Stratigraphy and Petrography of Viking Sandstones in the Bayhurst Area, Southwestern Saskatchewan

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Abstract

The Albian Viking Formation is an eastward prograding, wave-dominated clastic wedge underlain and overlain by marine shales. Oil and gas pools in the Viking Formation consist of stratigraphic and structural traps within linear sandstone bodies, generally oriented northwest-southeast, mimicking the paleoshoreline as it moved landward and seaward with changes in relative sea level. This study focuses on geological characteristics of two Bayhurst gas pools – Kindersley/Kerrobert Bayhurst West Viking and Kindersley/Kerrobert Bayhurst Viking – located in Townships 23 to 26 and Ranges 24W3 to 28W3 and covering an area of about 225 km^2 (87 square miles).

Core and well-log cross sections, together with sedimentary facies maps, illustrate the stratigraphic and reservoir architecture of the Bayhurst gas pools, which are characterized by reservoir units that are separated from each other by flooding surfaces, sequence boundaries, and ravinement surfaces. The reservoirs include sandstones of an incised-valley fill and an older retrograding barrier-island system that unconformably overlies shoreface and shelf deposits. The reservoirs are capped by transgressive marine shales of the Westgate Formation. Preliminary petrographic studies indicate that Viking sandstones are calcareous sublitharenites, and litharenites to lithic wackes. Porosity values range from 1 to 24% based on point counting with the highest porosities found in valley-fill and barrier-washover facies. Porosity is mostly primary although minor dissolution features exist. Cementation (quartz overgrowth and carbonates) is minor throughout, except at the Viking Formation top where massive calcite cement completely occludes porosity. Fluid inclusions in calcite cements are all monophase (liquid-only), indicating early cementation at relatively low temperatures.

Keywords: *Viking Formation, Lower Cretaceous, siliciclastics, Williston Basin, barrier island, lagoon, incised valley, shoreface sandstones.*

1. Introduction

The Viking Formation is a sandstone-dominated unit enclosed within marine shales of the Lower Colorado Group in the Western Canadian Sedimentary Basin. It was first discovered to be a gas-producing sandstone in 1917 by S.E. Slipper (Jones, 1961). Since then, the Viking and equivalent sandstones have proven to be prolific oil- and gas-bearing units and are still a target of exploratory drilling. Oil production from the Viking is concentrated in southern and central Alberta and southwestern Saskatchewan, and occurs in porous northwest-southeast–trending sandstone bodies. Gas production from the Viking is widespread in southern, central, and western Alberta; northeastern B.C; and western Saskatchewan. There are 75 Viking gas fields with initial established marketable gas reserves of over 1000 x 10^6m^3 (35 Bcf). Of these pools, 69 are in Alberta, four in Saskatchewan (including the Bayhurst Gas Field, Figure 1), and two in British Columbia (Bachu and Burwash, 1994). The Bayhurst Gas Field is made up of two pools, Kindersley/Kerrobert Bayhurst West Viking and Kindersley/Kerrobert Bayhurst Viking. These pools have a combined cumulative production of 332 x 10^6 m^3 (11.63 Bcf) from six wells. Further exploration in the Bayhurst and surrounding areas requires a better understanding of the reservoir architecture and controlling factors.

Much research has been conducted on the Viking Formation, especially in Alberta. In Saskatchewan, studies focusing on the Viking Formation include Jones (1961), MacEachern (1994), Reynolds (1994), and MacEachern *et al.* (1999), and theses by Pozzobon (1987) and Webber (1997). This paper concentrates on the stratigraphy and petrography of the Viking sandstones in the Bayhurst Gas Field in southwestern Saskatchewan, which encompasses Townships 23 to 26 and Ranges 24W3 to 28W3, an area of about 225 km^2 (87 square miles) located northwest of the large Shackleton Gas Field in the Milk River Formation (Figure 1). The purpose of the study is to unravel the stratigraphic and petrographic characteristics of the reservoirs in the Bayhurst pools and relate these to the regional architecture of the Viking Formation in the area.

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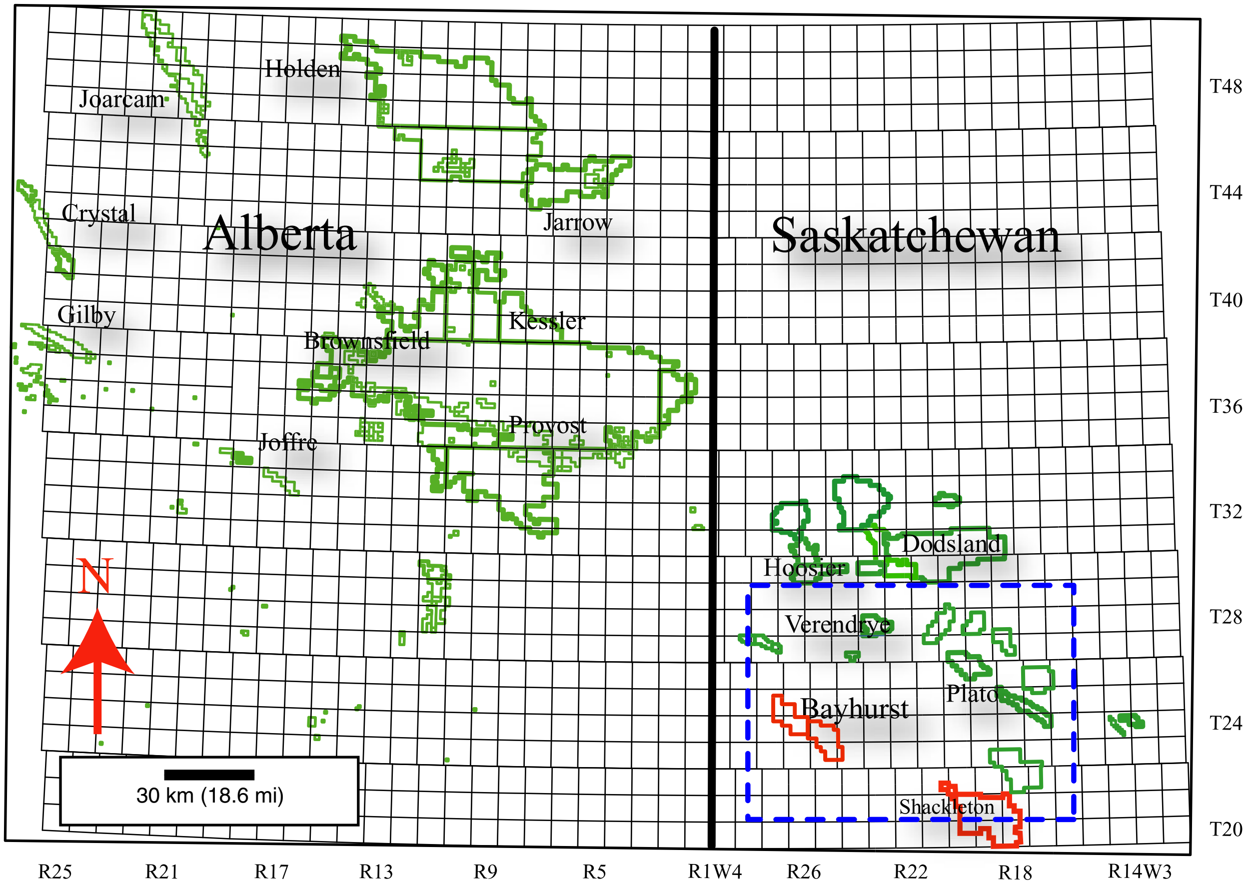

Figure 1 - Regional map showing the location of the Bayhurst Gas Field in southwestern Saskatchewan.

2. Geological Background

The Albian Viking Formation is part of the Lower Colorado Group of the Lower Cretaceous. The Viking and equivalent strata are found throughout most of the Western Canadian Sedimentary Basin (Leckie *et al.*, 1994) forming a coarse clastic wedge that prograded from the Cordilleran orogenic belt eastward into the foreland basin (Reinson *et al.*, 1994). The Viking Formation is mainly made up of coarsening-/sanding-upward successions of predominantly marine sandstones, siltstones and shales, chert-pebble lags, and bentonite marker beds. The eastward pinch-out of individual overall coarsening-/sanding-upward successions suggests an eastward prograding shoreline (Pozzobon and Walker, 1990). The Viking sandstone bodies in the Bayhurst area appear to be the southeastern extension of the Viking shoreline in Alberta (Figure 2). In Saskatchewan, the Viking Formation ranges from 15 to 35 m in thickness, increasing to more than 65 m thick in southwestern Alberta. Within the study area, the thickness of the Viking ranges from 22 to 30 m. It thickens to the southwest and gradually thins to the northeast, fining laterally to silty shale (Figure 3).

The Viking Formation is underlain by the Joli Fou Formation, Upper Albian in age, and overlain by marine shale of the Westgate Formation (Figure 4).

The Joli Fou is a dark grey, noncalcareous marine shale, approximately 20 m thick, with a small proportion of interbedded fine- to medium-grained sandstone. Minor amounts of nodular phosphorite, bentonite, pelecypod coquinas, and concretions of siderite, calcite and pyrite also occur (Leckie *et al.*, 1994). The Joli Fou Formation is very widespread. In western regions of Alberta and central regions of Alberta and Saskatchewan, it disconformably overlies the Mannville Group where the Basal Colorado/Spinney Hill are absent, and underlies the Viking Formation, disconformably in places.

