

Sedimentology, Ichnology, Petrology and Development of 3D Conceptual Numerical Model of Bulk-Flow Properties for the McMurray Formation in the Mackay River Area, Northeastern Alberta.

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Summary

Detailed sedimentological and ichnological evaluation was done for six drilled cores from the Lower Cretaceous McMurray Formation, results shows highly burrowed interval (F1) and moderately burrowed interval (F4). Petrology examination on samples for this intervals shows poor resource quality for F1 and excellent reservoir quality for F4, also mud to sand ratio is higher for the F1. With this background knowledge, a 3D conceptual model is constructed and populated with the interpreted facies. Analytical and Numerical model shows that arithmetic mean (Horizontal permeability) characterizes the F1, while harmonic mean (Vertical permeability) best characterizes F4. Results from numerical modeling shows a vertical flow path pattern for F4 and a random nearly horizontal flow pattern for F1. This information is most suitable for the well planning prior drilling and enhance oil recovery.

Introduction

The Alberta oil sands accounts for 98% of Canada oil resource, and most of these oil are contained within the Athabasca oil sand area (AOSA). This study focuses on the lower Cretaceous (Albian-Aptian) McMurray Formation, of the Mackay river area, adjacent the main valley system bitumen fairway, with more detailed concentration on the bioturbated interval.

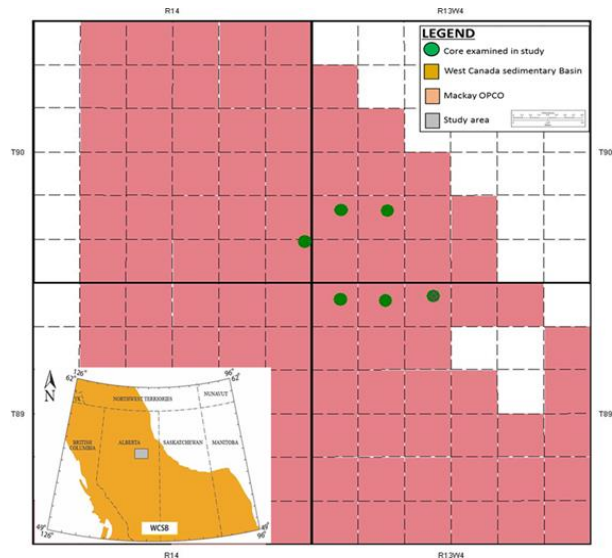


FIGURE 1: Study area. Background pattern shows portion of the Mackay OPCO area compare to the West Canada Sedimentary Basin. The location of studied core are: 1) 10-31-89-13W4; 2) 10-32-89-13W4; 3) 10-33-89-13W4; 4) 10-07-90-13W4; 5) 10-08-90-13W4; 6) 16-01-90-14W4.

Complexity in the sedimentary facies interplay has restricted detailed study within the McMurray Formation, and researchers are left with different perspective about the paleoenvironmental history (Ranger and Pemberton, 2007; Ranger and Gingras, 2007).

The study area

The McMurray Formation represent the last member of the Manville group in the AOSA, it's a thick clastic succession that was

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deposited during the Aptian-Albian time on the eastern margin of the West Canada Sedimentary Basin (fig. 1).

Method

This thesis has incorporated a sequence of scientific analytical method for adequate evaluation in order to minimize uncertainties associated with modeling. A summary of each of the methods used is discussed below.

Facies analysis takes both lithology and sedimentary features into consideration in order to describe a unit. Core analysis conducted for the context of this paper incorporated the facies classification established by Phillips et al. (2011).

