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Stratigraphic Reorganization and Reservoir Properties of the Monteith "C" Resource in Part of the Northwestern Alberta Basin.

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Summary

The gas bearing siliciclastics of the Monteith "C" Formation (sand, siltstone and shale) representing tide and fluvial influenced deltaic environments are organized in three sequences in a small exploration block of the 'Alberta Deep Basin'. Our sequence stratigraphic model shows that the thin nature of these sand bodies may be attributed to the gentle clinoform geometry, rapid sediment supply and a normal as well as forced regression, which in some cases resulted in completely detached sand bodies forming separate subplay. Flooding events with backstepping patterns are also evident. The Monteith "C" has a variety of subplays such as progradational attached sand layers of delta front to delta plain environments, detached sand bodies of delta front environments and channel systems of delta plain environments. These sands are likely to be distributed basinward extending delta lobes separated by tidal inlets. The cores cut through these sands show promising reservoir facies such as climbing ripple laminated, low angle cross-bedded and massive sandstones with poro/perm in the range of 2-8% and 0.01-2mD respectively. The internal composition of all sands is lower fine to upper fine grained sublitharinite with 93-99% quartz and other detrital grains, and with 1-7% clay (mainly illite). The pore systems are developed mainly by dissolution of chert grains with a trace of fracture and primary intragranular porosity. The primary porosity in the quartz dominated facies was occluded by common silica overgrowth cement and minor ferroan dolomite cement. Rarely, some pores were also occluded by illite, bitumen and pyrite cement. Occasionally, iron-rich clay and organic matter are concentrated along microstylolites. The Monteith "C" is a promising gas bearing resource, however, its optimization requires a detailed stratigraphic analysis prior to the development of exploration related maps and a drillable prospect.

Introduction

The Late Jurassic to Early Cretaceous strata of the Monteith "C" (*sensu* Miles et al., 2012) is one of the established tight gas sandstone resources in the northwestern 'Alberta Deep Basin'. The Monteith "C" has been informally subdivided into lower, middle and upper lithostratigraphic units that form layers of variable thickness (Figure-1). The sand bodies in lower layers are subtle with limited areal extent while sands of the upper layer show relatively wider areal extent. In general, the well data shows that the formation possesses a complex network of a large number of sands bodies of varying thicknesses and lateral extent. For this type of strata, refining an exploration target and developing a reservoir static model is a challenge. In the recent years academia has made valuable contributions to update its reservoir characteristics and subsurface distribution especially at a regional scale (Miles et al. 2010; Miles et al. 2012; Liliana et al. 2014). This paper likewise is an offshoot attempt to mature the Monteith exploration target in a specific area of the northwestern Alberta Basin and focus on the reorganization of the sand bodies and their reservoir properties.

