GS-14 Mineralogy, geochemistry and facies description of a potential Cretaceous shale gas play in western Manitoba (part of NTS 63K12)

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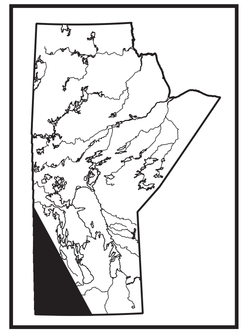

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Summary

Shallow shale gas occurrences have been recorded in Manitoba for decades; however, understanding of the geology of this potential economic gas resource is limited. Cretaceous shale units in Manitoba, including the Ashville, Favel and Carlile formations located in the southwest corner of the province, are excellent candidates for exploration. Detailed studies have been conducted on outcrops by the Manitoba Geological Survey. Mineralogical and geochemical analyses have been conducted on cores from a number of wells in this area. However, the work presented here is the first detailed subsurface mineralogical study of these formations. The goal of this study is to provide information needed to assist in exploration of this unproven, unconventional, shallow shale gas play.

Core examination, well-log interpretation and petrographic analysis are used to investigate the sedimentary structures, grain size, ichnology and degree of bioturbation, and consequently to describe the sedimentary facies. The identified facies range from noncalcareous organic mudstone to highly calcareous, bioturbated fine-grained sandstone. These represent a change from offshore fissile shale to shallower water, detrital carbonate-rich rocks. Bioturbation intensity varies from rare to moderate in the shale-dominated facies. This represents a relative distal environment, suggesting varying anoxic to oxic conditions. In contrast, the shallower water carbonate-rich facies show a higher degree of bioturbation. This suggests that oxic bottom-water conditions prevailed. Bentonitic beds occur at several intervals in the wells, indicating volcanogenic activity at the time of deposition. In a recent visit to a number of outcrops, fresh bentonite samples were taken for high-resolution dating. Bentonite beds also form good chronostratigraphic marker beds for stratigraphic correlation among wells throughout the study area.

X-ray fluorescence, from core and powdered samples, and X-ray diffraction are used to identify mineral composition and elemental abundances. One objective is to look at minerals from the perspective of their types of occurrence within these units. For example, carbonate occurs in three different forms within the shale units: as thin to thick well-preserved bivalves (*Inoceramus*); as coccoliths and foraminifera occurring as individuals in the mud matrix or concentrated in laminae to beds; and as cement. These different styles of carbonate show relatively analogous bulk mineralogy. However, each form impacts the reservoir properties and behaviour in different ways. It is crucial to conduct mineralogical studies in association with detailed sedimentological observations to get the most accurate interpretation, understanding and analysis.

More work on sequence stratigraphy at local and basin scales is being undertaken by the authors to investigate the changes in facies and environment of deposition of the formations farther westward.

Introduction

Shale gas plays are becoming progressively more important in the energy market as gas production from conventional reservoirs decreases. With the advances in exploitation technology, gas production from shale has become viable and economic.

The first modern exploration of shallow shale gas in Manitoba was initiated by EOG Resources Canada Inc. in 2003. Three shallow wells were drilled in the Waskada Field and perforated in the Assiniboine Member of the Favel Formation (Figure GS-14-1). These wells did not produce gas and were abandoned in 2006–2007 (Nicolas, 2008). Also in 2006–2007, Tundra Oil & Gas Partnership drilled three wells in Cretaceous shale units, which were also abandoned (Nicolas, 2008).

During the past few years, multiple inquiries have been made to the Manitoba Mineral Resources Division (MRD) by the oil-and-gas industry looking for information on shale gas potential in Manitoba. Consequently, the Shallow Unconventional Shale Gas Project was initiated by the Manitoba Geological Survey (MGS) in 2008.

Based on previous studies, southwestern Manitoba is a good candidate for extracting gas from shale formations at shallow depth (Nicolas and Bamburak, 2009). However, there is need for more studies to find the most productive shale intervals in the area and to design the proper techniques for gas extraction. Research in this recently started project will address several of these issues to better understand the shallow shale gas potential of these units. Previous work focused mainly on outcrops, whereas this project integrates these studies with subsurface data, core and well logs to provide a link between the surface and the subsurface, where the potential gas resource exists.