Correlative units of the Viking Formation include the Bow Island Formation in southwestern Alberta (Figure 4), the Newcastle Sandstone in Manitoba, the Pelican Formation in northeastern Alberta, and the Paddy Member (Peace River Formation) in the northwestern Alberta and northeastern British Columbia subsurface. Viking and equivalent units extend over practically the entire Western Canada Sedimentary Basin (Leckie *et al.*, 1994).

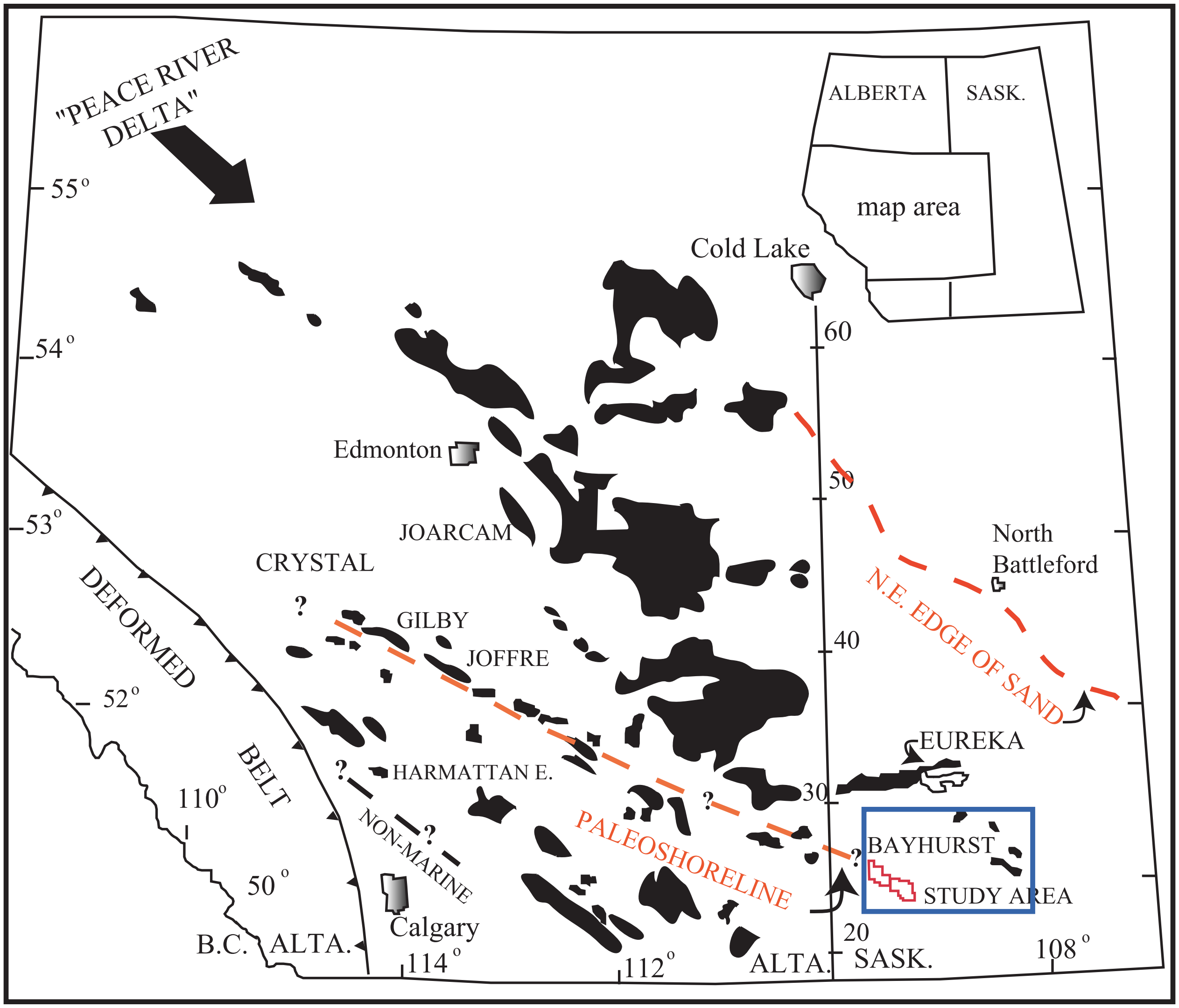

Figure 2 - Location map of the Viking fields in western Canada, showing the extension of shorelines into southwestern Saskatchewan (modified from Pozzobon and Walker, 1990).

The Upper Albian Westgate Member (McNeil and Caldwell, 1981) comprises shale above the Viking Formation and below the Fish Scales Formation, which is a regionally distinct marker bed readily recognizable on geophysical logs.

3. Facies Description

Based on careful examination of core from 23 wells scattered throughout the Bayhurst area, seven sedimentary facies have been recognized. Thirteen cores were considered to be good quality, the other nine cores to be poor quality (Figure 5). The term “facies” is used to summarize the descriptive aspects of the rocks, including the lithology, and physical and biological sedimentary structures.

a) Facies A: Bioturbated Sandstones and Mudstones

Facies A consists of very fine- to fine-grained sandstone with interbedded mudstones. The mudstone beds are abundant throughout; some are continuous across the width of the core whereas others are discontinuous due to bioturbation. The ratio of sand to mud ranges from 70:30 to 90:10. The mudstones are moderately to intensely bioturbated. Distinct trace fossils include *Zoophycus* (Z), *Teichichnus* (T), *Terebellina*, and *Planolites* (P) (Figures 6A, B, and C). The orientation of most of the trace fossils is horizontal; a few are vertical. Evidence of hummocky cross-stratification (HCS) or trough cross-bedding is rare, but present, and low-angle planar lamination

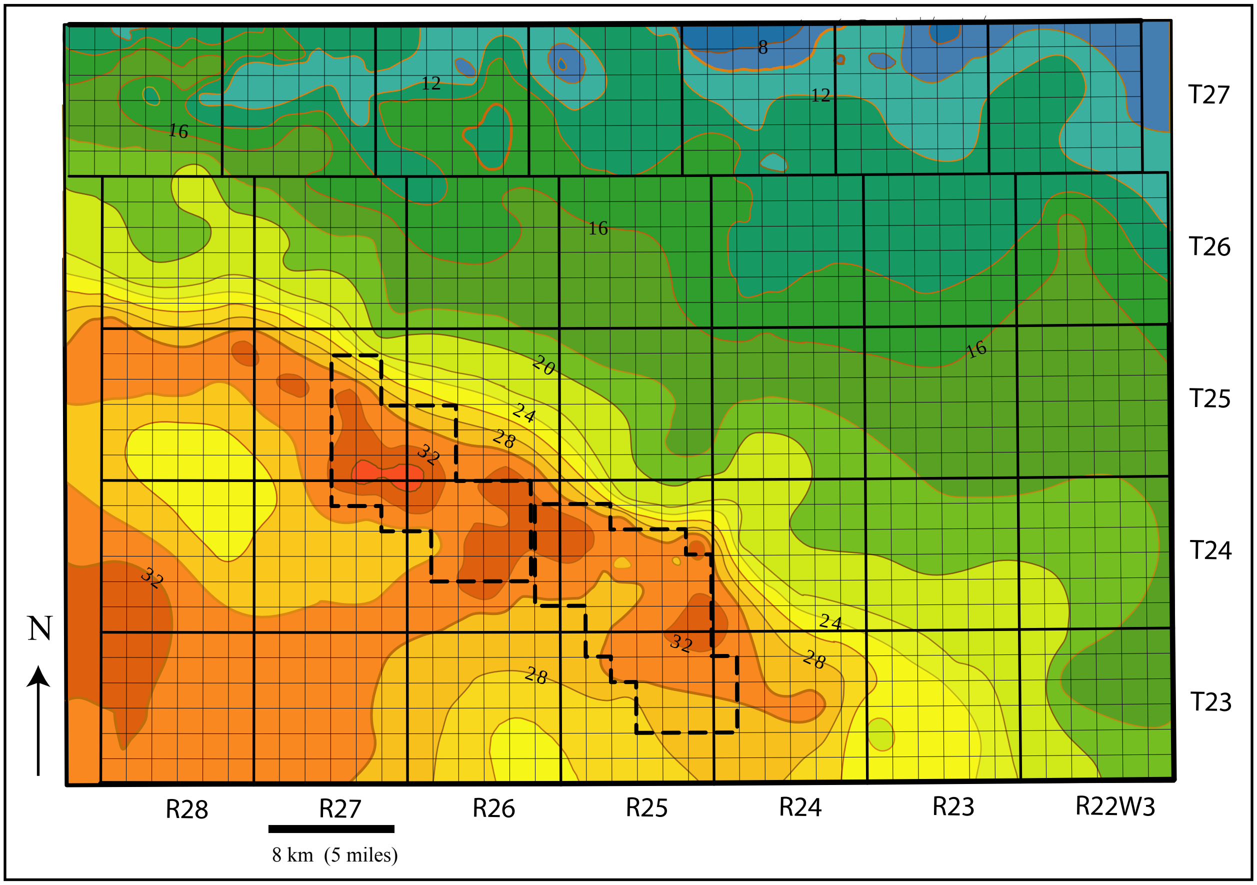

Figure 3 - Isopach map of the Viking Formation in the Bayhurst area.

also occurs. The facies is characterized by a sanding-upward trend. Pyrite concretions range in diameter from 1 to 2 cm.