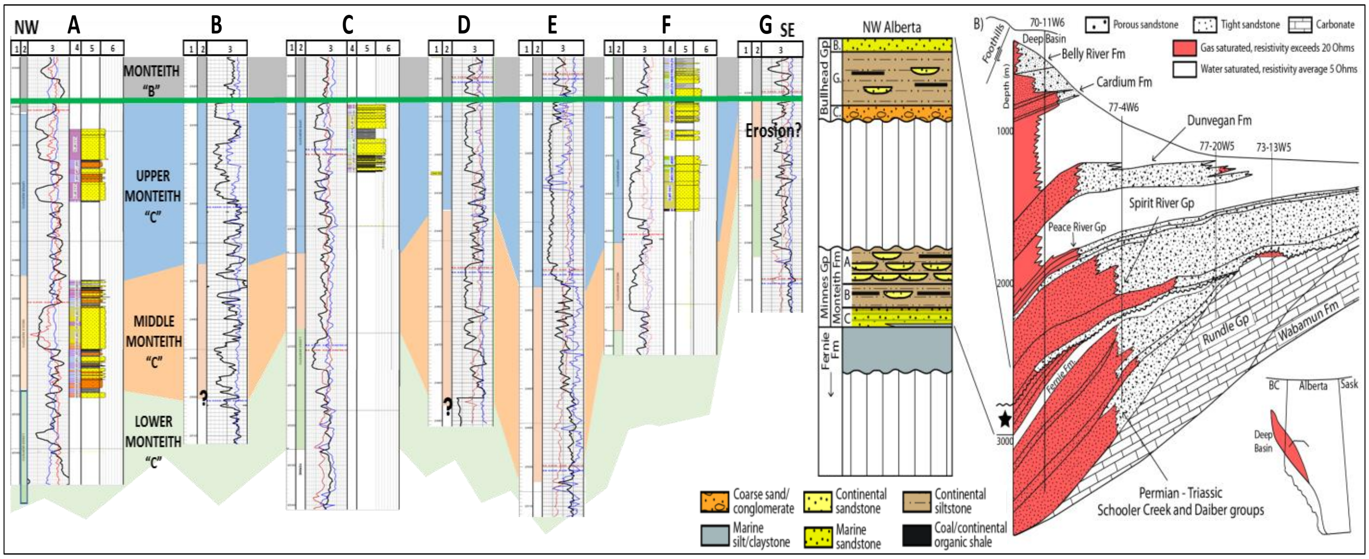

Figure-1: Late Jurassic to Early Cretaceous lithostratigraphy of the 'Alberta Deep Basin' (right; Modified after Kukulski et al., 2013). Left side shows the well log correlation with core facies; the Monteith "C further divided into lower, middle and upper lithostratigraphic units (from this study area); 1=scale, 2=formation name, 3=GR (black), neutron porosity (red), density porosity (blue), 4= core facies, 5= lithology, 6=grain size.

Methodology and Data Base

For this attempt, the stratigraphic framework was developed applying a log and core based sequence stratigraphic approach. Nearly 280m of core from 11 wells was investigated and documented in full detail providing a solid base for understanding depositional environments, log correlations and physical properties such as grain size, fracture and visual porosity of the reservoir sands. The cuttings analysis from 45 wells also provided a reasonable control for rock properties for the wells where core was not cut. The internal rock composition, pore system and cement were analyzed by petrography of 115 core and cutting samples. Further verification and quantification of the rock composition was achieved through XRD bulk and clay analysis. For visual verification of the pore system, clay and cement types, SEM imaging was done. XRF provided an independent measure of the elemental chemistry of the reservoir rocks.

Stratigraphic Framework, Core Facies and Modelling

The fine grained nature of the Monteith "C" sediments, especially in the study area is possibly attributed to the long distance transportation by basin axial channels from southeast to northwest that dispersed into the foredeep basin (Miles 2012). In the wells from the study area, fourteen core facies have been identified indicating pro-delta to delta plain environments (Figure-2). The facies and sedimentary structures reflect deposition persistently under tide and river influenced deltaic environments whereas wave influence is rare and sporadic. The pro-deltaic and storm influenced lower delta front facies (MF1 and MF2) defines the limits of Monteith "C" and intermittent tidal inlets. In the extreme basinward locations, presence of normal graded bedded facies (MF13) is noted indicating very fine grained turbidities deposited under hyperpycnal flow. The massive sandstone (MF4) showing layering due to dewatering is found associated with distal facies with slump features. The MF3 facies showing climbing ripple laminations (including herringbone ripples) with relatively thick layers qualifies as the best reservoir deposited most likely in delta front conditions. Other reservoir facies are sandstone with double shale drapes (MF5) suggesting tide influence, and high to low angle cross-bedding (MF8, MF10 and MF11) indicating wave influenced environments respectively. A variety of heterolithic facies including bioturbated and unbioturbated starved ripple laminated facies (MF7, MF6), organic rich shale and coal fragments (MF9a), alternative thin sand and mud rich facies (MF6) may represent delta plain environments with locally associated channel systems (MF14).

