



## Viking Lowstand Deposits in West Central Saskatchewan: Depositional Model for the Reservoir Units in Dodsland-Hoosier Area, Saskatchewan, Canada

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### Abstract

#### Introduction

The Late Albian Viking Formation is a rare example of an ancient marine deposit that can be traced and internally subdivided across a foreland basin, and as such provides a unique opportunity to contrast deposition under variable rates of subsidence, accommodation space and sediment supply. There have been numerous studies that have focussed on the allostratigraphic relationships and depositional history of the Viking Formation in Alberta, however, published studies of the Viking Formation in Saskatchewan are comparatively very few. The purpose of this study is to develop a regional allostratigraphic framework for Saskatchewan that is consistent with and complements the allostratigraphic framework developed for Alberta to evaluate the depositional history of the Viking deposits.

Most of the coarse Viking clastics in Alberta are long, narrow, northwest-southeast trending shore-parallel sandbodies, composed of a series of marine sandstone and conglomerate deposits, overlain and underlain by marine mudstone. In the Dodsland-Hoosier area (Fig. 1), a large Viking sandbody occurs as an east-west trending accumulation, approximately 75 km long and 9 km wide, and is composed of bioturbated muddy sandstone. These muddy sandstone deposits are interpreted to represent the eastward termination of the northeastward advance of coarse sandy material from the southwest. An allostratigraphic framework that illustrates the distribution and stratigraphic relationships of coarse clastics in the remote seaward part of the Viking Sea is necessary for successful exploration and exploitation of Viking reservoirs.

The study area is located between Twp 01-Rg 18 W3 in the southeast to Twp 40-Rg 29 W3 in the northwest (Fig. 2). The study area also includes the Hamilton Lake area in Alberta from Twp 29-Rg 01 W4 in the southeast to Twp 36-Range 11 W4 in the northwest. The Dodsland-Hoosier area is located in Twp 30-Rg 19 W3 in the southeast to Twp 32-Range 28 W3 in the northwest (Fig. 2). This study is based on the detailed measurement of 40 cores and 70 resistivity log signatures; 15 cores and 25 log signatures are from the Dodsland-Hoosier area.



### Viking allomembers and bounding discontinuities

The allostratigraphic framework (Fig. 3) of the Viking Alloformation in Saskatchewan consists of 5 allomembers (allomember A-E) bounded by four major transgressive erosional discontinuities (BD1-BD4).

#### Allomember A and BD1

Allomember A consists of a bioturbated silty mudstone that coarsens upward from mudstone to sandstone and is abruptly terminated by BD1. The mudstone in the lower part is difficult to differentiate from the underlying Joli Fou Shale. The overall thickness varies from 5.5 to 17 m with a general trend of increasing thickness toward the south. BD1 is a sharp contact that abruptly overlies the muddy sediments of Allomember A and is commonly marked by vertical to sub-vertical burrows of *Skolithos* and *Thalassinoids* up to 5-7 cm long that penetrate into the underlying unit.

The mudstone and trace fossil assemblage suggest that Allomember A was deposited in an offshore environment. The gradational coarsening-upward trend indicates gradual progradation of offshore facies in distal marine conditions. The sharp-based sandy beds are interpreted as storm deposits. After progradation of Allomember A, a relative sea level rise (BD1) resulted in increased wave scour, transgressive lag concentration, and subsequent retrogradation of finer sediments. BD1 is a transgressive surface of erosion (TSE).

#### Allomember B and BD2

Allomember B varies from 3.5 m to 13 m, with increasing thickness toward southern Saskatchewan and is composed of bioturbated muddy siltstone grading upward to sandy siltstone. The upper contact of Allomember B is marked by sharp BD2 contact that abruptly overlies the bioturbated sandy siltstone of Allomember B and is overlain by coarse glauconitic deposits of variable thickness of Allomember C. The BD2 erosional surface shows a steeper eastward facing slope with erosional relief of about 12 m in the Hamilton Lake-Sedalia area and 7 m in the Dodsland area.

