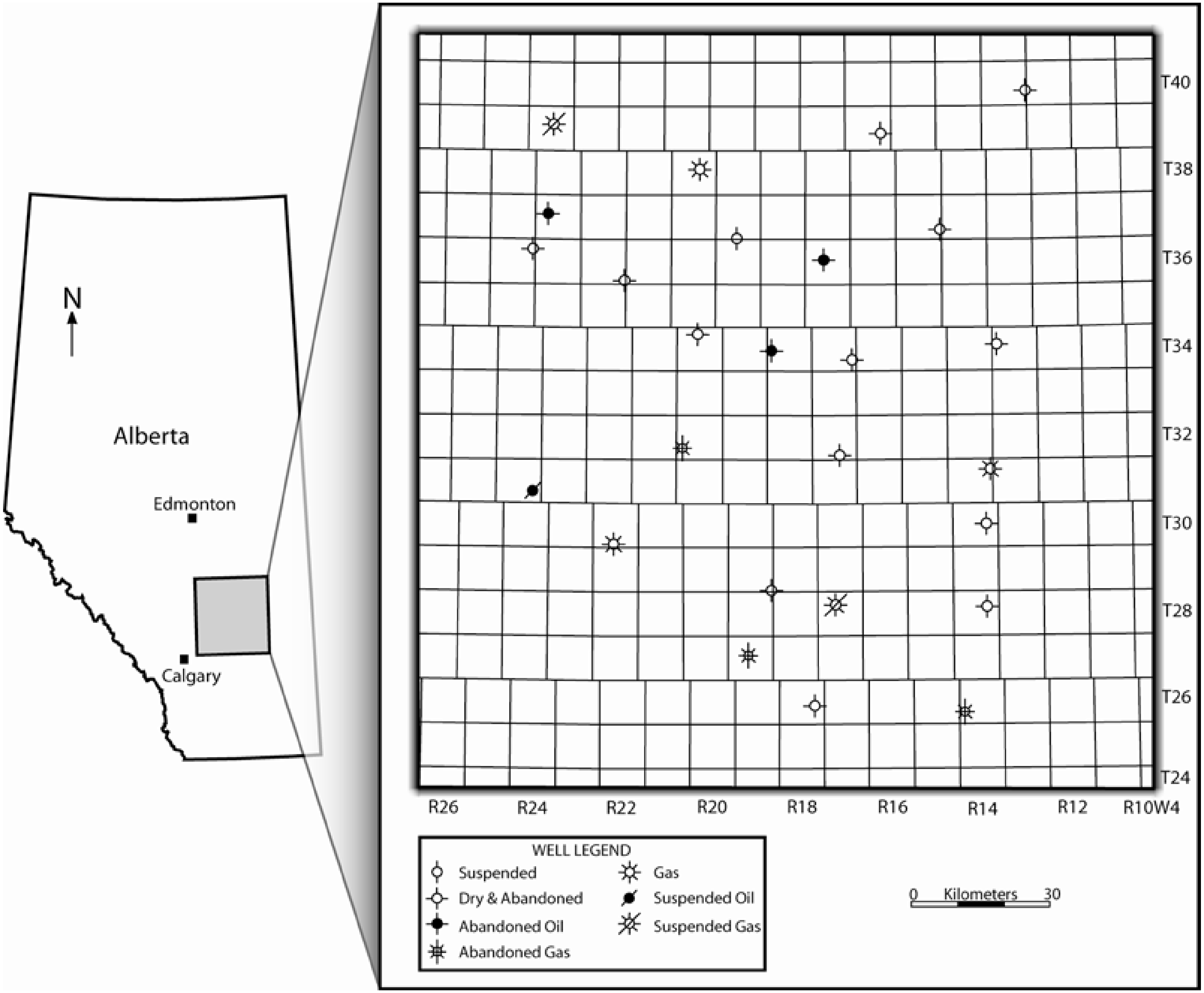

Figure 1. Location map of the study area. Well symbols indicate locations of examined Viking core.