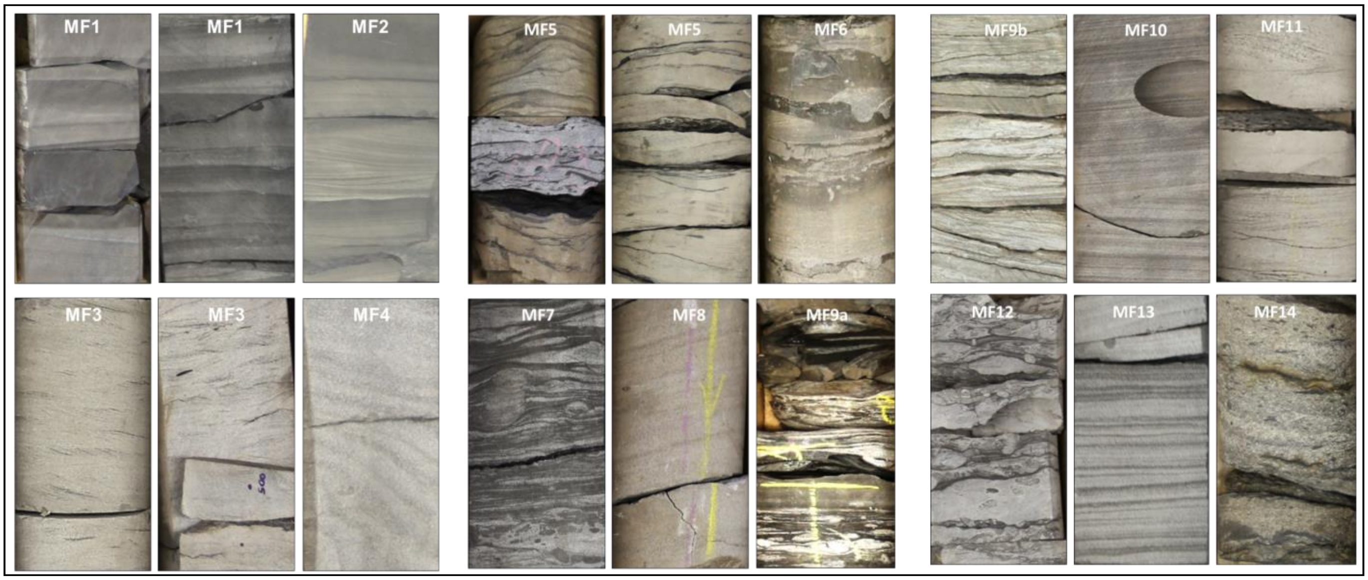

Figure-2: Lower Monteith Core facies identified in 280m core coverages in 11 wells.