Allomember B is interpreted to have deposited below fair weather wave base in an offshore setting, and gradually shallowing from distal offshore to transitional offshore to lower shoreface conditions. The overall coarsening-upward trend suggests progradation in an offshore environment where sediments were sourced from a prograding shoreline. The sharp and regional extent of the BD2 contact overlain by coarse conglomeratic deposits would indicate a major relative sea level rise resulting in increased wave scouring and erosion of the underlying unit. BD2 is a transgressive surface of erosion (TSE).

#### Allomember C and BD3

Allomember C varies in thickness from 1.2 m in the Dodsland area to about 23 m in southern Saskatchewan, and is composed of fining upward bioturbated silty mudstone in the lower part, and an upper coarsening upward glauconitic bioturbated silty sandstone that is abruptly terminated (BD3). The upper sandstone unit forms the main reservoir in the Dodsland area. BD3 is a prominent erosion surface that removes a significant part of Allomember C although locally BD3 is truncated by BD4 west of the Hamilton Lake area. Overall, BD3 has a steeper eastward facing slope with about 18 m erosional relief in the Hamilton-Sedalia area 9 m in the Dodsland area.



Allomember C is interpreted to have formed below fair weather wave base in a transitional offshore to lower shoreface environment. The overall coarsening-upward trend suggests progradation with sediments sourced from a prograding shoreline. Finally, the prograding transitional setting was subsequently flooded during BD3 transgression and offshore conditions returned to the Dodslan area. The regional extent and sharp nature of the BD3 surface overlain by a conglomerate deposit suggest that it is an erosion surface. The overlying fining-upward bioturbated muddy siltstone of allomember D indicates a rise in relative sea level, increased wave erosion, and subsequent retrogradation. All this evidence suggests that BD3 is of transgressive surface of erosion origin.

#### Allomember D AND BD4

Allomember D is a relatively coarse grained unit in Saskatchewan, up to 6.5 m thick in the Dodslan area, 17 m in southern Saskatchewan, and is terminated by a sharp contact (BD4). In the Dodslan area, a 1 cm thick deposit containing coarse quartz sandstone and chert granules marks the base of Allomember D.

BD4 is a regionally extensive erosion surface that truncates the underlying facies sandy siltstone, muddy sandstone and sharp-based sandstone beds of Allomember D. Vertical, fL sand filled burrows of *Skolithos* and *Thalassinoides* are found at the BD4 surface and penetrate downward into the underlying Allomember D. Up to 7 m erosional relief is present on the BD4 surface in the Dodslan area suggesting erosional removal of underlying allomember D during BD4 erosion.

Allomember D represents a progradational depositional system. The coarsening upward unit represents shoreface deposits, reflecting progradation below fair weather wave base. In southern Saskatchewan a sharp-based sandstone deposit in the very upper part of Allomember D reflects an increase in energy and is interpreted to have formed in the middle to lower shoreface environment. Forced regression resulted in rapid progradation of the shoreface which led to abrupt emplacement of shoreface sandstone directly on offshore mudstone deposits. The regional extent and sharp nature of the BD4 surface overlain by a variable coarse deposit suggest that it is an erosion surface. A period of regional erosion exposed a firmground that was modified by organisms and subsequent ravinement, suggesting that BD4 is of transgressive surface of erosion origin.

#### Allomember E

Allomember E is the topmost unit of the Viking Alloformation, composed of dark grey to black silty mudstone up to 20 m thick. The upper contact is gradational with the overlying Westgate Alloformation. The base of Allomember E in the Dodslan area is marked by a 10 cm thick deposit of fine sandstone with scattered chert granules or about a 40 cm thick sandy mudstone with dispersed mudstone clasts and chert pebbles (up to 3 cm in diameter). Allomember E is interpreted to have been deposited in a low-energy, quiet offshore environment. The sharp-based thin silty beds represent sporadic storm events. Allomember E was gradationally overlain by the Westgate Alloformation.