Description

Facies 1 is described as heavily bioturbated sand and mud interbedded, has high degree of bioturbation, Facies 2 is described as heavily bioturbated sand with mudstone-filled burrowed with bioturbation intensities (B.I 3-6). Sand is moderately-sorted and is saturated with hydrocarbon. Facies 3 is described as weakly to moderately bioturbated wavy bedded fine grained sand, B.I range from 2-3, It is abundantly impregnated with bitumen. Fine grained sediments mostly occur as grey mudstone characterized by having a sharp base, Facies 4 is described as moderately bioturbated fine grained sandstone with mud and silt in-filling burrows. B.I range from 3-4, heavily bioturbated with Glossifungites assemblages. Facies 5 is described as moderately to heavily bioturbated planar glauconitic sand and sandy mud, belongs to the lower portion of the Wabiskaw member. Facies 6 is described as Greyish mudstone to bluish silty mud with sand inter-bedded.

Lithology accessories common within these intervals are streaks of quartz crystals, coal, shell fragments, pyrite nodules and pyrite. Common ichnogenera are; *Chondrites*, *Teichichnus*, *Thalassinoides*, *Skolithos*, *Asterosoma*, *Planolites*, robust *Rosselia socialis*, *Teichichnus*, *Spirophyton*,

Macaronichnus segregatis. *Zoophycos*. Sedimentary structures are; wavy-bedding, rhythmic inter-laminae, low-angle planar stratification, low angle horizontal stratification, current and Oscillation ripple-lamination.

Interpretation

F1 is interpreted to be background fully marine sedimentation of a shallow embayment with fully marine sedimentation. F2 is interpreted to be background bay-fill sedimentation of a stable, fully marine, shallow marine embayment. F3 is interpreted to be fully marine bay-fill sedimentation of a shallow sheltered embayment, transition between background bay fill and tidal sand bar deposit. F4 is interpreted to be shallow fully marine proximal lower shoreface deposition in a fair weather condition. F5 is interpreted to be distal offshore deposit with mixed tide- and wave-influenced deposition associated with fair weather and remnant distal tempestites above storm wave base. F6 is interpreted to be shelfal mud deposit below the storm wave base.

Influence of bioturbation on resource potential

Bioturbation has been regarded as an influencing agent of permeability and porosity in rocks (Pemberton and Gingras, 2005; Lemiski et al., 2011; Gingras et al., 2012; La Croix et al., 2013). Since trace fossils alter the textural attributes of porous media, in certain instances they may become the primary fluid conduits for the migration and production of oil, natural gas, and water. For this study, two approaches are incorporated to understand bioturbation and resource potential; Petrology and permeability modeling.

Petrology

Three thin section samples were collected from each of the six wells for thin sections analysis. Basically carried out to estimate porosity through point counting for reservoir potential

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and also identify common minerals, grain color, texture, shape and composition. The samples were impregnated with resin containing blue dye, blue epoxy stain represent the pore space. These samples are further transfer into the XRD lab to acquire information about the minerals crystallinity, polymorphs types and clay minerals present.

Statistical evaluation of bulk reservoir permeability

The total bulk reservoir permeability of a flow media can therefore be calculated using three types of averaging estimations – the Arithmetic-, Geometric-, and the Harmonic mean averaging methods on a logarithm scale (Eqn. I –III). The total bulk permeability of any flow media is a representative of the permeability of the homogenous sample in a linear and steady-state under standard pressure and boundary conditions (Pickup et al., 1995, Baniak et al., 2013). In the Equations, K_i is the permeability of each layer, d_i is the individual layer thickness, d is the total thickness, and d_i/d is the weighted volume.

$$k_{arithmetic} = \sum_{i=1}^n \frac{k_i d_i}{d} \dots\dots\dots (Eqn. I)$$

$$k_{harmonic} = \frac{1}{\sum_{i=1}^n \frac{d_i}{k_i d}} \dots\dots\dots (Eqn. II)$$

$$In(k_{geometric}) = \sum_{i=1}^n \frac{In(k_i) d_i}{d} \dots\dots\dots (Eqn III)$$

In this study the weighted volume represent the volume of clay and sand (sand: mud ratio) which are in-turn related to the burrow intensity. Based on computation using the averaging techniques above, plots of permeability in a homogenous settings versus mud: sand ratio were constructed, the three averages represent different trends in flow-path through the system. The arithmetic plot represent flow in the highest permeability direction, the Harmonic plot represent flow in the lowest permeability direction and the geometric plot represent flow in an undefined direction.