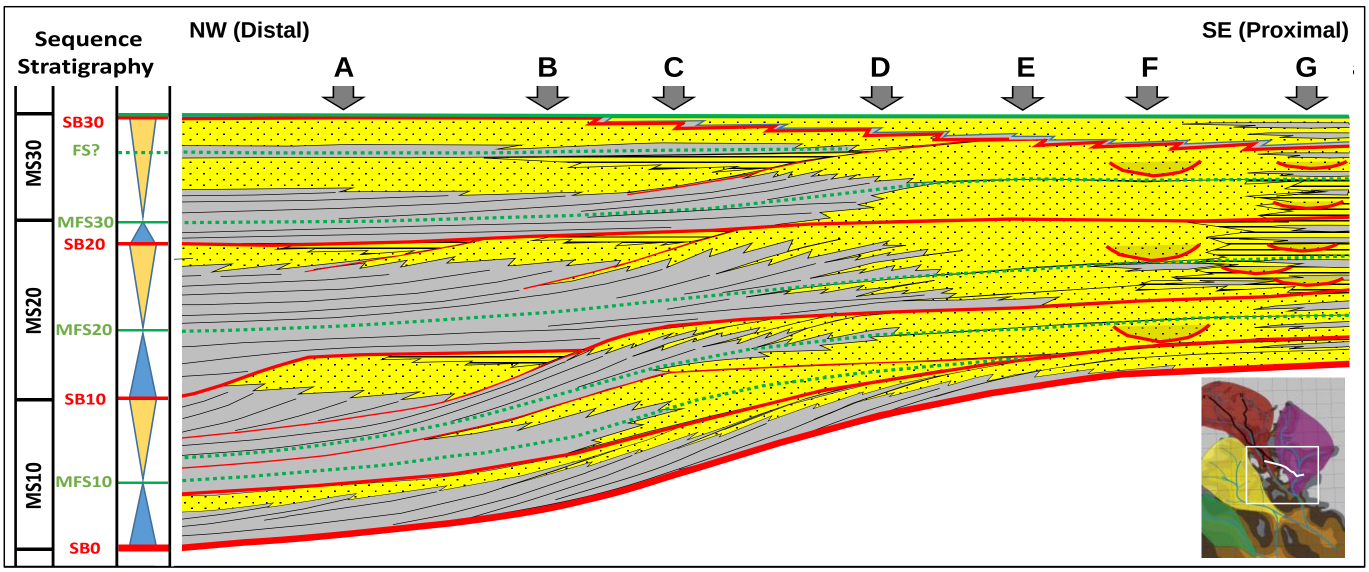

Figure-3: Generalized stratigraphic sequence model of lower Monteith "C" Formation. The white bordered block shows the approximate position of the study area and shown cross-section. The base map modified after Miles et al. 2010, is used for reference to show the approximate position of the study area and cross-section in the regional context.

These facies and interpreted depositional environments have played a key role in developing well log correlations and a sequence stratigraphic model (Figure-3). The overwhelming steeply prograding clinoform pattern can be interpreted from well logs. The rapid progradation is a definitive element of the Monteith sediments, however a deeper insight suggests that the sediments were deposited on a relatively gentle ramp with an intermittent forced regression factor that caused deposition of isolated sharp based sand bodies embedded within prodeltaic facies. Log patterns and facies support the presence of many flooding surfaces. In the well log cross-sections (flattened at the top Monteith "C"), three sequences (MS10-MS30) are interpreted which are likely to be third-order (Figure-3). The sequence (MS10) lies at the basal part of the Montieth "C". Within this sequence, the positioning of the sand bodies demonstrate a retrogradational pattern, however, due to the outpaced supply, retrogradational log patterns were seldom developed. In the sequence (MS10) two fourth order packages, or parasequences, were interpreted each with transgressive system tract (TST) and highstand system tract (HST) components. The HST of the second parasequence is followed by an interpreted falling stage system tract (FSST) based on an isolated sharp-based sand body in Well-A representing delta front facies (mainly MF3). Two sequence stratigraphic cross-sections were developed.

This FSST sand lies immediately above the pro-deltaic facies and exhibits turbidite and slump features. This facies contrast indicates forced regression. The log response and facies association of the interval just above this sand body was once again turned into pro-deltaic shale and non-reservoir facies suggesting a transgression that shifted the sandy facies landward and defines the TST of sequence MS20. A number of flooding surfaces are interpreted and subsequent to this flooding a progradation began and the sandy layers started to spread toward the distal part of the study area during HST. The same process repeated once again and sequence SB30 was deposited with two parasequences. It is observed that sands within all sequences are much thicker and connected in the proximal side as compared to distal direction. The thickness and connectivity of sands in the proximal direction and rapid facies change towards the distal side suggest an intense nature of the transgression. The rise in sea level and sediment supply must be balancing each other and thus resulted in aggradation.

Play Fairway Concept

A fairway map of Monteith "C" was developed using net/gross ratio (60% cut-off applied to Gamma Ray log), depositional environments and core facies (Figure-4). The map shows SE-NW trending, long and narrow deltaic lobes separated by relatively deeper marine areas forming tidal inlets. The proximal southwestern area has thicker, usually attached sands bodies deposited during TST and HST with frequent channel systems. These sands are connected and prograde basin-ward. Whereas the distal northwestern area has predominantly non-reservoir facies where detached sands were deposited during FSST. The detached sands of HSST and connected sands of TST and HST are potential subplays. Our model indicates that further towards the northwest, in the distal side, there must be more than one detached sand body deposited in response to the gradual falling of sea level.