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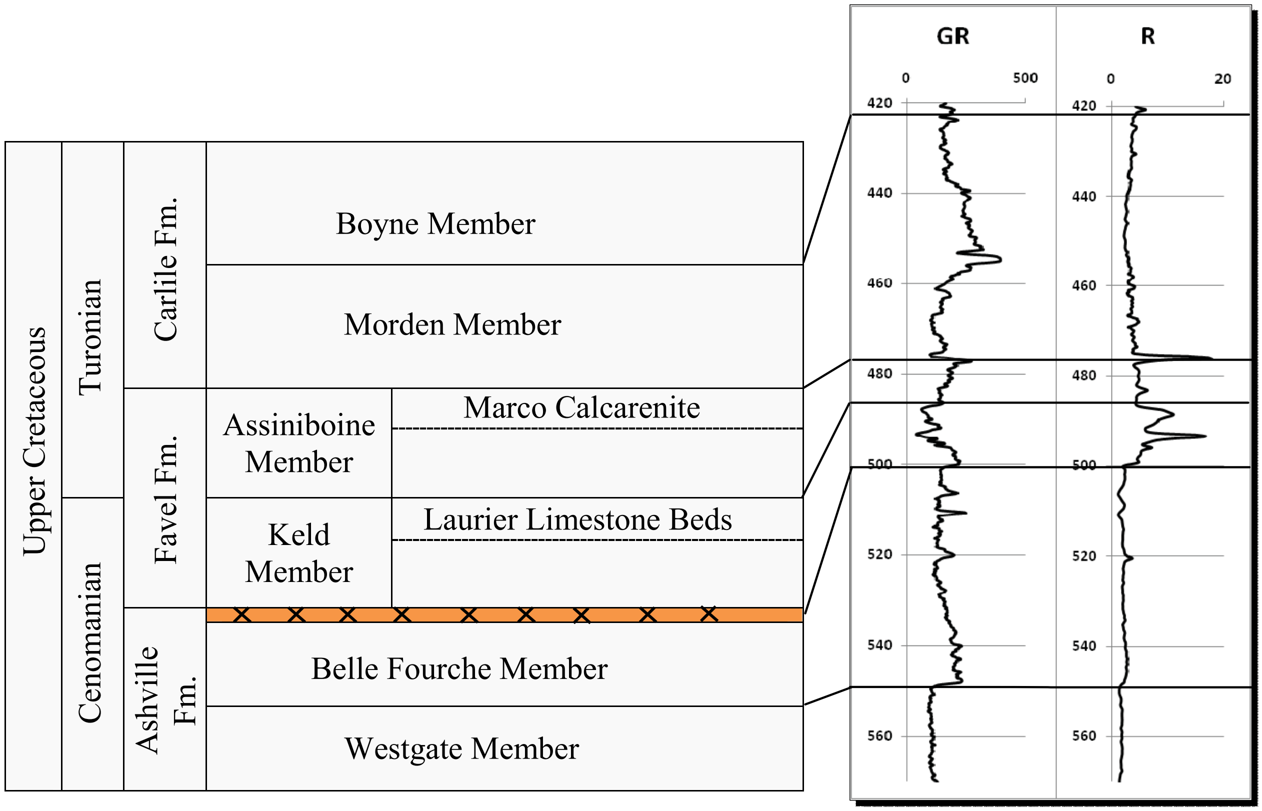


Figure GS-14-1: *Stratigraphic chart showing the nomenclature for the Upper Cretaceous formations in southwestern Manitoba (after Nicolas, 2008). On the right are the related typical gamma-ray (GR) and resistivity (R) well logs for well 3-27-1-25W1 (well depth in metres).*

This study is being conducted on Upper Cretaceous formations in southwestern Manitoba, including the upper Ashville, Favel, and Carlile formations. This study examines a number of wells drilled in this area. Figure GS-14-2 shows the study area and the locations of these wells.

Sedimentology

Facies description

Core descriptions and microscopic observations integrated with well-log interpretations yield ten major lithofacies (facies). These facies are recognized based on grain size, mineralogy, fossil content etc. The mud-dominated facies with the lowest degree of bioturbation are interpreted as having been deposited below storm wave-base in a marine environment. The mud-dominated fossiliferous facies are interpreted to have been deposited in a marine-shelf environment above storm wave-base but below fair-weather wave-base. These contain planar stratified *Inoceramus* shell hash beds deposited by storm-induced, higher energy currents reworking the shallow shelf. The sand-dominated facies, consisting of coarse carbonate grains, reflect the shallowest water environment, which, together with the high degree of bioturbation, suggest deposition in a well-oxygenated, proximal offshore to lower shoreface setting.

Organic-Rich Mudstone Facies (OM): This facies consists of dark grey, slightly to noncalcareous, fissile mudstone (Figure GS-14-3). Microscopic pyrite grains are present through the whole interval. This facies is characterized by high gamma-ray log readings. The lack of traction current bedforms and bioturbation, along with the relatively high organic content, suggest deposition in a relatively deep anoxic environment.

Speckled Mudstone Facies (SM): This facies consists of calcareous, light grey, silty mudstone interbedded with beds containing dispersed fine sand–sized white specks of fecal pellets and planktonic foraminifera. Sedimentary structures are mainly graded beds, parallel lamination and minor ripples, with the latter providing evidence of periodic traction currents operating on the seafloor in the shallow-marine environment (Figure GS-14-3).