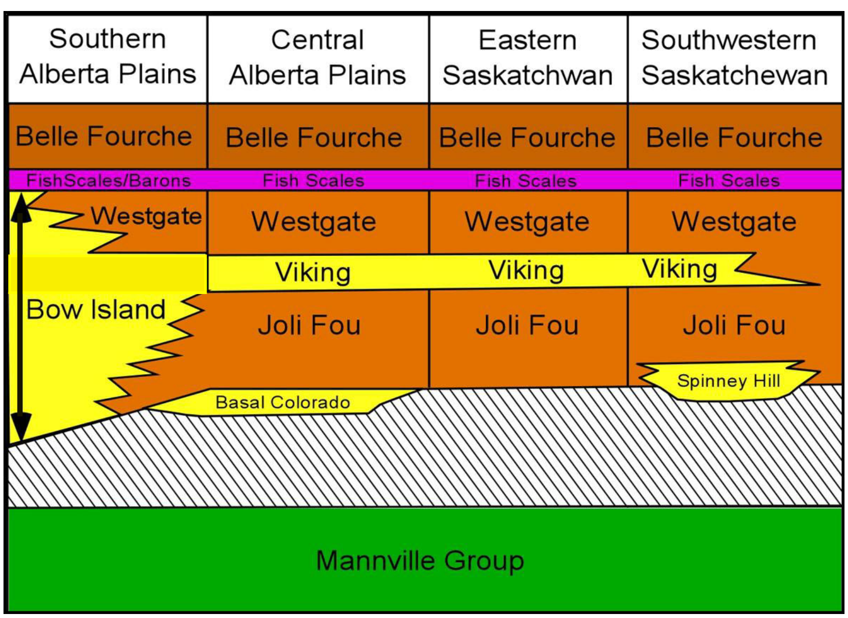

Figure 4 - Stratigraphic correlation chart of the Viking Formation and equivalent Bow Island Formation.

The muddy sandstones of Facies A are interpreted to have been deposited in lower shoreface to transition-zone settings under fluctuating moderate- to low-energy conditions. This interpretation is based on the presence of dominant *Cruziana* ichnofacies (MacEachern, 1994) and of storm deposits, represented by HCS, that are interbedded with bioturbated mudstones (Walker and James, 1992). The *Cruziana* ichnofacies is most characteristic of subtidal, poorly sorted and unconsolidated substrates. Conditions typically ranged from moderate-energy levels in shallow waters below fair-weather wave base but above storm wave base, to low-energy levels in deeper, quieter waters. Sediment deposition rates ranged from negligible to appreciable, but were not normally rapid (Pemberton, 1992a).

b) Facies B: Sandstone with Organic-rich Laminations

Facies B consists of fine- to medium-grained sandstone interbedded with rare mudstone layers .The sandstone is well to very well sorted with little bioturbation. Recognizable trace fossils include *Ophiomorpha* burrows approximately 1 to 3 cm in diameter (Figure 6D). Coal and plant fragments a few millimeters to centimetres across are abundant, occurring preferentially in laminations. Chert clasts are rare and are up to 5 mm in diameter. Trough cross-bedding or swaley cross-stratification (SCS) is common (Figure 6E). Facies A and B make up the basal three coarsening-upward parasequences of the basal portion of the Viking Formation.

Facies B is interpreted to have been deposited in a high-energy, sandy shoreface environment, based on the presence of trough cross-bedding or SCS (Walker and James, 1992) and of the *Skolithos* ichnofacies indicated by *Ophiomorpha* burrows (MacEachern, 1994). The *Skolithos* ichnofacies is indicative of relatively high levels of wave or current energy, and is typically developed in slightly muddy to clean, well sorted, loose or shifting particulate substrates. Increasing energy levels enhance physical reworking, thus tending to obliterate biogenic structures and preserve physical sedimentary structures. Such conditions commonly occur in the sandy shoreface of beaches, bars, and spits (Pemberton *et al.*, 1992a).

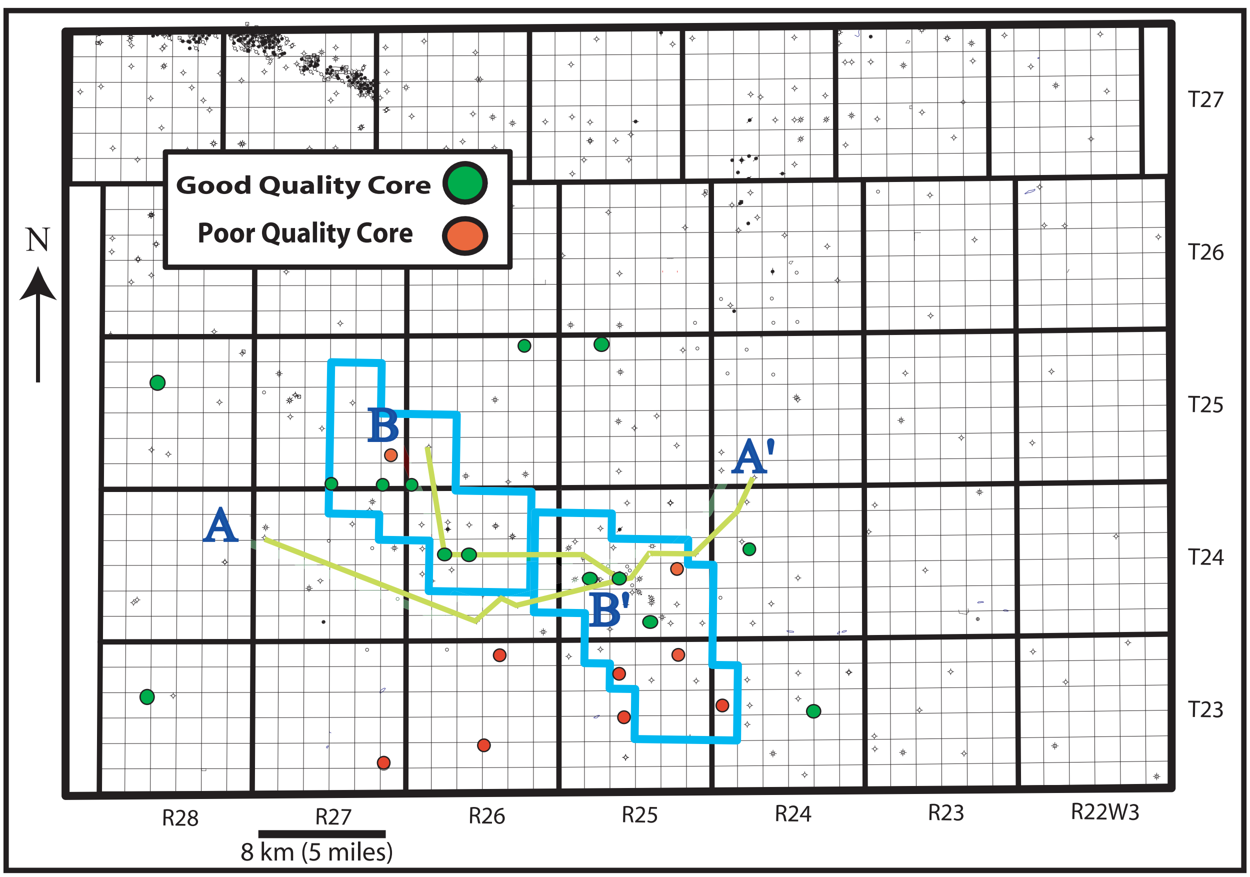

Figure 5 - Map showing locations of a) the 23 cores logged, of which 14 (green) were considered to be of good quality (green) and nine (red) of poor quality; and b) cross-sections A-A' and B-B'.