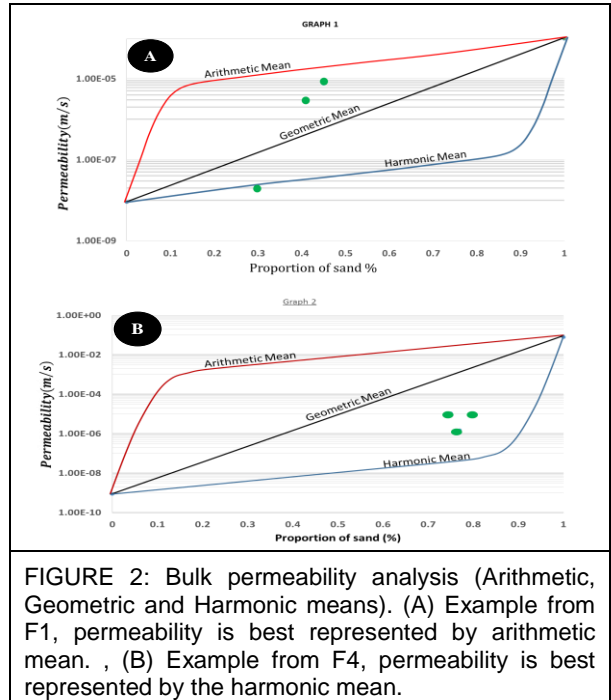


FIGURE 2: Bulk permeability analysis (Arithmetic, Geometric and Harmonic means). (A) Example from F1, permeability is best represented by arithmetic mean. , (B) Example from F4, permeability is best represented by the harmonic mean.

Numerical Modeling

A conceptual 3D model was constructed for mud and ichnogenera distribution in a grid cell with dimensions of 40 x 40 x 20 cm and was discretized so that each grid cell size is 0.4 x 0.4 x 0.2. Petrophysical property (hydraulic conductivity) was created to conform to the conceptual facies distribution trend. Fluid flows in three dimensions, as such, the conductivity property is simulate in three dimensions; K_x (Hydraulic conductivity in the direction of the model X-axis), K_y (Hydraulic conductivity in the direction of the model Y-axis) and K_z (Hydraulic conductivity in the direction of the model Z-axis). Boundary conditions were set to honor the flow directions, and it helps to define the exchange of flow between the model and the external system. Start (100m) and stop (101m) heads were assigned as input and output respectively. From the Flow simulation using the Visual MODFLOW software, input and discharge (Q) values are derived for each run.

$$Q \propto A \frac{h_1 - h_2}{L} \quad Q = -KA \frac{\Delta h}{L} \dots\dots\dots (Eqn. IV)$$

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Bulk permeability values are therefore calculated using Darcy's equation and from the hydraulic conductivity values derived from the steady-state flow model in Visual MODFLOW at constant initial head boundary. The arithmetic-, harmonic-, and geometric average can therefore be calculated from logarithm point graph.