#### Depositional history: model for dodslan-hoosier area

The Viking Alloformation represents an overall transgressive depositional sequence, punctuated by relative sea level fluctuations. The existence of four transgressive surfaces of erosion (TSE) indicates that at least four major fluctuations of relative sea level occurred during Viking time.



Deposition of each allomember (except allomember A) begins above a TSE that is overlain by coarsening-upward progradational sequences.

The bounding discontinuities enclose the allomembers. Erosional shoreface retreat of BD surfaces has been documented by illustrating erosional relief on the surfaces, presence of lag deposits above the contact, disappearance of underlying facies and log markers, and overlying fining-upward and coarsening-upward marine facies. The morphology of the erosion surfaces generally shows a steeper eastward facing dip that flattens out basinward (eastward).

In the Dodsland-Hoosier area, the Viking Alloformation consists almost exclusively of marine sediments dominated by bioturbated muddy sandstone to mudstone deposits of transitional to open marine environment. In general, allomembers become thinner and muddier eastward, suggesting a sediment source to the west. Further eastward, muddy sandstone deposits grade to mudstone deposits about 120 km northeast of Dodsland. Several transgressive-regressive units within the Viking are bounded by regionally extensive transgressive erosional surfaces (TSE), suggesting repeated fluctuations of relative sea level. BD surfaces are overlain by relatively deeper marine muddy deposits (TST) of retrogradational origin which are subsequently overlain by coarsening-upward deposits (HST) of progradational origin.

Reservoir units in the upper part of allomember C and D display an overall coarsening-upward trend that locally thickens eastward. This may be caused by an increased sedimentation rate during BD2 and BD3 regressive events, proximity to the shoreline, local dispersal of sediments, or simply the result of a distant prograding shoreface. The coarser sediments could also be transported from the nearby lowstand shoreface in the Sedalia area to about 60 km away in the deeper offshore setting of the Dodsland area to form the long and narrow shoreface-oblique sandbody. However, there should be an appropriate mechanism that would explain and support the notion.

This study proposes that the reservoir sandbodies above BD2 and BD3 were formed in ebb-tidal delta setting when sandy materials were transported to offshore Dodsland area by tidal inlet systems similar to modern sand ridges along the U.S. Atlantic coast and offshore Netherlands. Any record of sedimentary structures of the tidal system would have been destroyed by later shelf dynamics, transgressive events, and intense bioturbation. This model would explain the formation of “shoreface-oblique sand ridge” in a dominantly transitional-offshore (below fair weather wave base) setting.

Ebb-tidal delta system consists of multiple lobes of sand accumulations at the seaward side of the tidal inlets. Sands are usually sourced from the nearby barrier island systems by wave action and tidal currents through the tidal inlets. The model is essentially built on two fundamental elements: a supply of sandy materials from a barrier island in the form of a trailing ebb-tidal delta lobe, and a narrow sandbody (channel-like of ephemeral tidal inlet system) separating the offshore body from the shoreface.

The main reservoir deposits in the Dodsland area formed in progradational ebb-tidal delta setting fed by estuarine tidal channels in the Sedalia area. Progradation occurred during periods of stillstands of the transgressive events. Sandbodies were deposited by turbid ebb-tidal currents in distal ebb-tidal setting as lowstand lobes. Sands in tidal inlets were carried by ebb-tidal currents



and transported to deeper water offshore region of the Doddsland area by strong turbulent currents. The suspended sediments formed aggrading small-scale ripples in distal ebb-tidal delta setting below effective wave base. The overall size of the Doddsland deposit is relatively large (75 km long, 9 km wide) than most of the documented examples. It is likely that several tidal inlets initiated the development of multiple delta lobes, and were later modified and amalgamated to form the present geometry.