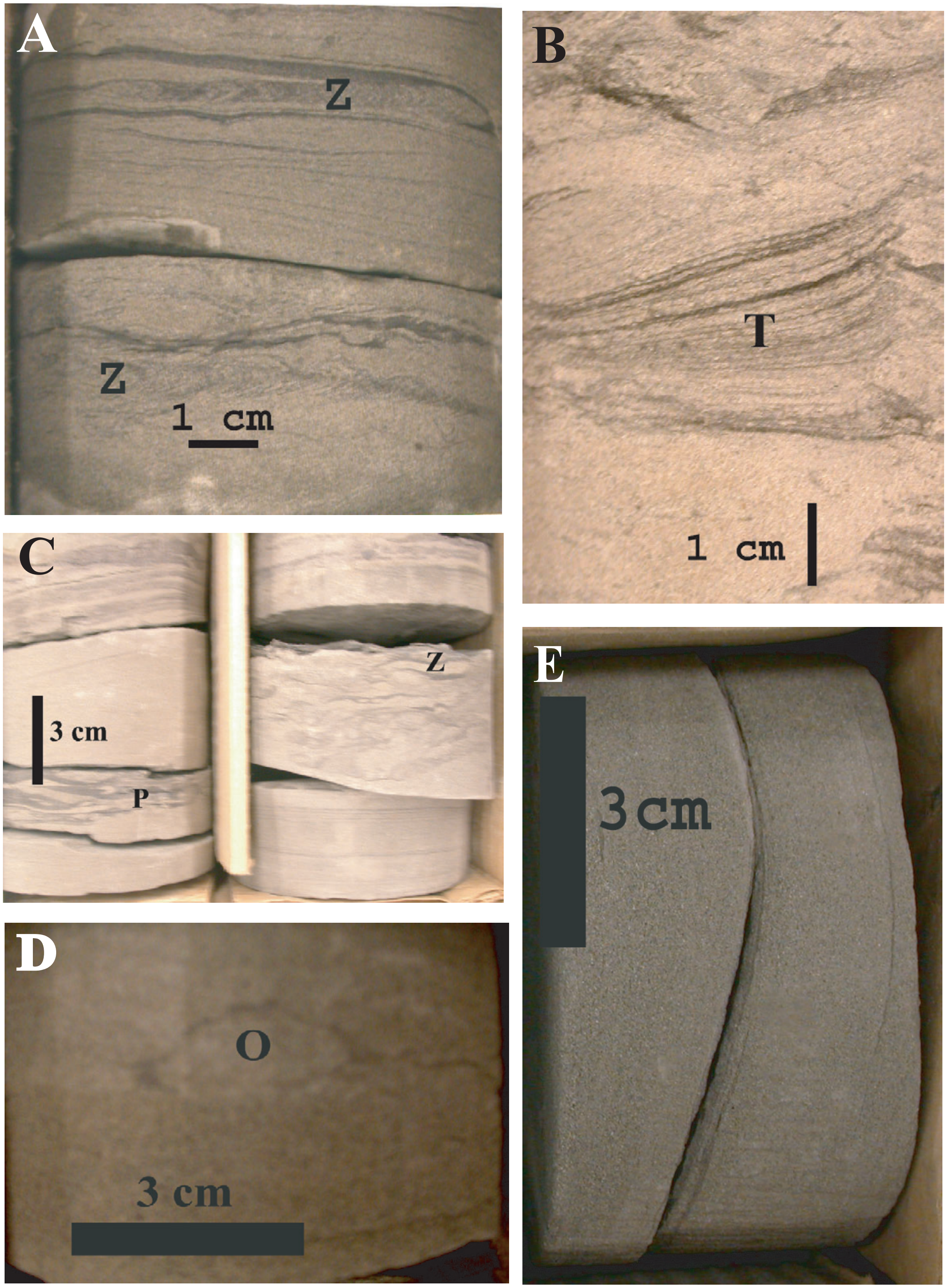

Figure 6 - A) **Zoophycos** *(Z) burrows of Facies A (7-21-24-26W3, 695.25 m [2281 ft]). B)* **Teichichnus** *(T) burrows of Facies A (7-22-24-26W3, 697.08 m [2287 ft]). C)* **Planolites** *(P) and* **Zoophycos** *(Z) horizontal burrows of Facies A (4-6-25-26W3, 721.77 m [2368 ft]). D)* **Ophiomorpha** *(O) burrow in medium-grained sandstone of Facies B (4-6-25-26W3, 712.93 m [2339 ft]). E) Evidence of trough cross-bedding or swaley cross-stratification within Facies B (4-6-25-26W3, 717.19 m [2353 ft]).*

c) Facies C: Sandstone with Organic-rich Mudstones

Facies C consists of very fine-grained sandstone interbedded with organic-rich, dark brown to black mudstones (Figure 7A). Bioturbation, dominated by *Planolites* and *Thalassinoides* burrows, is moderate to intense within the mud layers. Sandstones of Facies C are poorly sorted, containing abundant chert pebbles and coal fragments up to 3 cm across. Sandstone-filled syneresis cracks radiating from a central point as discontinuous, sinuous and spindle structures (Plummer and Gostin, 1981) occur within the organic-rich mudstones (Figure 7B). In cross-sectional view, they are V- or U-shaped (Plummer and Gostin, 1981; Figure7B). The lower contact of Facies C is sharp whereas the upper contact is gradational into Facies D.

Sandstones with organic-rich mudstones of Facies C are interpreted to have been deposited in a restricted, brackish-water, lagoonal environment behind a barrier. The syneresis cracks indicate fluctuating salinities. De-watering of swelling clays occurs with fluctuations in salinity in a restricted environment and causes the clay lattices to shrink and contract, resulting in the cracking of the mud (Plummer and Gostin, 1981). The cracks are infilled with sand when higher energy sediments are deposited in the lagoon. Brackish-water lagoonal facies are characterized by *Planolites* and *Thalassinoides* trace-fossil assemblages. Lagoonal environments support brackish-water trace-fossil assemblages which reflect the stressed ecosystem (Pemberton *et al*., 1992b).

d) Facies D: Massive Sandstone with Coal and Plant Material and Shell Fragments

Facies D consists of fine- to medium-grained, clean sandstone with few mudstone interbeds. Bioturbation is rare with scarce *Ophiomorpha* burrows present. The sandstone has a high content of coal and plant debris (Figure 7C). Shell fragments are also present, ranging from 1to 5 mm across. The sandstone is poorly sorted, containing disseminated chert clasts up to 5 mm in diameter (conglomerate in grain size). It has a sand to mud to coal- and plant-debris ratio of 90:8:2. Calcite concretions occur preferentially around burrows. Facies D lacks depositional sedimentary structures, having no visible bedforms. The lower contact is gradational from Facies C, and the upper contact is preferentially cemented with calcite just below the contact with the Viking chert-pebble lag.

This massive sandstone with coal and plant material and shell fragments (Facies D) is interpreted to be a barrier-washover deposit that was formed during a relative sea-level rise. Parts of the barrier were eroded on the seaward side of the lagoon and redeposited over the lagoonal deposits. *Ophiomorpha* burrows of the *Skolithos* ichnofacies are indicative of a sandy shoreface environment (MacEachern, 1994).

e) Facies E: Sandstone with Calcite Concretions

Facies E consists of fine- to medium-grained, clean sandstones (Figure 7D). Bioturbation is rare, with some *Ophiomorpha* (*Skolithos* ichnofacies) burrows being present. Coal and plant debris is present throughout the unit, and shell fragments ranging from 1 mm to less than 10 mm across are scattered throughout. The sandstones are poorly sorted, containing abundant chert pebbles up to 1 cm in diameter. Calcite concretions ranging from 0.5 to 1 cm across probably formed preferentially around burrows (Figure 7E). Facies E is similar to Facies D except it contains slight cross-bedding, low-angle planar bedding, and other depositional structures that indicate wave-dominated environments. It has an east-west–trending orientation, whereas Facies D is oriented northwest-southeast. The upper 0.8 m (2.5 ft) of the sandstone are completely cemented by calcite below a chert-pebble lag marking the unconformable contact between the Viking Formation and shales of the overlying Westgate Formation (Figures 8A and 8B).

Facies E is interpreted as an incised-valley fill; sediments of Facies C and Facies D were eroded during a relative sea-level fall and lowstand; the resulting incised valleys were filled with fine- to medium-grained sandy shoreface deposits (indicated by *Skolithos* ichnofacies, shell fragments, and chert pebbles) during the subsequent transgression (MacEachern, 1994).

f) Facies F: Chert-pebble Conglomeratic Sandstone

Facies F is a poorly sorted conglomeratic sandstone. It contains dark chert pebbles ranging in diameter from a few millimetres up to, rarely, 4.5 cm. Its thickness ranges from one-pebble thick layers to accumulations more than 20 cm thick. The chert pebbles of this facies volumetrically make up from 10 to 40% of the rock (Figure 8A). Recognizable trace fossils are absent in the conglomerate facies. The lower contact is sharp with Facies D or E. Its upper contact is sharp with Facies G, fissile grey shale (Figure 8B).

Facies F is interpreted as a transgressive pebble lag deposited during a rapid relative sea-level rise.

g) Facies G: Fissile Grey Shale

Facies G consists of a medium to dark grey shale (Figure 7F). It contains siderite concretions up to 5 cm across and