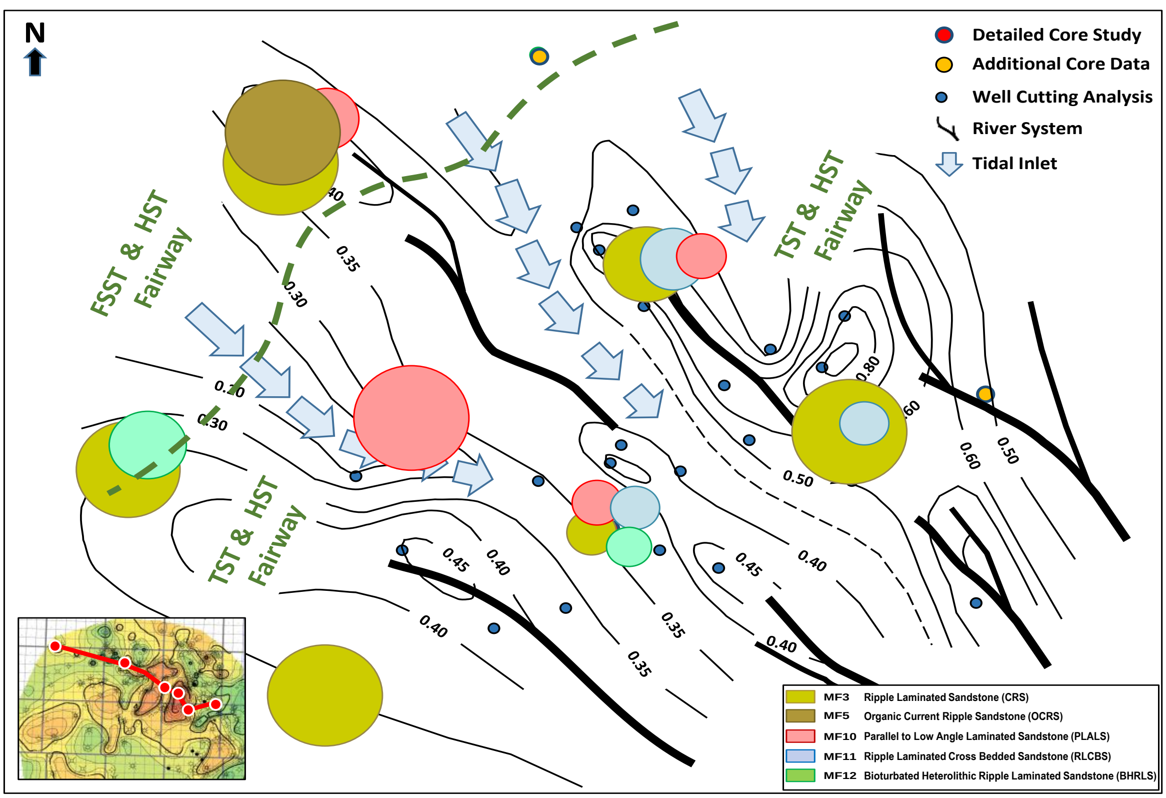

Figure-4: A simplified fairway map of the Upper Monteith "C" Formation showing the study area. On lower left is a 'Net to Gross' map of the Upper Monteith "C" for reference.