Fissile Shale Facies (FS): This facies comprises medium to dark grey, slightly to noncalcareous, fissile mudstone (Figure GS-14-3). Based on microscopic studies, this fissility could be due to the presence of laminae of clay clasts. There are minor bivalve fragments present within the facies. Facies FS is observed within the upper and lower Morden Member (Figure GS-14-1). The dominance of planar laminae suggests deposition in a relative low energy, marine environment.

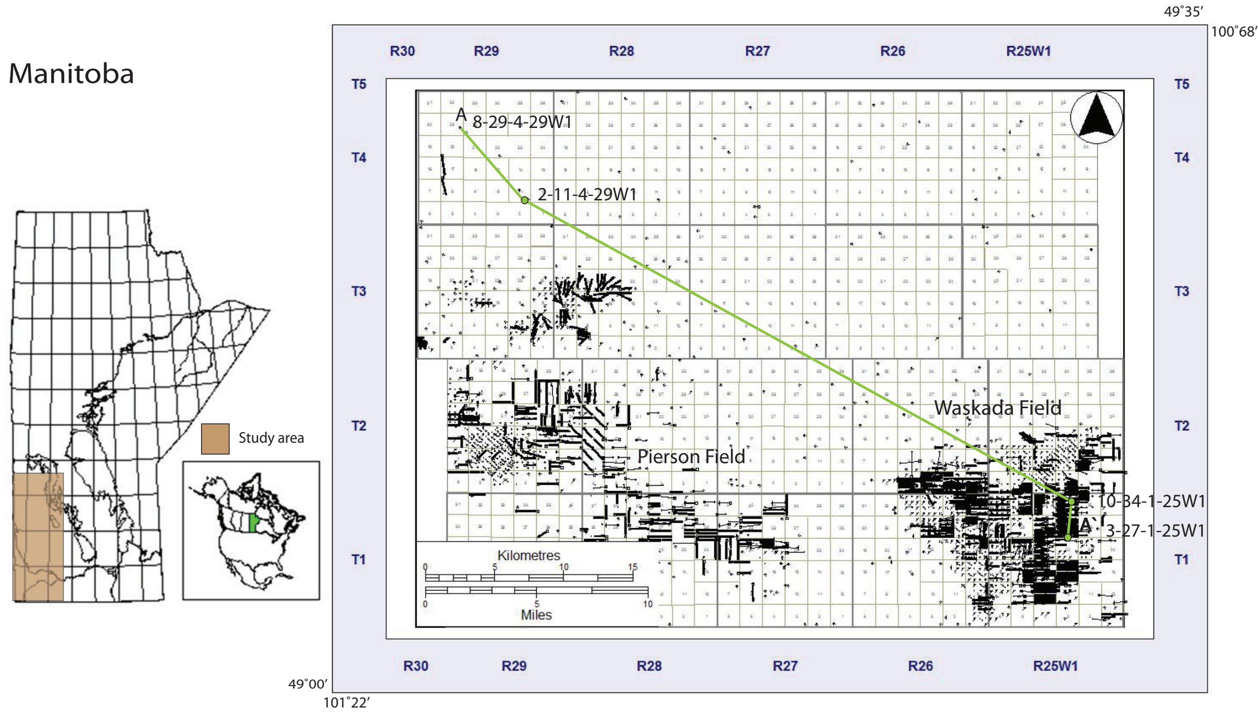


Figure GS-14-2: *Location of the study area (shaded) in the southwestern corner of Manitoba. The 55 km long, northwest–southeast cross-section A–A′ (depicted in Figure GS-14-4) is indicated.*

Massive Claystone Facies (MC): This facies is composed of noncalcareous, medium grey, massive claystone with siltstone laminae. Some small fossils are present and there are no visible sedimentary structures (Figure GS-14-3). This unit is only observed in the uppermost part of the Ashville Formation (Figure GS-14-1). This facies may be related to an anoxic, very low energy depositional environment.

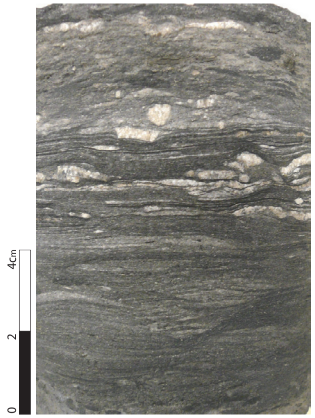
Bivalve-Rich Mudstone Facies (BM): This facies comprises dark grey mudstone with thin laminae to thick beds of *Inoceramus* shell debris and foraminifera tests. Shell hashes are abundant in this facies, with the bases showing evidence of loading into underlying sediments (Figure GS-14-3). Intervals with high shell content show low gamma-ray and high resistivity readings. This facies is interpreted to have been deposited in a marine-shelf environment above storm wave-base but below fair-weather wave-base. *Inoceramus* shell hash beds were deposited by storm-induced, higher energy events.