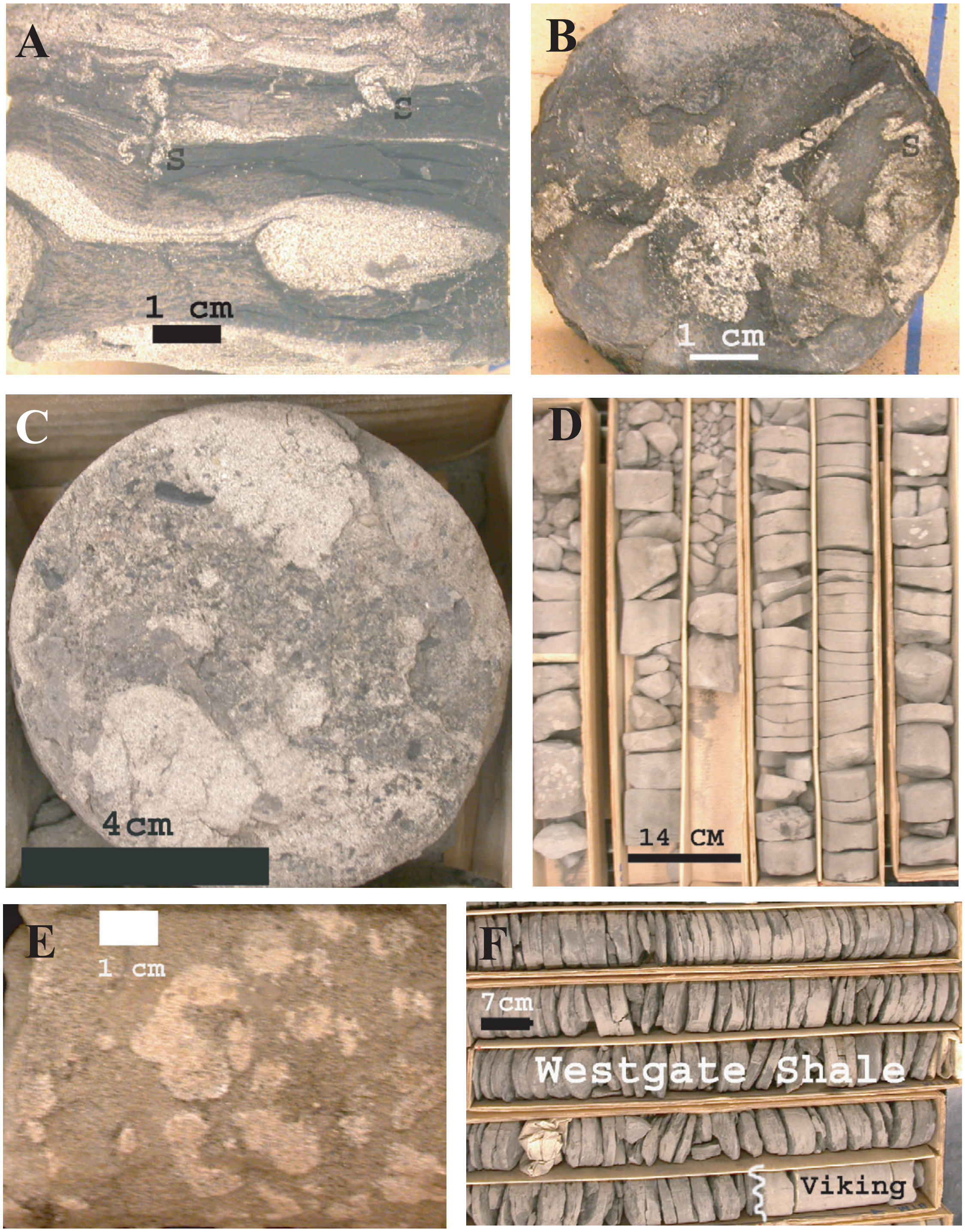

Figure 7 - A) Syneresis cracks (S) within organic-rich mudstones of Facies C, indicating changing salinities within a restricted lagoonal environment (Facies C) behind a barrier; syneresis cracks are evidence of changing salinities in a restricted environment (11-14-24-25W3, 686.71 m [2253 ft]). B) Planar view of syneresis cracks (S) within the lagoonal mudstone with a fill of medium-grained sandstone and coal fragments (Facies C) (11-14-24-25W3, 687.02 m [2254 ft]). C) Poorly sorted sandstone with an abundance of coal and plant debris and chert clasts concentrated in beds within Facies D (4-6-25-26W3, 709.27 m [2327 ft]). D) Transgressive, incised-valley-fill, fine- to medium-grained reservoir sandstones of Facies E (7-22-24-26W3, 683.36 to 687.93 m [2242 to 2257 ft]). E) Nodular calcite concretions in fine- to medium-grained, clean sandstones (Facies E) (7-22-24-26W3, 682.14 m [2238 ft]). F) Fissile grey shale (Facies G) of the Westgate Formation overlying the Viking sandstone (7-22-24-26W3, 677.57 to 681.23 m [2223 to 2235 ft]).

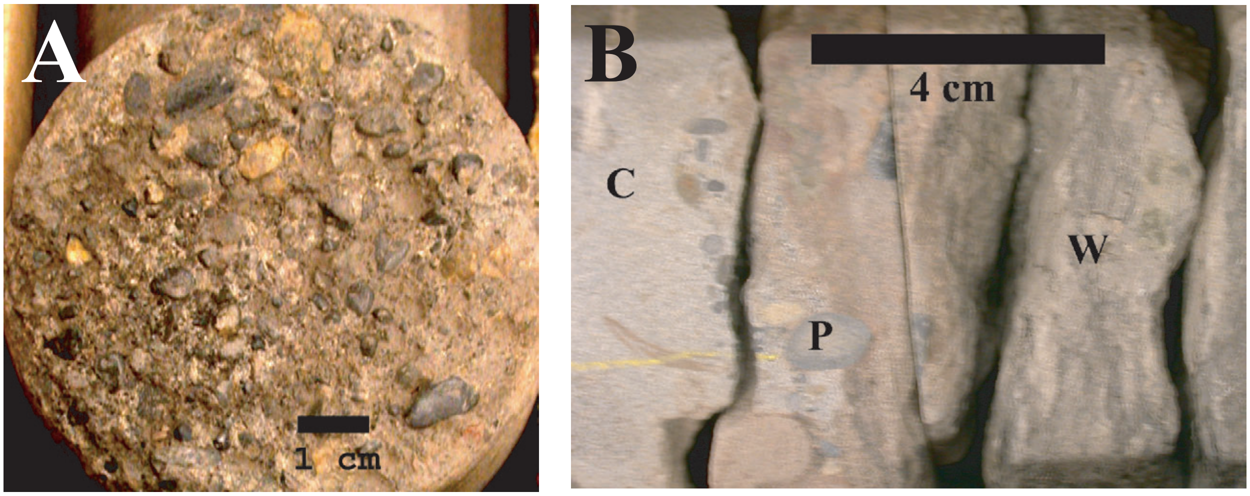

Figure 8 - A) Viking pebble bed overlying a transgressively reworked sequence boundary and ravinement surface (SB 2–RS) at the contact between the Viking and Westgate formations (7-22-24-26W3, 680.62 m [2233 ft]). B) Core photograph showing the calcite-cemented sandstone (C) at the top of the Viking Formation in sharp contact with the Viking chert-pebble lag (P) and the overlying Westgate shale (W) (10-03-24-25W3, 673.30 m [2209 ft]).

pyrite concretions up to 2 cm in diameter. Laminated siltstone layers are present, but rare, within the shales.

The fissile grey shale of Facies G is interpreted as having been deposited in a relatively deep, offshore, marine environment with rare siltstones representing storm deposits.

4. Sequence Stratigraphic Analysis

The lower contact of the Viking Formation (Facies A) is generally gradational from the underlying Joli Fou shale (Facies G) of the Lower Colorado Group, and is the result of a fall in relative sea level that produced a seaward shift in facies. This transition facies (Facies A) is superimposed on an open-marine shelf facies (Facies G). The muddy sandstones of Facies A are interpreted to represent lower shoreface to transition-zone sedimentation under fluctuating moderate- to low-energy conditions that persisted throughout deposition of the lower part of the Viking Formation (Figures 9, 10, 11, and 12A), which consists of three sanding-upward successions. These three successions are progradational parasequences of transition-zone up into shoreface deposits (Facies A and B). Each is capped by a flooding surface (FS-1, -2, and -3) (Figures 9, 10, and 11).

The progradational transition-zone to shoreface deposits (Facies A and B) are unconformably overlain by barrier-washover and lagoonal deposits (Facies D and C), reflecting a basinward shift in facies and fall in relative sea level. The sea-level fall resulted in an eastward shift of the shoreline to a location lying to the east of the study area, thereby causing its subaerial exposure and the formation of an unconformity or sequence boundary 1 (SB-1; Figures 9, 10, and 11). During a subsequent rise in sea level, a barrier-island and lagoonal environment developed in the study area, the deposits of which overlie the transgressive reworked sequence boundary (SB 1-FS; Figure 10). As sea level continued to rise, the barrier island migrated landward over the lagoon deposits as indicated by the presence of barrier-washover sandstones (Facies D) above lagoonal facies (Facies C). Almost the entire barrier was eroded during the continued transgression and, in several cores, the only evidence of it is a bed of coarse sandstone overlying the lagoonal mudstone (Figures 11 and 12.3).