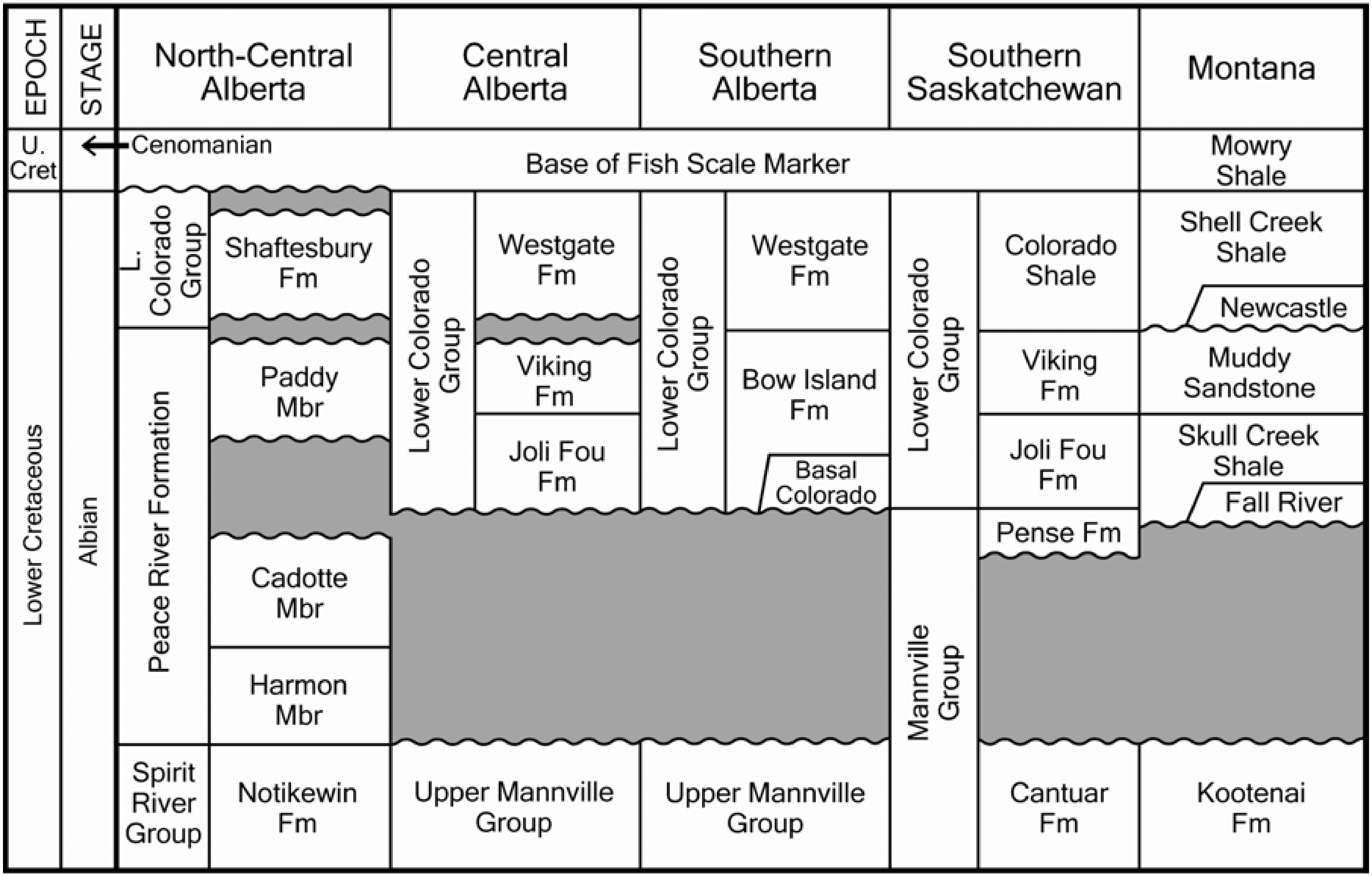

Figure 2. Stratigraphic correlation chart. Modified after MacEachern et al. (1999).