Foram-Bivalve–Rich Mudstone Facies (FM): This mudstone facies is associated with abundant dispersed planktonic foraminifera tests or laminae consisting of these tests. Bivalve shell fragments are locally present. It is moderately bioturbated, with some sedimentary structures such as ripples (Figure GS-14-3). Facies FM is observed within the lower Keld and lower Assiniboine members of the Favel Formation (Figure GS-14-1).

Bentonitic Facies (B): This facies consists of bentonite beds of varying thickness, colour and fabric observed throughout the studied interval. Their thickness ranges from less than one to tens of centimetres (Figure GS-14-3). Their colour varies from white-blue to olive grey. These bentonite beds are typically normally graded and can be seen on the gamma-ray logs as high-gamma-ray response kicks. Bentonite beds are an indication of different periods of volcanic activity during deposition.

Fine-Grained Carbonate Facies (FC): This facies comprises fine-grained limestone with rare or cryptic bioturbation and has a sharp basal contact with the underlying mudstone. There is a fining-upward trend within these units that may be a result of temporary, relatively high energy currents in an otherwise low-energy marine environment (Figure GS-14-3).

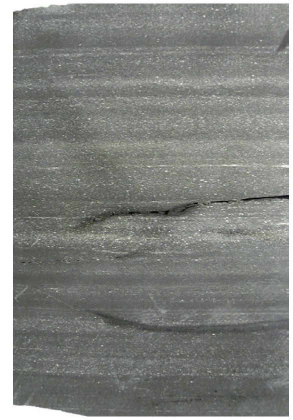
Coarse-Grained Carbonate Facies (CC): This facies consists of coarse carbonate grains and abundant larger fossil fragments. The facies is commonly intensely bioturbated (Figure GS-14-3). Pyrite grains are present. Facies CC usually overlies a mud-dominated facies and forms a resistant carbonate bed demarcating the top of the Keld and Assiniboine members of the Favel Formation (Figure GS-14-1). These carbonate beds appear as units with very low gamma and very high resistivity readings (Figure GS-14-4). This lack of mud and large grains, together with the intense bioturbation, indicate that this



Facies FM:
Foram and bivalve–rich mudstone, rare ripples

Facies BM:
Bivalve–rich mudstone, planar stratification

Facies OM:
Organic–rich, fissile mudstone



Facies SM:
Speckled mudstone, finely laminated, silt–sized foraminifera grains in mudstone

Facies MC:
Massive with medium to thick parting, noncalcareous mud/claystone.

Facies FS:
Slightly to noncalcareous fissile shale, rare broken bivalve fragments

Facies FC:
Fine–grained carbonate (limestone), rare bioturbation

Facies CC:
Coarse–grained carbonate (limestone), heavily bioturbated

Facies CS:
Carbonate–rich, silty sandstone, common bioturbation

Facies B:
Massive or normally graded bentonite beds

Figure GS-14-3: *Core photos illustrating major facies classification in wells 3-27-1-25W1 and 10-34-1-25W1. These cores are from the Favel Formation and Morden Member in the study area, southwestern Manitoba.*