The essential ingredients of this model postulate a shoreface (perhaps barrier island-attached) west of Doddsland that sourced sediments for the ebb-tidal delta, and a tidal-inlet that cut through the shoreface and transported sediments to the ebb-tidal delta region (Fig. 4). Doddsland area became a concentrated sink of deposition when sands were transported offshore from the nearby Sedalia lowstand shoreface through the inlet system (in the area of 11-36-029-01W4) forming the Doddsland sandbody as an extension of the Sedalia shoreface in an offshore setting; thus the ebb-tidal delta deposited on a gentle eastward dipping substrate. Therefore, both ebb-tidal delta complex and tidal inlet system formed the nucleus for the Doddsland sandbody development. Subsequently, short-term shelf hydrodynamics and long-term eustatic processes had acted upon to fabricate the present morphology and internal stratigraphy of the Doddsland-Hossier sandbody.

### Conclusions

This study documents the easternmost extent of the NW-SE trending Viking lowstand shoreface deposit preserved in the Sedalia Oil Field in Alberta. The lowstand condition is represented by incised valley and incised shoreface deposits and interpreted to have formed during two separate relative sea level falls during pauses in transgressions (BD2 and BD3 transgressions). This shoreface extends into southern Saskatchewan where much thicker Viking deposits are preserved.

The allomembers are retrogradational sequences overlain by coarsening upward progradational units that formed during periods of stillstands of the transgressions. Major discontinuities are also recognizable in deeper water offshore Doddsland-Hoosier Area. Lateral progradation of the shoreface deposits and simultaneous vertical aggradation of adjacent offshore deposits were periodically interrupted by relative fluctuations of sea level that generated erosion surfaces extending from the Sedalia lowstand shoreline for about 60 km basinward (eastward) to the offshore Doddsland area.

Unlike most of the Viking deposits in Alberta and Saskatchewan that are NW-SE trending shore-parallel sandbodies, Doddsland is an E-W trending shore-oblique, relatively deeper water, highly bioturbated deposit. Allomember C and D contain the main reservoir units in the area. The Doddsland Viking sandbody is interpreted as the offshore deposits of the Sedalia shoreface. Subsequently, short-term shelf hydrodynamics and long-term eustatic processes modified the sandbody to its present morphology and internal stratigraphy.