A subsequent sea-level fall caused incision of valleys (SB 2) up to 12 m deep into the lagoonal (Facies C) and barrier-washover (Facies D) deposits (Figures 10, 11, and 12.4). The shoreline fed by these incised valleys was at least 40 km to the east of the Bayhurst pools, as no lowstand shoreline deposits have been seen within the study area. During a following sea-level rise, the sequence boundary (SB 2) at the base of the incised valleys was reworked and the incised valleys backfilled. Core logging shows that the incised valleys were infilled by marine, wave-dominated, clean sandstones (Facies E) (Figures 10, 11, and 12.5). As the incised valleys were transgressed, they were widened and adjacent coarse sediments were eroded and deposited in them, as indicated by the high abundance of chert pebbles within the incised-valley fill (Figure 11). This transgression continued, leading to complete infilling of the incised valleys. That a significant section was probably eroded during the transgression is indicated by the thick ravinement lag of chert pebbles (Facies F), the Viking grit (Figure 8). On the interfluves outside the incised valleys, SB 2 was eroded during the transgression, and any evidence of subaerial exposure removed. Here, the pebble lag represents the sequence boundary (SB-2) merged with the ravinement surface (RS) (Figure 11). The chert-pebble lag (Facies F) marks a sharp contact between the Viking Formation and the

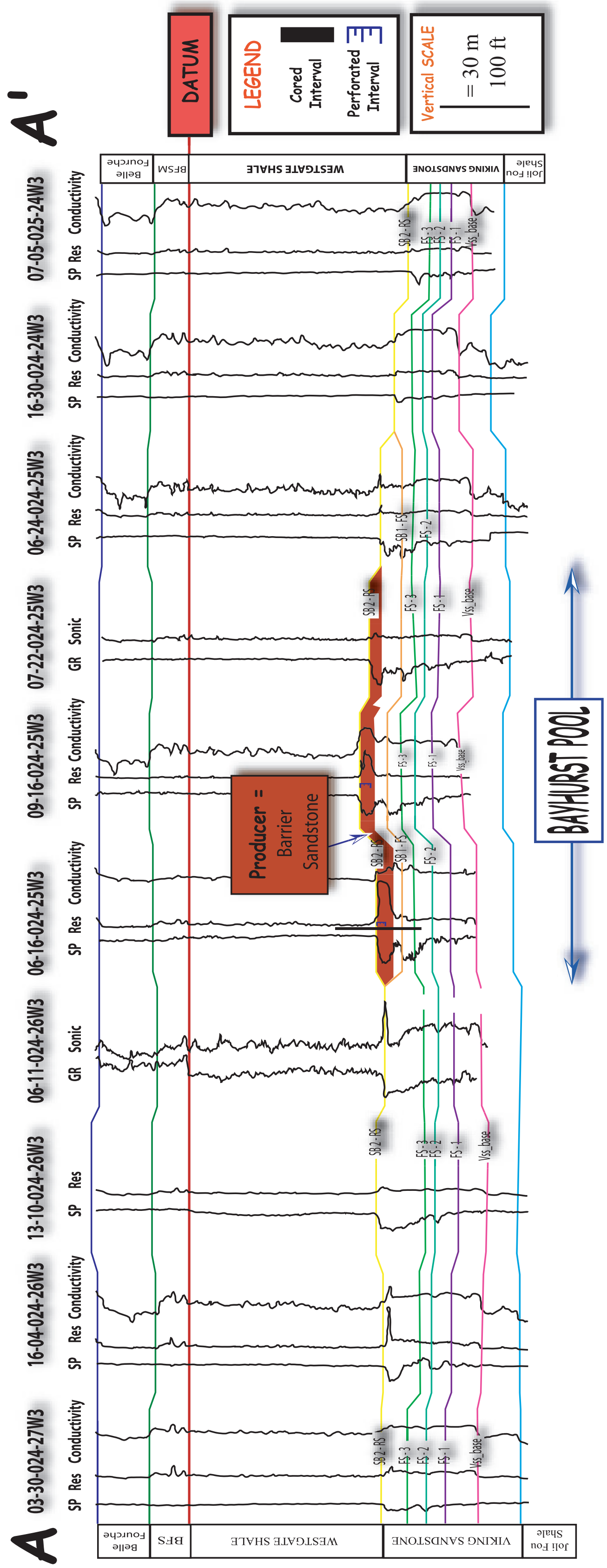

Figure 9 - Cross-section A-A' showing the lower Viking sandstones of transition-zone to lower shoreface deposits separated by flooding surfaces (FS-1, FS-2, and FS-3) followed by a sequence boundary (SB 1) and the overlying lagoonal and barrier-washover deposits within the Bayhurst pools. BFS, Base Fish Scales; BFSM, Base Fish Scales marker; and Vss, Viking sandstone.

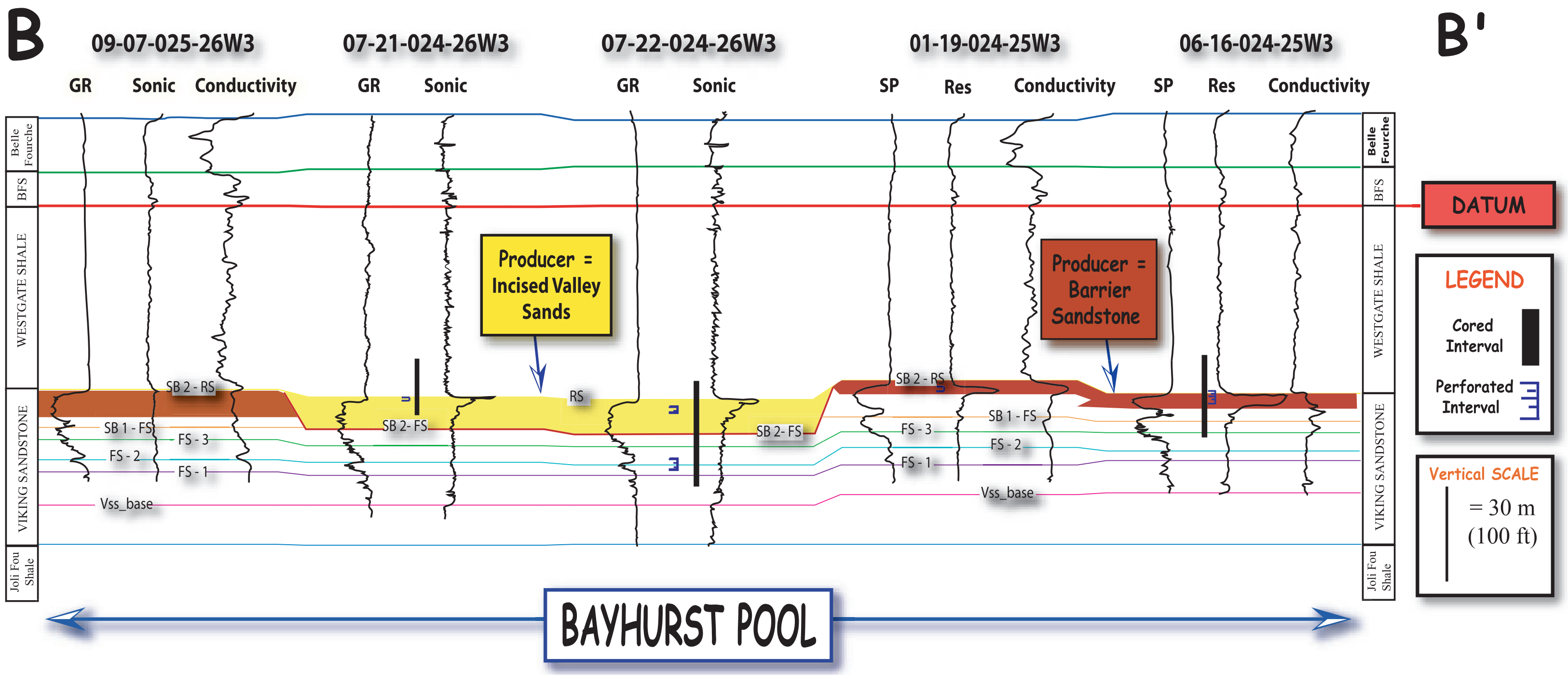

Figure 10 - Cross-section B-B' showing an incised valley cut into the lagoonal and overlying barrier-washover deposits. BFS, Base Fish Scales; and Vss, Viking sandstone.