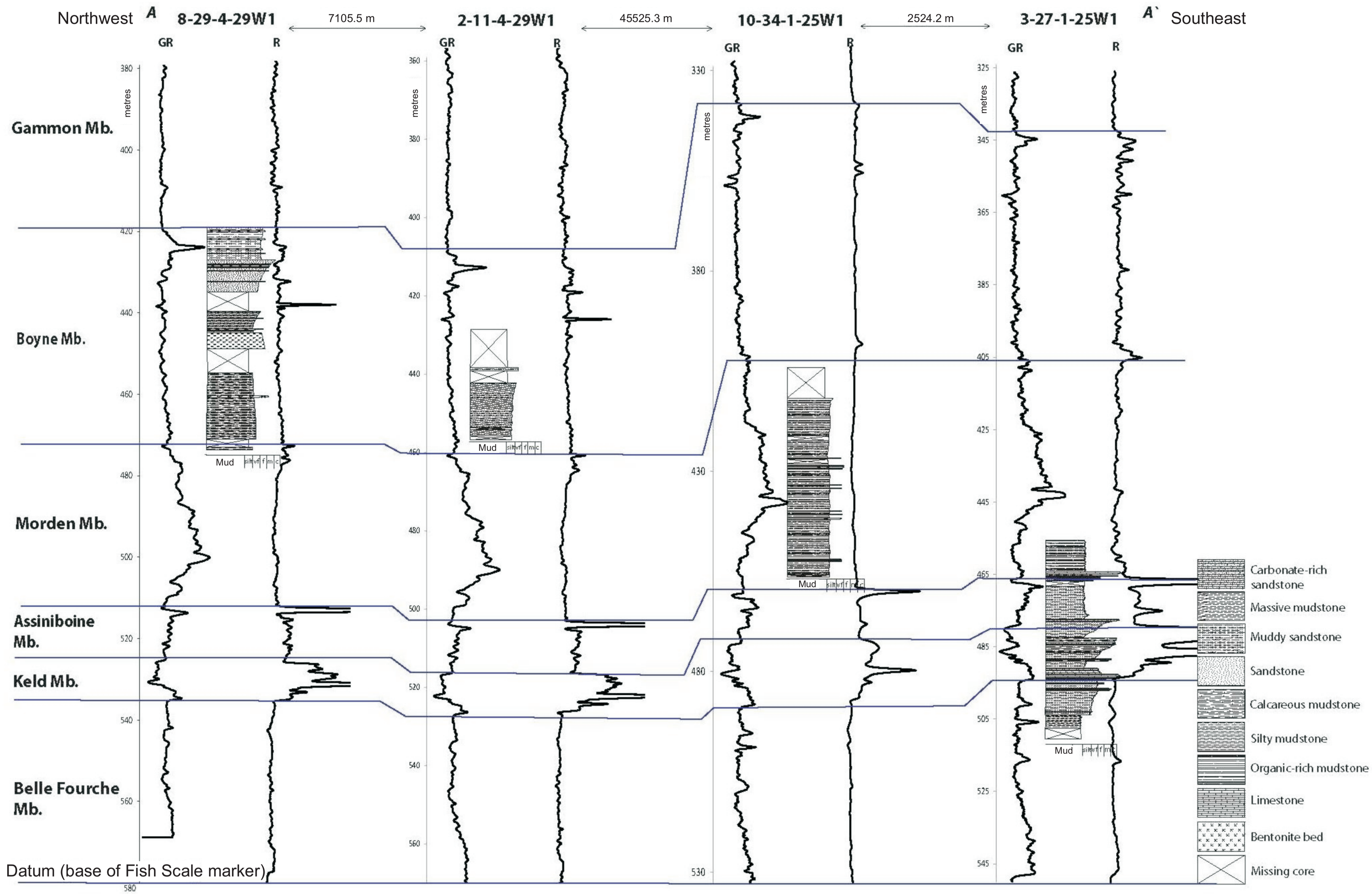


Figure GS-14-4: *Cross-section A–A' (location is given in Figure GS-14-2), showing lithostratigraphic, gamma-ray and resistivity correlation of Ashville (Belle Fourche), Favel (Keld and Assiniboine) and Carlile (Morden and Boyne) formations and their members, southwestern Manitoba. Lithology descriptions for the cored intervals in different wells are also shown. Details of porosity, total organic carbon (TOC) and gas content for well 10-34-1-25W1 are shown in Figure GS-14-5. The length of the cross-section is almost 55 km. There is a reasonable consistency of the log patterns, suggesting a low-relief basin.*

facies was deposited in a moderately high energy, open-marine setting.

The core description, gamma-ray log and core-analysis data for the well at L.S. 10, Sec. 34, Twp. 1, Rge. 25, W 1st Mer. (abbreviated 10-34-1-25W1), covering Morden Member interval, is displayed in Figure GS-14-5. The entire section is composed of mudstone with different degrees of fissility. Two facies are observed in this core: a basal and upper, medium grey, noncalcareous mudstone (MC) and a middle unit comprising dark grey, noncalcareous, organic-rich fissile shale (OM). The latter is characterized by relatively high gamma-ray readings compared to the former facies. The higher values of gas content are in line with higher porosity and total organic carbon (TOC) content, which occurs within the interval of the organic-rich, fissile shale facies. There are also several thin bentonite beds within this shale.

Mineralogy and geochemistry

Shale and mudrock consist of diverse suites of major and trace elements; trends in these data are useful indicators of potential source and reservoir rocks. Thus, in the evaluation of shale, understanding the elemental composition and geochemical characteristic is crucial. This information can be used to create proxies of depositional environment, chemistry of water, provenance and diagenetic changes during and after deposition, resulting in different hydrocarbon-source and reservoir properties. In this study, the bulk of the mineralogy data are collected using a bench-top energy-dispersive X-ray fluorescence (ED-XRF) unit; the technique is nondestructive and quantitative. Several control samples were also analyzed using destructive X-ray fluorescence and X-ray diffraction methods. The result from the two sources is reasonably comparable, as shown in Figure GS-14-6.

Mineralogical analysis associated with microscopic work provides sufficient knowledge to understand the type and abundance of mineralogical phases present as a key factor in evaluation of the hydrocarbon potential of shale. For example, the proportion of the two major mineral phases silica and carbonate, as well as their types of occurrence, provide an understanding of depositional environment, water geochemistry, organic richness, maturity and reservoir petrophysical properties. X-ray fluorescence data on the well 3-27-1-25W1 reveal a negative relationship between SiO_2 and $CaCO_3$ (Figure GS-14-7a). There is an association between Al_2O_3 and K_2O phases, suggesting their co-occurrence in clay minerals (Figure GS-14-7b, c). Pyrite and U values also follow the same trend, indicating that FeS_2 is more dominant in reducing organic-rich environments (Figure GS-14-7d, e; Bottrell et al., 1998). Figure GS-14-7f illustrates the association between V as a redox-sensitive element and TOC. In fact, V can be used as a proxy for higher TOC values, and Mn can be inversely used as a proxy for more oxidizing environments (Swanson, 1961). The ternary diagram in Figure GS-14-8