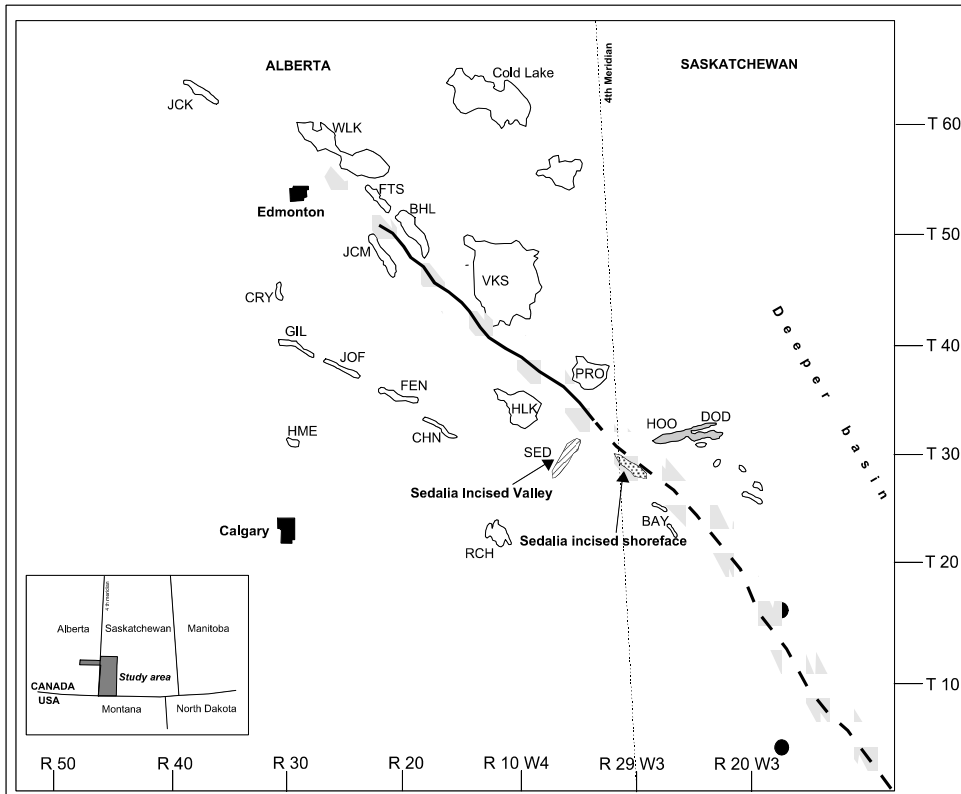
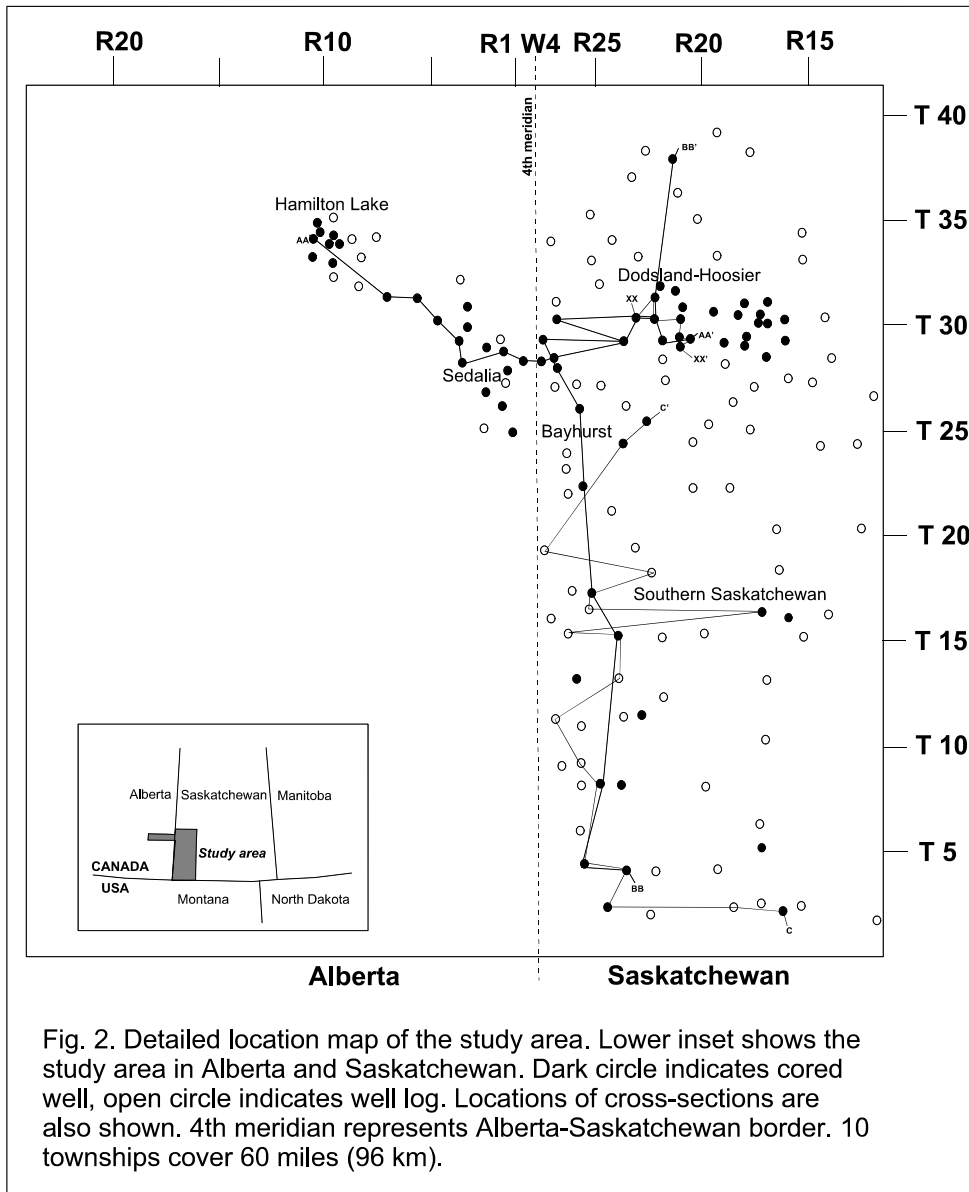