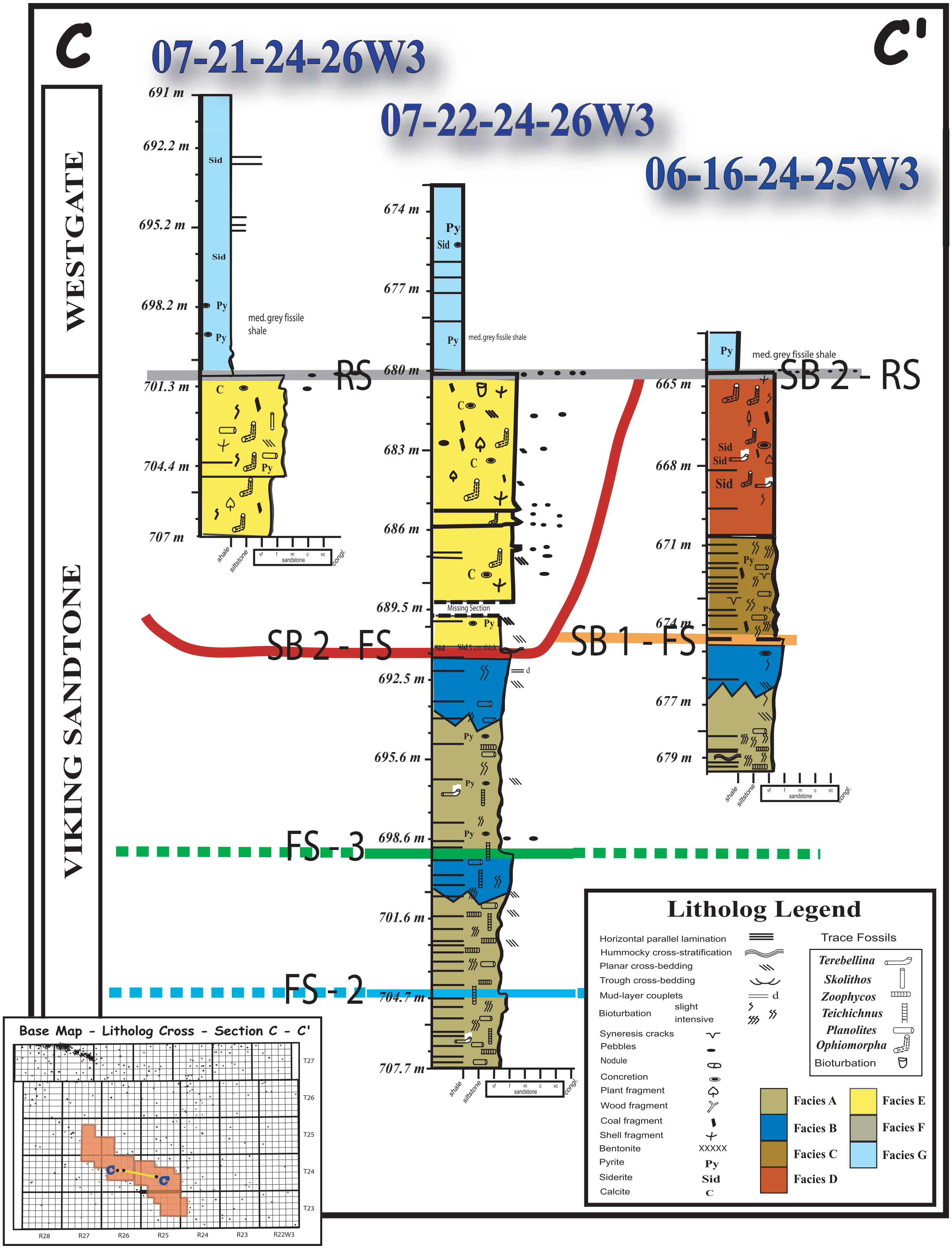

Figure 11 - Core cross-section C-C' showing depositional-facies configuration of the Viking sandstones within the Bayhurst gas pools.

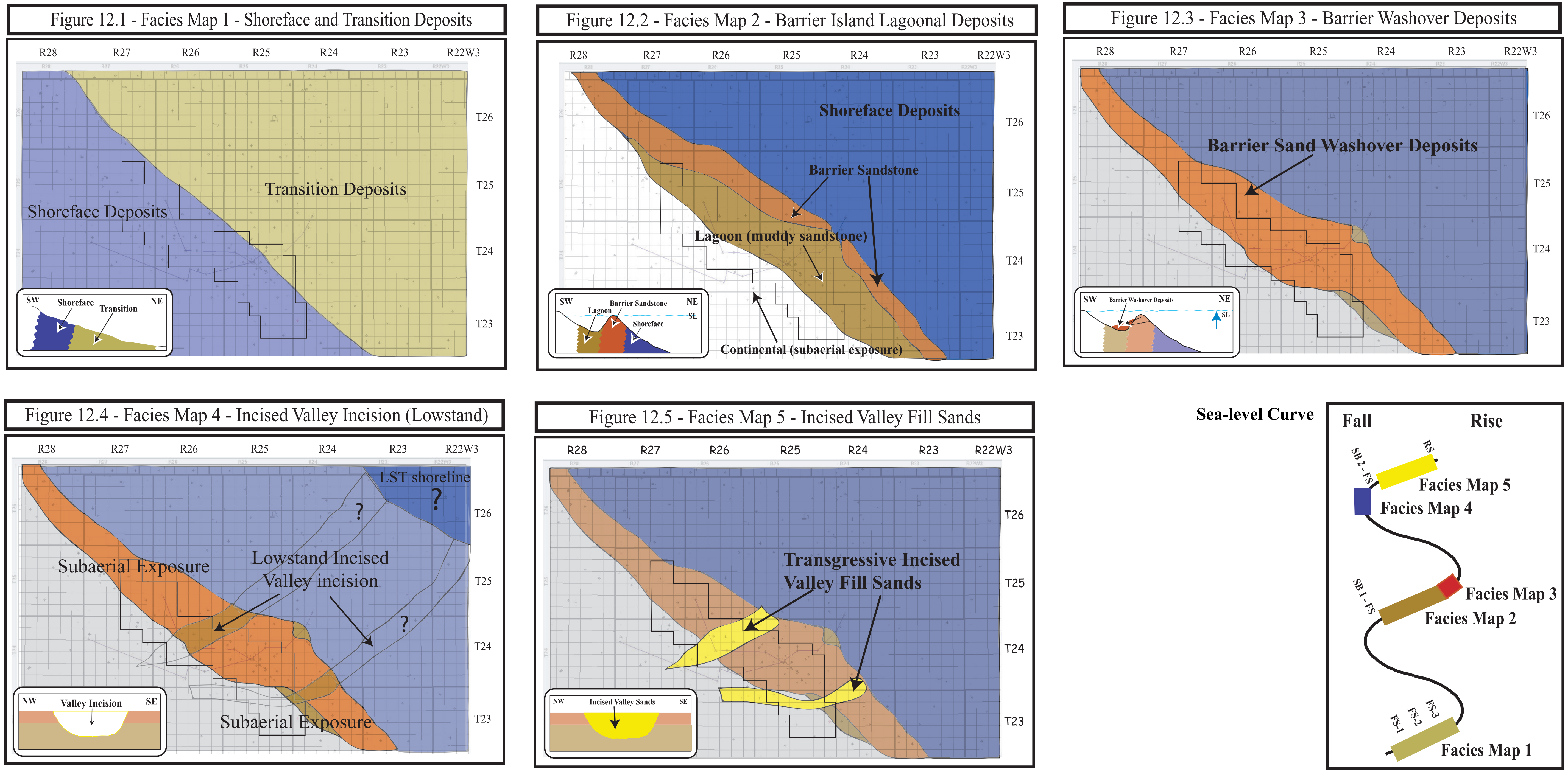

Figure 12 - Facies maps showing the evolution of sedimentary environments in the Bayhurst area.
12.1) Approximate distribution of shoreface and transition-zone sediments of Facies A.
12.2) The distribution of lagoonal and barrier-washover deposits and of adjacent shoreface sediments to the east and subaerial exposure to the west.
12.3) With sea-level rise and resultant transgression, the barrier island was eroded away and barrier-washover sands (Facies D) were deposited over lagoonal sediments of Facies C.
12.4) Distribution of incised valleys up to 12 m deep cut into lagoonal and barrier-washover deposits; the correlative lowstand shoreline was located northeast of the study area.
12.5) Backfilling of the incised valleys by shoreface sands (Facies E) during subsequent rise in sea level.
Lower right figure: Relative sea-level curve showing the timing of the sequence stratigraphic surfaces and Facies Maps 1 to 5.

overlying marine shales of the Westgate Formation (Facies G) deposited as a result of continued transgression (Figures 9, 10, and 11).

5. Petrographic Studies

Sandstones of the Viking Formation in the Bayhurst area can be classified as litharenite, lithic wacke, and calcareous sublitharenite (Figure 13), based on point counting of thin sections. Sandstones of the transition zone to lower shoreface facies (Facies A) and of the barrier-washover facies are lithic wackes. In contrast, the incised-valley fill (Facies E) consists of sublitharenite, litharenite, and lithic wacke, supporting the interpretation of these deposits as lowstand and early transgressive deposits overlying a major unconformity.

Porosities estimated from point counting range from 1 to 24%, with the highest values within the incised-valley fill (Facies E) and barrier-washover deposits (Facies D). The lowest porosities occur within the lower shoreface to transition-zone facies (Facies A) and the 0.6 to 0.8 m of massive, calcite-cemented sandstones at the top of the Viking Formation (Figures 8B, and 14A, 14B, and 14C). Porosity is interstitial and is interpreted as mostly primary. Cementation by quartz overgrowths and calcite is minor throughout the Viking except at the top of the formation where massive calcite cement completely occludes the porosity (Figure 14D).

The paragenetic sequence as seen in thin section 03-CK-04 (Facies E) includes early calcite cementation successively followed by quartz overgrowth and late calcite cementation. Cements in sample 03-CK-04 are made up of 95% calcite and <5% quartz overgrowths. The edges of the quartz overgrowths are locally euhedral and appear to be in a growth compromise relationship with calcite cements suggesting that either the calcite and quartz were precipitated contemporaneously, or the calcite postdated quartz precipitation (Figure 15). The quartz overgrowths are recognized by the dust lines between the detrital grains and the overgrowths (Figure 14E). Detrital grains are made of 45 to 85% quartz grains, 10 to 55% rock fragments, and less than 5% feldspars so the Viking sandstones are mineralogically immature (45% quartz) to submature (85% quartz) (Figure 13). Based on point counting of 03-CK-04, framework grains are quartz (86.7%) and lithic fragments (13.3%) normalized and, because the sample is made up of 71% calcite cement, it is classified as a calcareous sublitharenite.