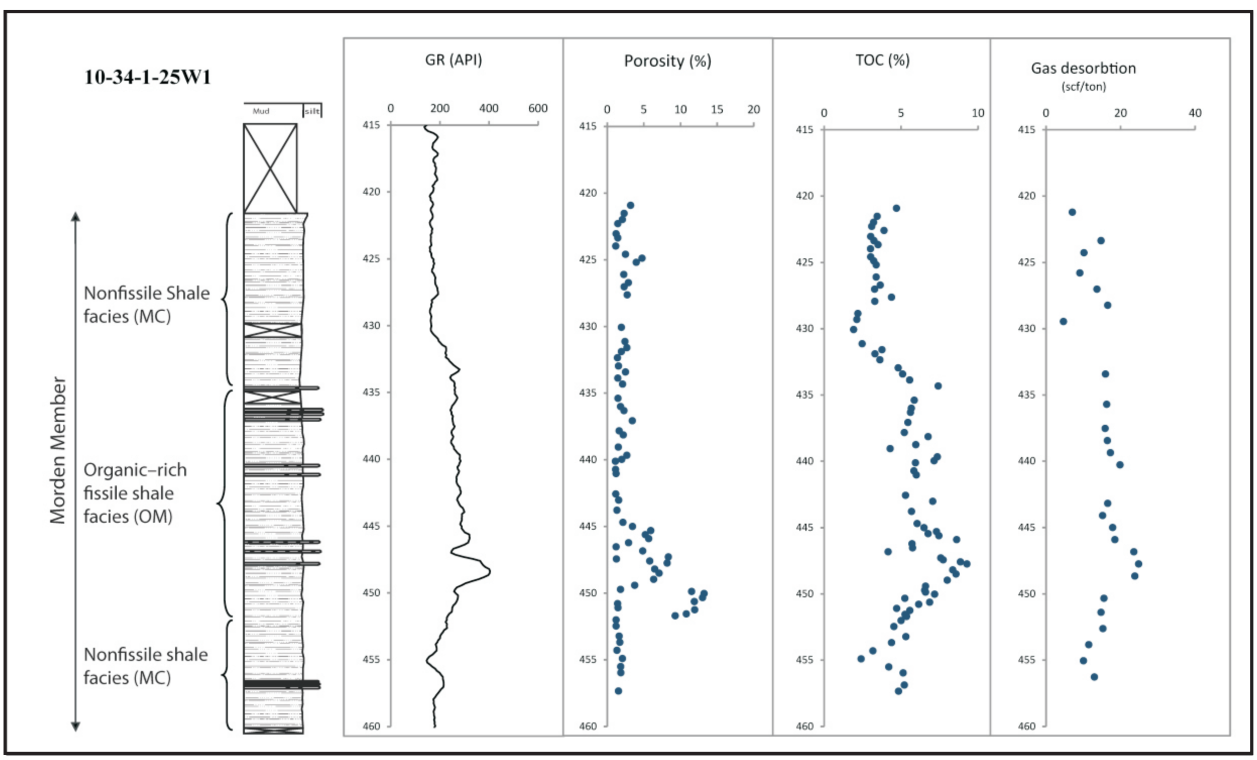


Figure GS-14-5: *Core description and associated facies with geophysical well log (gamma-ray) and measured values of porosity (%), TOC (%) and gas content (standard cubic feet per ton, or scf/ton) for the well 10-34-1-25W1, covering the Morden Member interval (EOG Resources Canada Inc., 2004), southwestern Manitoba. This well is depicted in its regional context in Figure GS-14-4. Abbreviations: GR, gamma ray; TOC, total organic carbon.*