Fig. 1. Paleogeographic synthesis of the depositional events and associated features. Major Viking oil and gas fields in Alberta and Saskatchewan are also shown. Note the location of the Dodsland area in regional context. The dark line represents the postulated easternmost lowstand shoreline, the dashed part is based on this study and the solid part is based on data from Joarcam area (Walker and Wiseman, 1995) and Hamilton Lake area (Burton and Walker, 1999). The two significant erosional features the Sedalia Incised Valley and Sedalia Incised Shoreface are presented. 4th meridian represents Alberta-Saskatchewan border. 10 townships cover 60 miles (96 km). The fields identified are ANT-Antelope; BAY-Bayhurst; BHL-Beaverhill Lake; CHN-Chain; CRY-Cystal; DOD-Dodsland; FEN-Fenn; FTS-Fort Saskatchewan; GIL-Gilby; HOO-Hoosier; HLK-Hamilton Lake; HME-Harmattan East; HUD-Hudson; JCM-Joarcam; JCK-Judy Creek; JOF-Joffre; KRK-Kirkwall; PRO-Provost; RCH-Richdale; SED-Sedalia; SLK-Sullivan Lake; VKS-Viking-Kinsella; WLK-Wilcox.



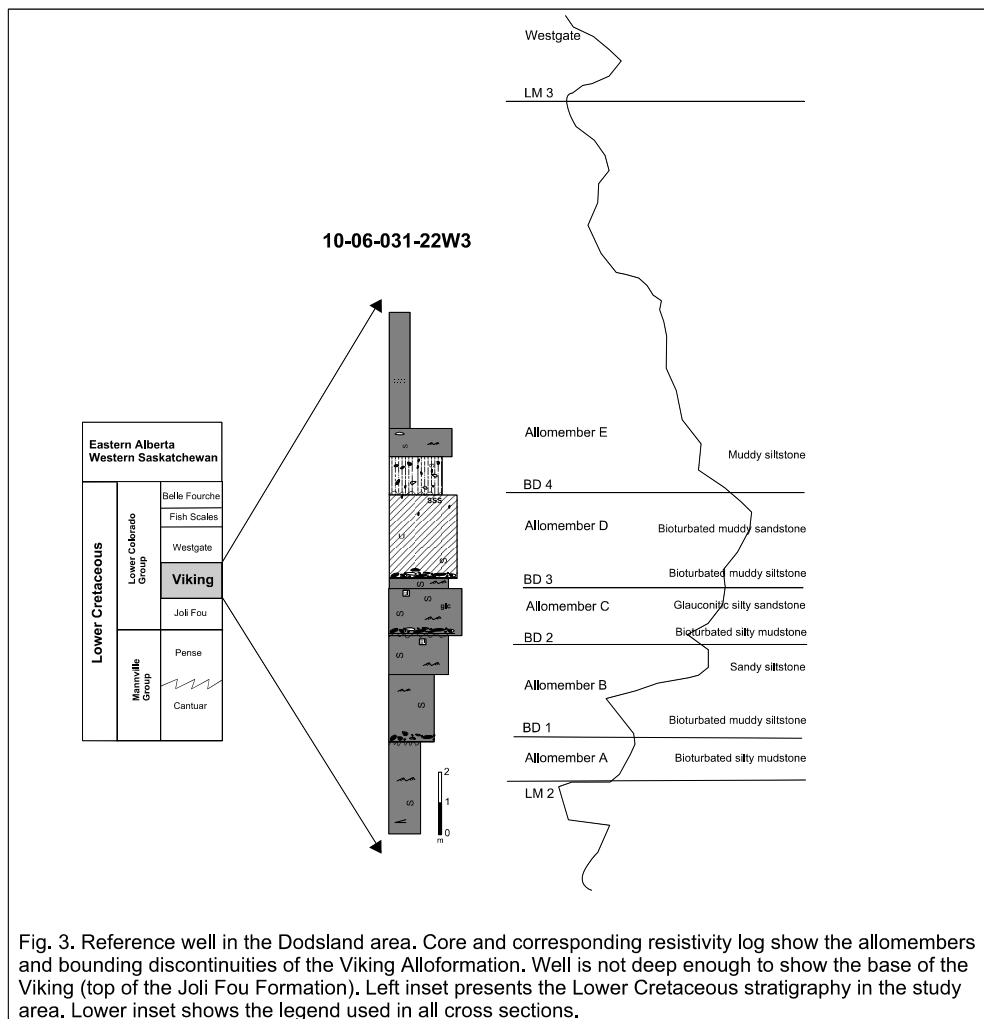