Figure 3. Expressions of the uppermost transgressive surface of erosion demarcating the top of the Viking Formation. (A) Two pebble horizons in the lag above the TSE in well 08-01-036-22W4. (B) *Skolithos* infilled with coarse sand lag highlighting the *Glossifungites* surface at the TSE in well 02-04-037-19W4. (C) Sideritized firmground overlain by a pebble rich deposit in well 16-11-031-24W4. (D) Apparent gradational contact from Viking deposits to Westgate Shales in well 02/07-22-038-20W4.

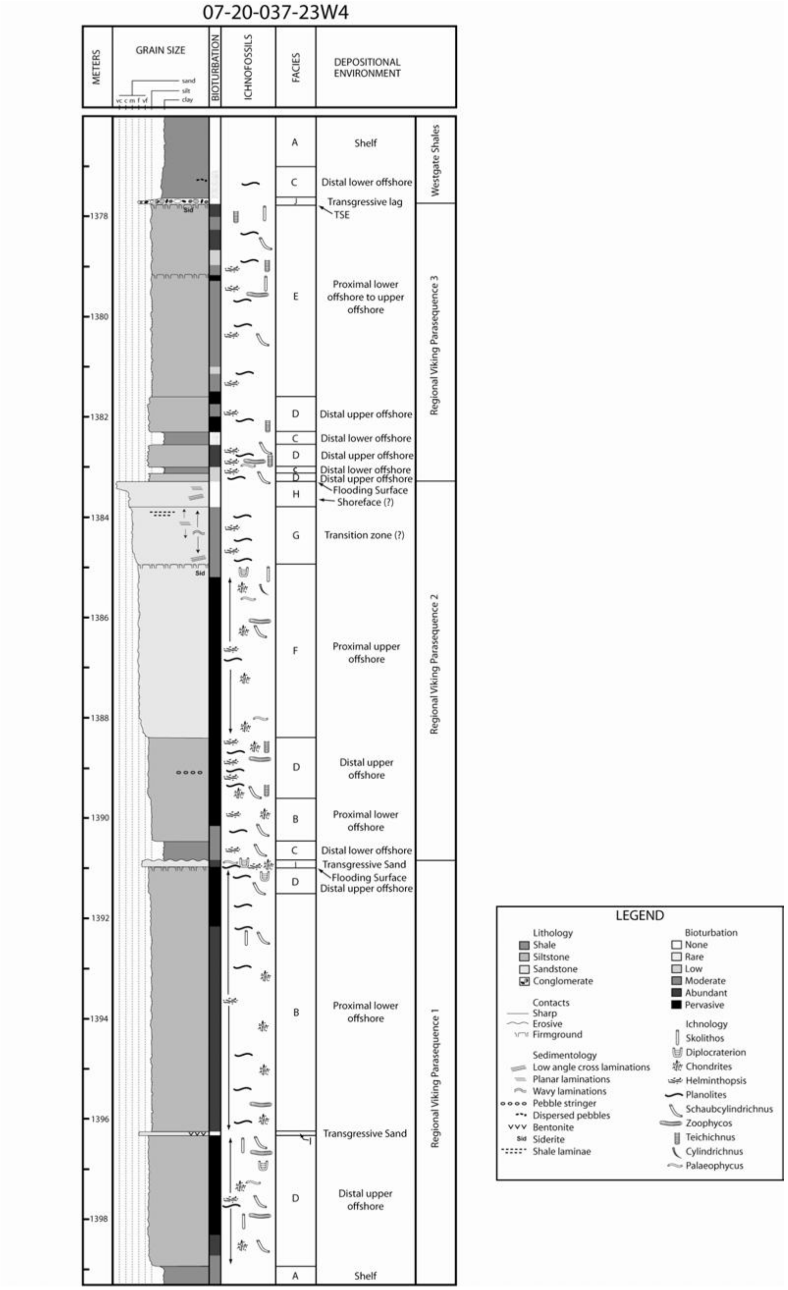

Figure 4. Litholog from well location 07-20-037-23W4.