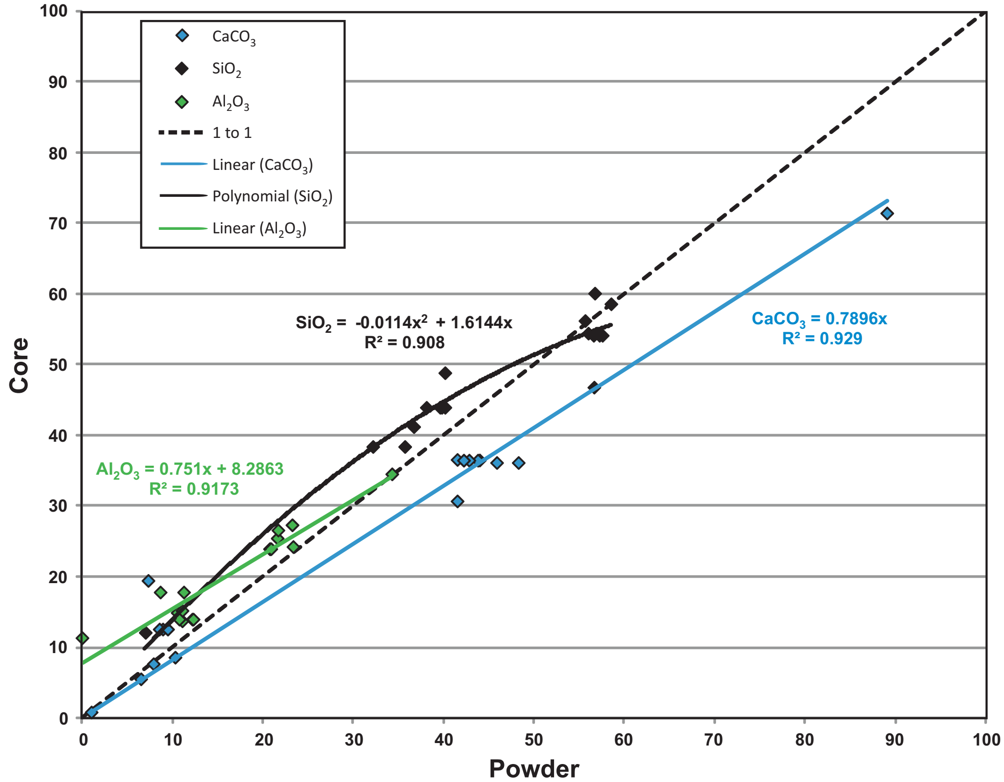


***Figure GS-14-6:** Overall linear correlation in major oxide values (determined using XRF) between core and powder. In all cases, the core XRF results are consistent with results generated using traditional powder XRF.*

indicates that the Favel Formation, compared to the average bulk shale, is a carbonate-rich mudstone with relatively high clay content.

Economic considerations

Shallow shale gas has attracted a good deal of interest in Manitoba, as a potential local source of gas. Several studies have been conducted on outcrops of the Cretaceous shale strata, whereas this study is complemented by a subsurface study of core and well-log data to aid in evaluation and exploration of this potential gas resource in southwestern Manitoba. Additionally, this study allows comparison between formations in Manitoba and their producing stratigraphically equivalent strata in other parts of the Western Canada Sedimentary Basin. The Keld and Assiniboine members of the Favel Formation in Manitoba are the equivalent of the gas-producing Second White Specks shale in Alberta, which provides encouragement for additional research on hydrocarbon potential of these formations.

Acknowledgments

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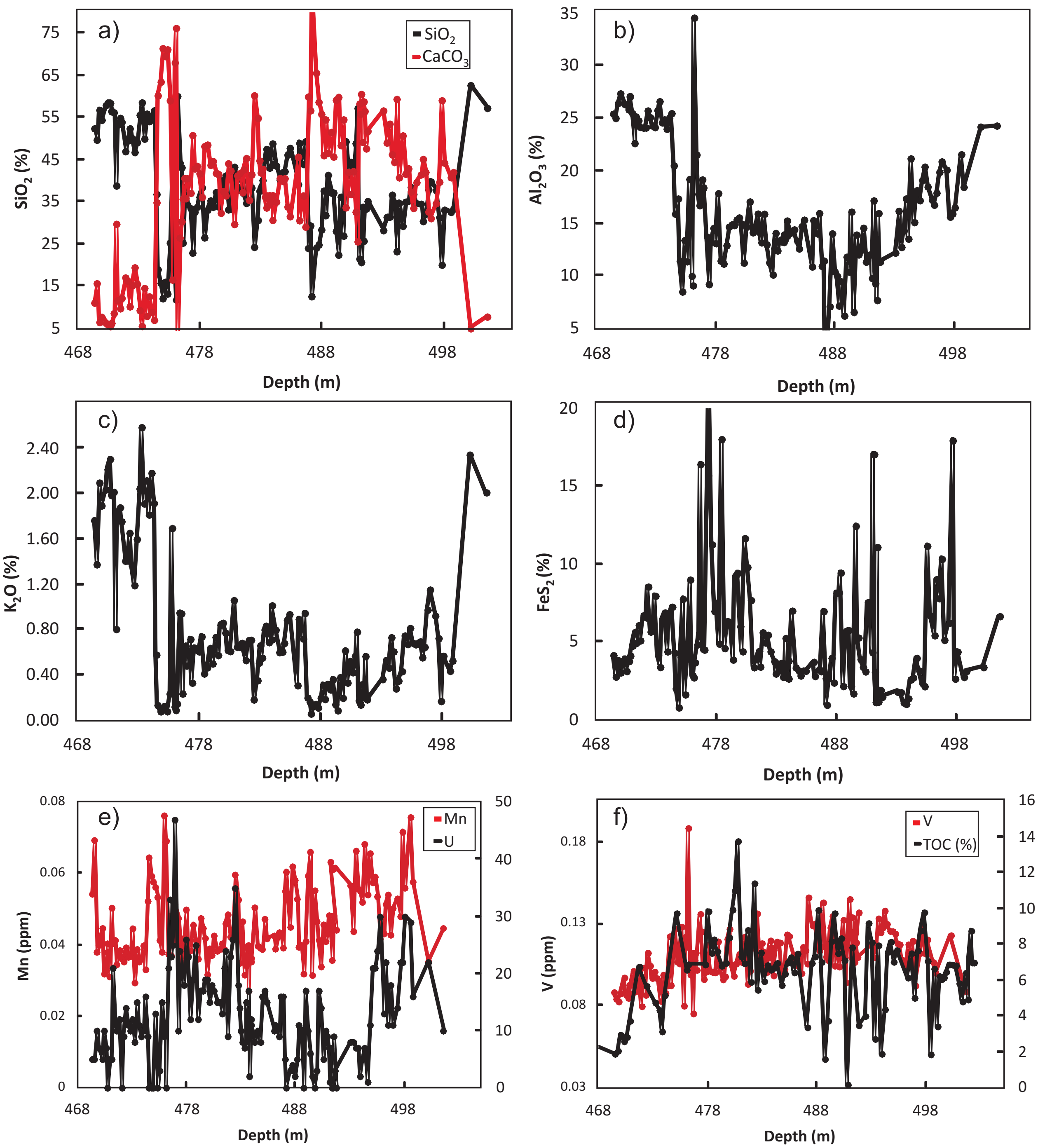