Fig. 3. Reference well in the Dodsland area. Core and corresponding resistivity log show the allomembers and bounding discontinuities of the Viking Alloformation. Well is not deep enough to show the base of the Viking (top of the Joli Fou Formation). Left inset presents the Lower Cretaceous stratigraphy in the study area. Lower inset shows the legend used in all cross sections.



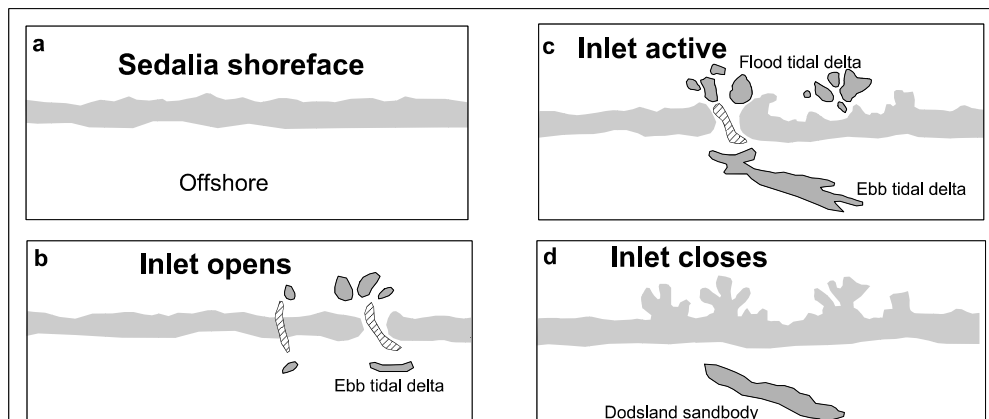


Fig. 4. Schematic depositional model for the Dodsland area. **a)** Sedalia shoreface was the main source for the Dodsland sandbody. **b)** Tidal-inlet originates and begins to carry sediments offshore to form ebb-tidal delta lobes. **c)** Landward and seaward tidal-inlet migration result in flood and ebb-tidal delta lobes in response to relative sea level rise and fall. The resultant vector direction of tidal-inlet migration ultimately produce the obliquely trending ebb-tidal delta sandbody. **d)** Inlet closes, and sand transport and deposition are eliminated. Ebb-tidal delta is subject to reworking by marine processes of waves, currents, and organic activity resulting to shoreface-oblique Dodsland sandbody. Modified from McBride and