Reservoir Properties

Petrography of sandstone samples from all facies reflects that internal composition is sublitharenite with grain size ranging from lower fine to upper fine grained, occasionally trace lower medium grained, subangular to subrounded and well sorted (Figure-5). The framework grains consists of 80-92% monocrystalline quartz, 1-5% polycrystalline quartz, 5-12% chert fragments, trace plagioclase feldspar (Albite), 2-10% sedimentary rock fragments, trace mica, pyrite, siderite, organic matter and heavy minerals, with occasional trace glauconite. Rock fragments include shale and rare trace detrital dolomite. The mode of poro/perm shown in the cross plot from the core plugs data is in the range of 2-8% and 0.2-2mD. Likewise the average porosity from the thin section study also ranges from 2-8% and estimated permeability 0.2 -1.5mD. However, both data sets have several values exceeding these limits. Higher permeability values are possible due to the presence of microfractures. Porosity is not uniformly distributed and is of a patchy nature. The total porosity is mainly intragranular (secondary) developed due to the leaching of the chert grains and minor intergranular (primary) porosity, trace fracture porosity and rare trace micro-porosity. The porosity was commonly occluded by silica overgrowth cement and trace to minor ferroan dolomite cement. Clay is present as very thin rim around some of the grains and occasionally concentrated at the grain contacts. Rarely some pores are lined with bitumen and occluded by organic matter and pyrite. Occasionally iron rich clay and organic matter are concentrated along microstylolites. The XRD data shows silica (quartz and chert) 89-99%, clay mineral 1-7% as predominantly non-swelling illite. However, in some wells subordinate ferroan dolomite and siderite cement is also recorded.

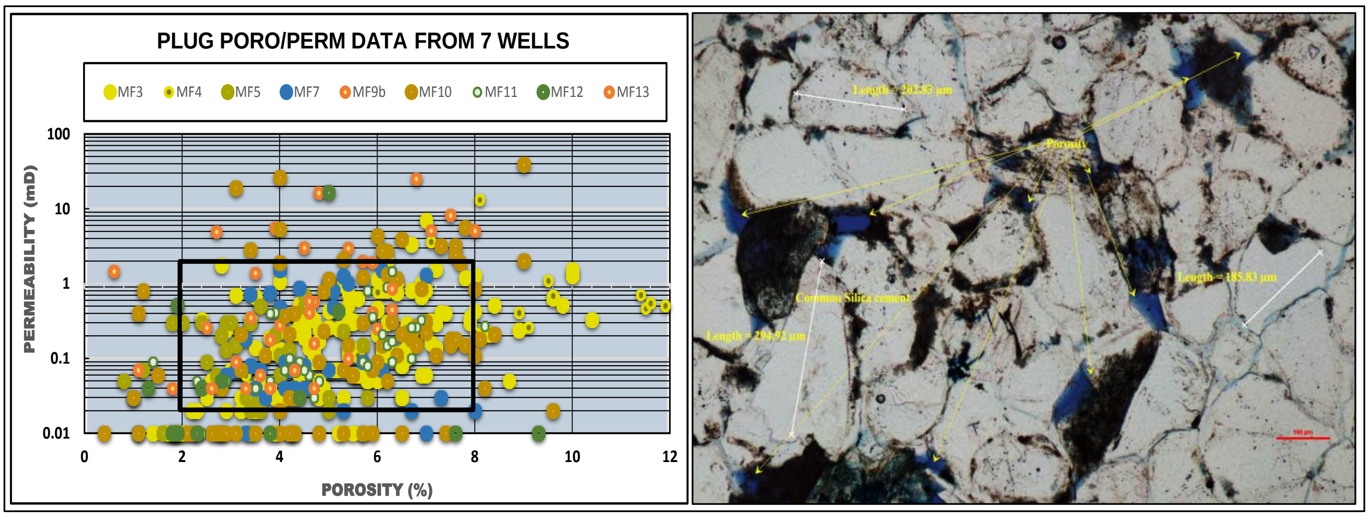

Figure-5: (left) Core plug poro/perm plot with black square encompassing the frequent occurring values; (right) thin section microphotograph from upper Monteith "C" Formation.

Conclusion

The Monteith "C" is a promising tight gas resource of the 'Alberta Deep Basin' that possesses a variety of sand subplays such as attached TST and HST deposits, detached FSST deposits and channel systems. Toward the distal side, detached sands embedded within pro-deltaic shale/siltstone are good potential stratigraphic targets depending upon appropriate structural components. The quality of the major reservoir facies do not differ much and generally show a linear poro/perm relationship. Clay content (mainly illite) is low. High quartz fraction with common quartz overgrowth making it a favourable frac candidate. However, the complex internal stratal pattern make it a difficult target. Such issues of this Monteith resource, require high resolution sequence stratigraphy that will lead to the optimization of exploration related maps and models.

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