***Figure GS-14-7:** Cross-plots of different elemental compositions versus depth for the well 3-27-1-25W1, southwestern Manitoba (mineralogical data generated by ED-XRF): **a)** SiO_2 and $CaCO_3$ (%), showing the reverse relationship between the two major oxides; **b)** Al_2O_3 (%), showing the same trend as SiO_2 in plot (a); **c)** K_2O (%), showing a trend that almost matches those of Al_2O_3 and SiO_2; **d)** pyrite (FeS_2, %); **e)** two minor elements, U and Mn (ppm), that display an inverse relationship; **f)** TOC (%) and V (ppm), an element indicative of reducing environments (TOC data from well report provided by CBM Solutions LTD, 2002).*

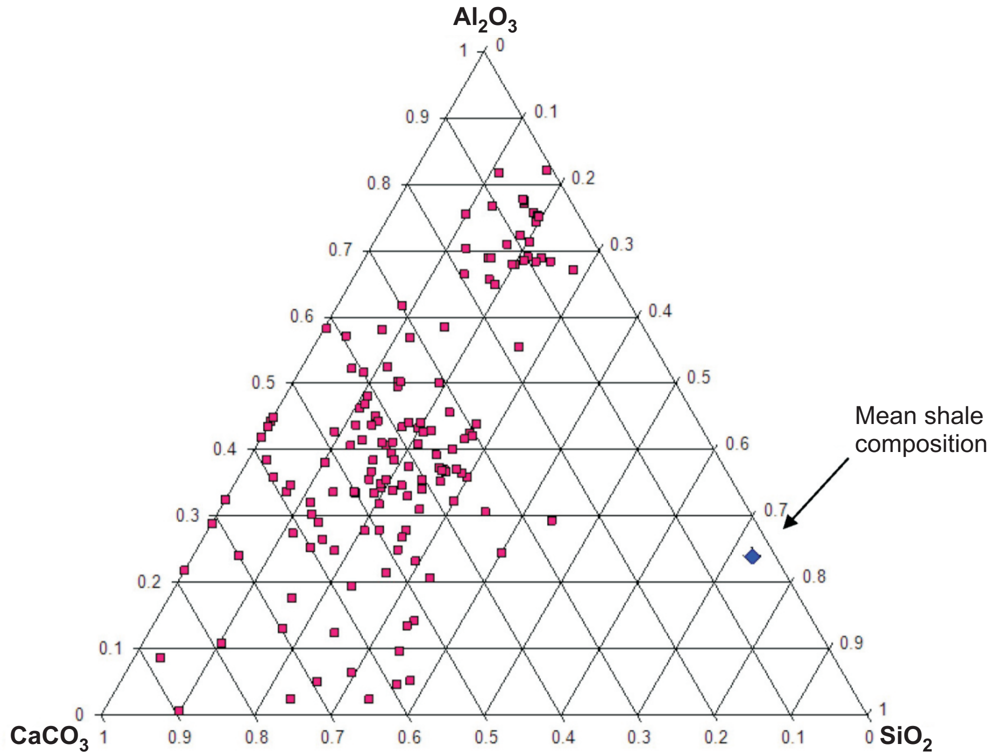

***Figure GS-14-8:** Ternary diagram using ratios of the three major elemental compositions (generated by ED-XRF) in the Favel Formation and Morden Member, southwestern Manitoba. Blue diamond shows data point for average shale (Wedepohl, 1991).*

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