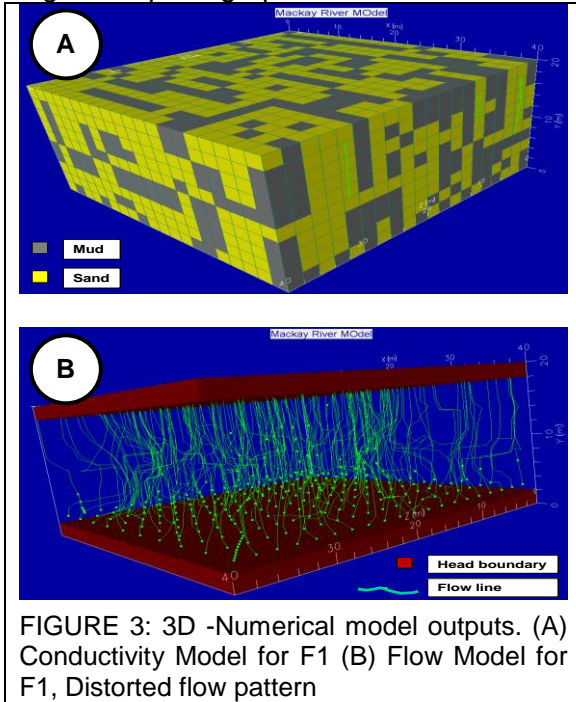


FIGURE 3: 3D -Numerical model outputs. (A) Conductivity Model for F1 (B) Flow Model for F1, Distorted flow pattern

Results

Based on petrology analysis, the lower part of the studied area is composed of quartz-rich lithic sandstones with Precambrian cratonic source inferred, and the upper portion range from lithic sandstone to subarkosic sandstone. Results from diffractograms indicate that the samples main constituent is quartz in about 90 percent proportion of the entire rock volume and it is the same for all the six samples analyzed, kaolinite clay present.

Results from the relationship between weighted volume and permeability is plotted on the graph in fig. 2A & B. From the first sample Data point superimposed from Model bulk permeability plotted in the arithmetic domain, indicating preference to horizontal permeability. The second graph shows flow characterized by harmonic mean. Vertical permeability preferred.

Presence of clay intercalations and interlaminations- low permeable fabrics in a flow system will affect the resource potential of the media. Results from flow simulations shows that preferred flow path for F1 is horizontal and vertical for F4 (figure 3 & 4).

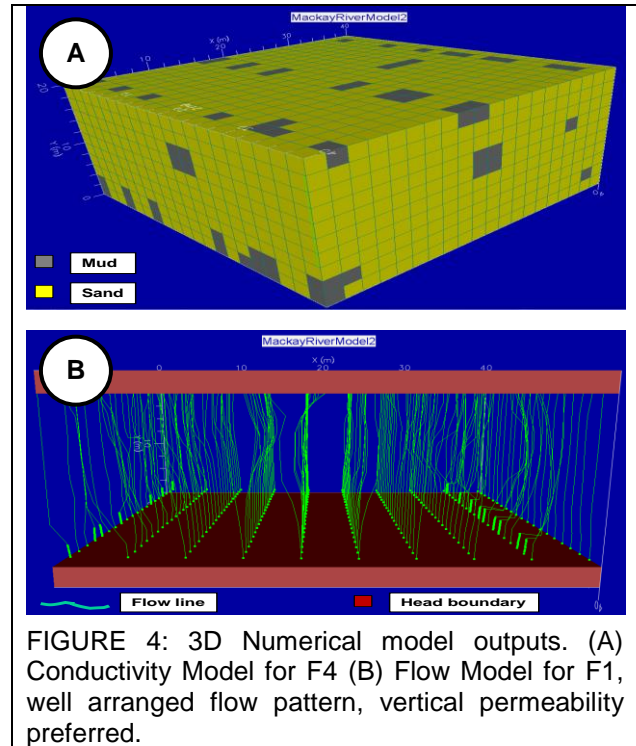


FIGURE 4: 3D Numerical model outputs. (A) Conductivity Model for F4 (B) Flow Model for F1, well arranged flow pattern, vertical permeability preferred.

Conclusions

Particle most preferred migration path is dependent on the distribution of non-permeable fabrics within the system. In the massive sand facies, flow-path line is smooth and in specific alignment, indicating homogenous and isotropic condition for fluid flow, however, within the highly bioturbated facies, the flow-path lines are very random and scattered though the media. Particles tend to follow the higher permeable zone, and therefore gives a much distorted overall pattern.

Acknowledgements

I will like to thank Schlumberger, and geoLOGIC systems Ltd. for the software's used.

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