Fluid-inclusion analysis has been performed on a sample of calcite cement (03-CK-04) within the incised-valley-fill sandstones (Facies E) from well 7-22-24-26W3 at depth 681 m (2235 ft) (Figure 8B). This interval of calcite-cemented sandstones occurs consistently just below the contact between the Viking sandstones and the overlying Westgate shale. The calcite cement is poikilotopic and has occluded almost all of the pore spaces in the sample reducing the primary porosity to less than one per cent (Figure 14D). There is an abundance of monophase inclusions ranging from <2 μm to 3.5 μm occurring mainly in calcite cement and, less commonly, in quartz overgrowths (Figures 14E and 14F). The abundance of monophase all-liquid fluid inclusions indicates early cementation at low temperatures of probably less than 50°C (Chi *et al.*, 2003).

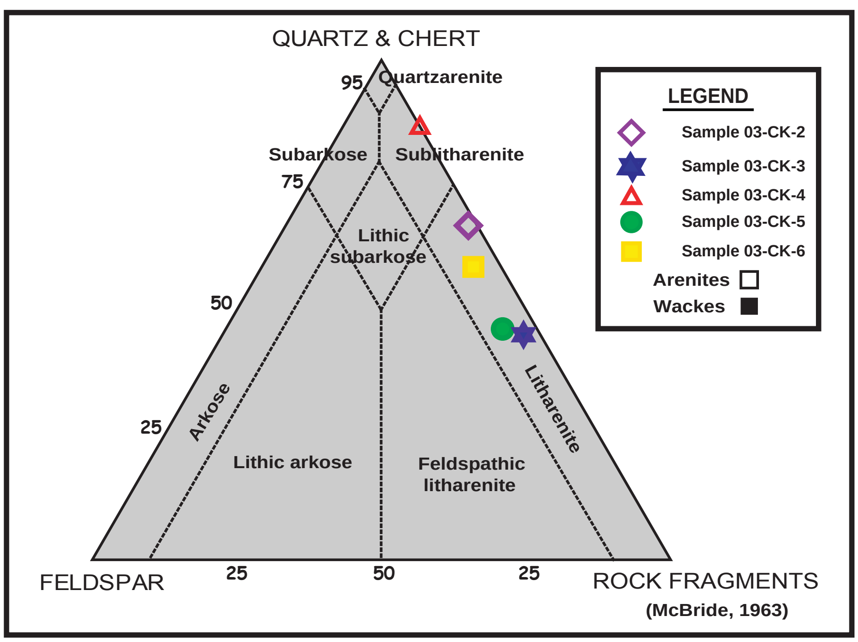

Figure 13 - Petrographic classification of Viking sandstones after McBride (1963).

6. Conclusions

The prolific Bayhurst Gas Field occurs within intercalated transitional, shoreface, lagoon, incised-valley, and barrier-washover deposits of the Viking Formation, with barrier-washover and incised-valley sandstones forming the main reservoirs. Within the Bayhurst area, five flooding surfaces, two sequence boundaries, and one ravinement surface have been recognized. The Viking sandstone reservoirs are capped by tight Westgate shales. The Viking sandstones are classified as calcareous sublitharenite, litharenite, and lithic wacke, with the most immature sandstones occurring within the incised-valley fill. Seven lithofacies – bioturbated sandstones and mudstones, sandstone with organic-rich

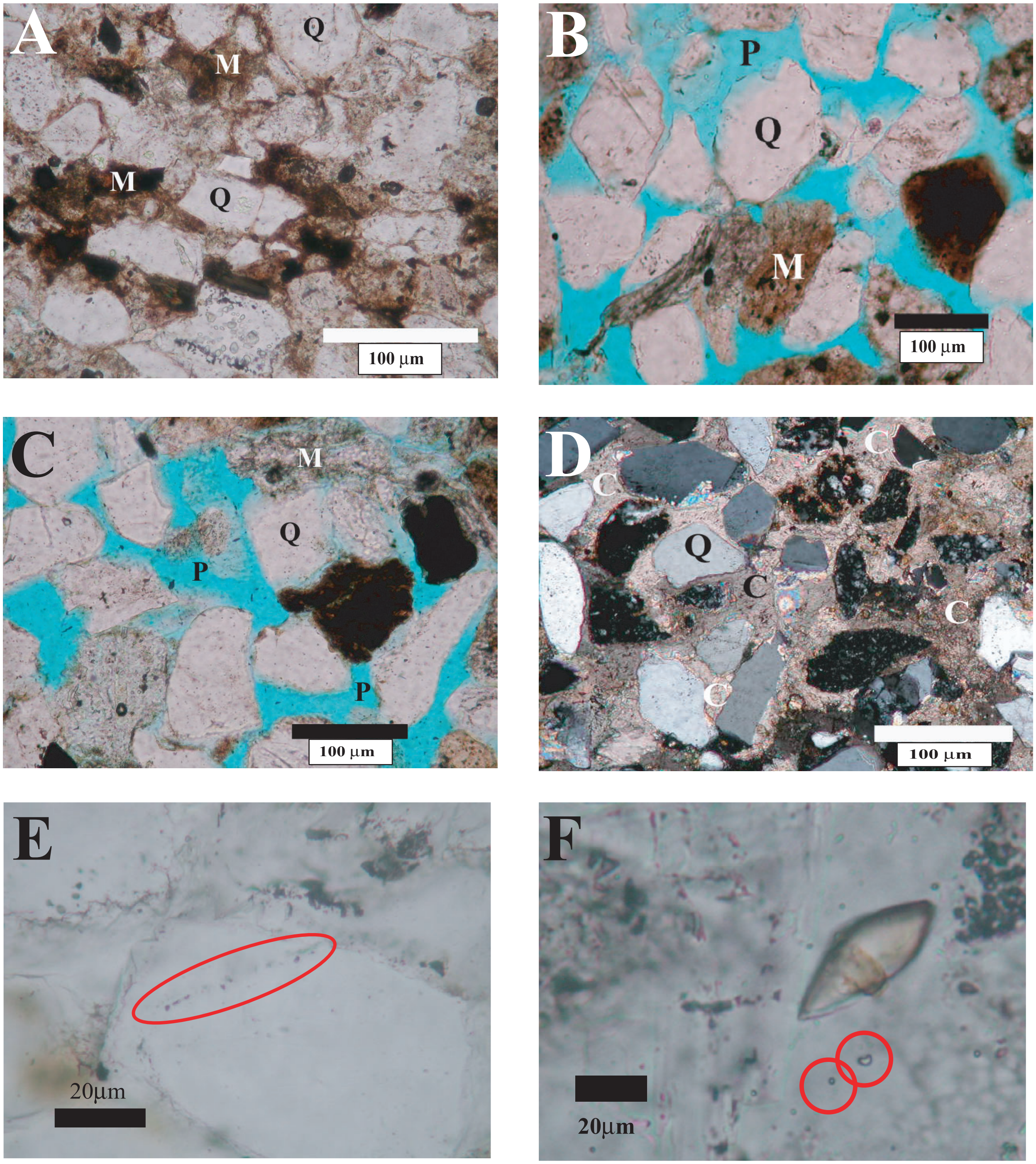

Figure 14 - Photomicrographs showing various textures and composition of Viking sandstones. A) Lithic wacke from Facies A (bioturbated sandstones and mudstones) with 3.5% porosity, 46% quartz (Q), 6% feldspar, and 48% lithic fragments based on point counting; M, matrix; Sample 03CK-5, 7-22-24-26W3, 700.74 m (2299 ft), plane polarized light. B) Structureless sandstone (Facies D) with 24% porosity (P), 58.5% quartz (Q), 4.9% feldspar and 36.6% lithic fragments; M, matrix; Sample 03CK-6, 10-03-24-25W3, 676.35 m (2219 ft), plane polarized light. C) Lithic wacke with calcite concretions (Facies E) with 20 to 23% porosity (P), 45% quartz (Q), 3% feldspar and 52% lithic fragments; M, matrix; Sample 03CK-3, 7-22-24-26W3, 687.78 m (2256.5 ft), plane polarized light. D) Poikilotopic calcite cement (C) in the sandstone near the top of the Viking Formation (Facies E); calcite cement has completely occluded porosity, which is less than 1%; the sandstone can be classified as calcareous sublitharenite; Sample 03CK-4, 7-22-24-26W3, 681.23 m (2235 ft). E) Monophase (liquid) fluid inclusions distributed along the dust line between detrital quartz grain and overgrowth cement (Facies E), 7-22-24-26W3, 680.62 m (2233 ft). F) Monophase (liquid) fluid inclusions in the calcite cement (Facies E), 7-22-24-26W3, 680.62 m (2233 ft).

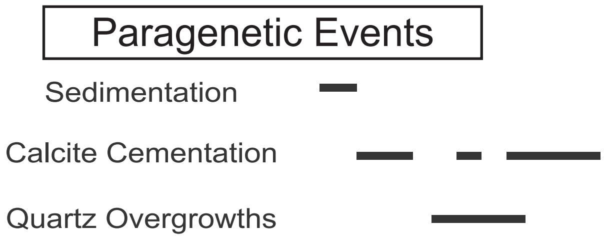

Figure 15 - Paragenetic sequence including sedimentation and diagenetic events influencing the Viking sandstones of the Bayhurst gas pools.

laminations, sandstone with organic-rich mudstones, massive sandstone with coal and plant material and shell fragments, sandstone with calcite concretions, chert-pebble conglomeratic sandstone, and fissile grey shale – have been recognized within the various depositional environments. Porosity values based on point counting range from 1 to 24%, with highest values in the incised-valley fill (Facies E) and barrier-washover facies (Facies D).

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