Qualitative and Quantitative Characterization of McMurray Formation Chute Channel Deposits with Implications to Oil Recovery

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Summary

Chute channels are common in modern meandering river deposits, and also recognized in the Lower Cretaceous McMurray Formation outcrops and subsurface (Fustic et al., 2013; Fustic et al., in press). Of particular interest to this study are two chute channel deposits exposed at the McMurray Formation Type Section (Fig. 1A-C), described as encased channels within inclined heterolithic stratification (IHS) of upper point bar deposits, and interpreted as products of short lived channels (Fustic et al., 2013).

To improve understanding of the nature of selected chute channel deposits, criteria for their recognition in the subsurface, and the impact on oil recovery. These two exposures were studied using advanced photogrammetry and digital outcrop characterization technology. Three-dimensional outcrop models were constructed from hundreds of georeferenced images taken by unmanned aerial vehicles (UAV), and generated models were used as a portal for reservoir architecture mapping including measurements of individual channel widths, thicknesses, and areal extents.

The erosional nature of contacts at the base suggests that the incision and early deposition are caused by high-energy flood events. Each chute deposit is comprised of three architectural elements: cross beds and/or breccia at the base; lateral accretion; and vertical accretion deposits. Overlying lateral and vertical accretion indicate a period of steady flow and progressive chute channel infill. The presence of lateral accretion sets suggests that channels experienced a constant flow and migration for an extended period of time. Both channels are sand dominated. Modern and ancient depositional analogues are used to refine two proposed conceptual depositional models including (i) two contemporaneous chute channels (Fig. 1D), and (ii) a single curvilinear chute channel exposed at two different locations on the studied outcrop (Fig. 1E).

Data and proposed depositional models provide criteria for distinguishing chute channel deposits from stacked channel deposits in drilled wells and demonstrate that chute channels contribute to increased reservoir connectivity and potential to increase oil recovery.

Introduction

Meandering river chute channels, defined as narrow passages across point bars through which water flows rapidly, are commonly caused by flood events. Studies dealing with chute channel depositional processes and architecture are rare. Examples include modern chute channel studies by Constantine et al., (2010), Gay et al. (1997), Zinger et al. (2011) and ancient chute channel deposit studies by Ghinassi (2011) and Ghinassi et al., (2013 and 2016). None of studies reported the impact chute channel deposits may have on reservoir connectivity and inferred petroleum recovery.

The McMurray Formation is the primary host of one of the world largest oil reservoirs known as the Athabasca Oil Sands Deposit. The McMurray Formation Type Section, located on the Athabasca River was described by many authors in the past (Bell, 1884; McConnell, 1893; Ells, 1914; McLearn, 1917; Carrigy, 1959; Hein et al., 2001; Fustic et al., in press). The outcrop is comprised of three stratigraphic units named Early, Late, and the Latest McMurray (Fustic et al., in press). The sedimentology and reservoir architecture had been interpreted only qualitatively.

Recent technology advancements in photogrammetry for outcrop modeling and visualization are utilized to refine qualitative descriptions and provide the quantitative analyses of selected chute channel deposits with the aim to: 1) document and compare dimensions of channels and architectural elements; 2) interpret depositional processes (erosion, accretion, aggradation) and overall channel morphodynamics; 3) discuss implications for petroleum reservoir developments with focus on Steam Assisted Gravity Drainage (SAGD) operations.

Methods

Three dimensional outcrop modeling and visualization, includes (i) high resolution imaging by UAV's; (ii) creation of three-dimensional (3D) surface models; and (iii) measurements and both qualitative and quantitative interpretation of geological features. Pix4D Mapper Software (product of Pix4D Inc.) was used for processing images, creating realistic 3D outcrop models, and measurements.

Digital photogrammetry applies the same principles of classical photogrammetry. Multiple overlapping, low distortion georeferenced images with decimeter scale relative accuracy allows for precise definition of millions of points used to build three dimensional meshes. The precise photo location information obtained by global positioning system (GPS) mounted on camera is carried in each color digital image. Software processes both red-green-blue (RGB) and GPS information, to produce photo-realistic 3D models. The technology is superior for studying spatial characteristics of geological features. It is faster, more reliable and more precise than characterization using conventional outcrop mapping, scaled gigapan images and LIDAR (Light Imaging Detection and Ranging).

Described channel deposits and their relationship with hosting IHS of a large-scale point bar deposit, are used as a portal for creating conceptual diagrams about the impact on steam chamber growth in SAGD operations.

Examples

Compared with interbeds of fine-grained sandstone and mudstone in IHS, coarser-grained sandstone formed in chute channels is characterized by better reservoir properties in terms of porosity and permeability. Additionally, chute channels improved the connectivity between individual sandstone beds within IHS (Fig. 2C). Considering substantial chute channel width, thickness, and areal extent (Table 1) a potentially significant impact on SAGD operations may be inferred.

In SAGD, two parallel wells are placed closely at the bottom of the reservoir. In the absence of sand-filled chute channels, mudstone beds of IHS will have higher impact on preventing steam growth (Fig. 2A-B). In contrast, the presence of encased sand-filled chute channel deposits improves reservoir connectivity and steam growth accessing more of the reservoir (Fig. 2C-D).

Conclusions

Photogrammetry and constructed 3D outcrop models proved to be useful for detailed mapping and characterization of two chute channel deposits exposed at the McMurray Formation Type Section.

Chute channel deposits are composed of three architectural elements: channel base comprised of breccia in Chute 1 and cross-beds in Chute 2; short lateral accretion sets; and predominant vertical accretion deposits. Two channel exposures at similar elevations can be interpreted as two contemporaneous chute channels, or perhaps parts of the same chute deposit exposed at two different locations along the outcrop.

The presence of sand-filled chute deposits within IHS of upper point bar deposits improves reservoir connectivity, inferring better oil recovery by Steam Assisted Gravity Drainage technology.

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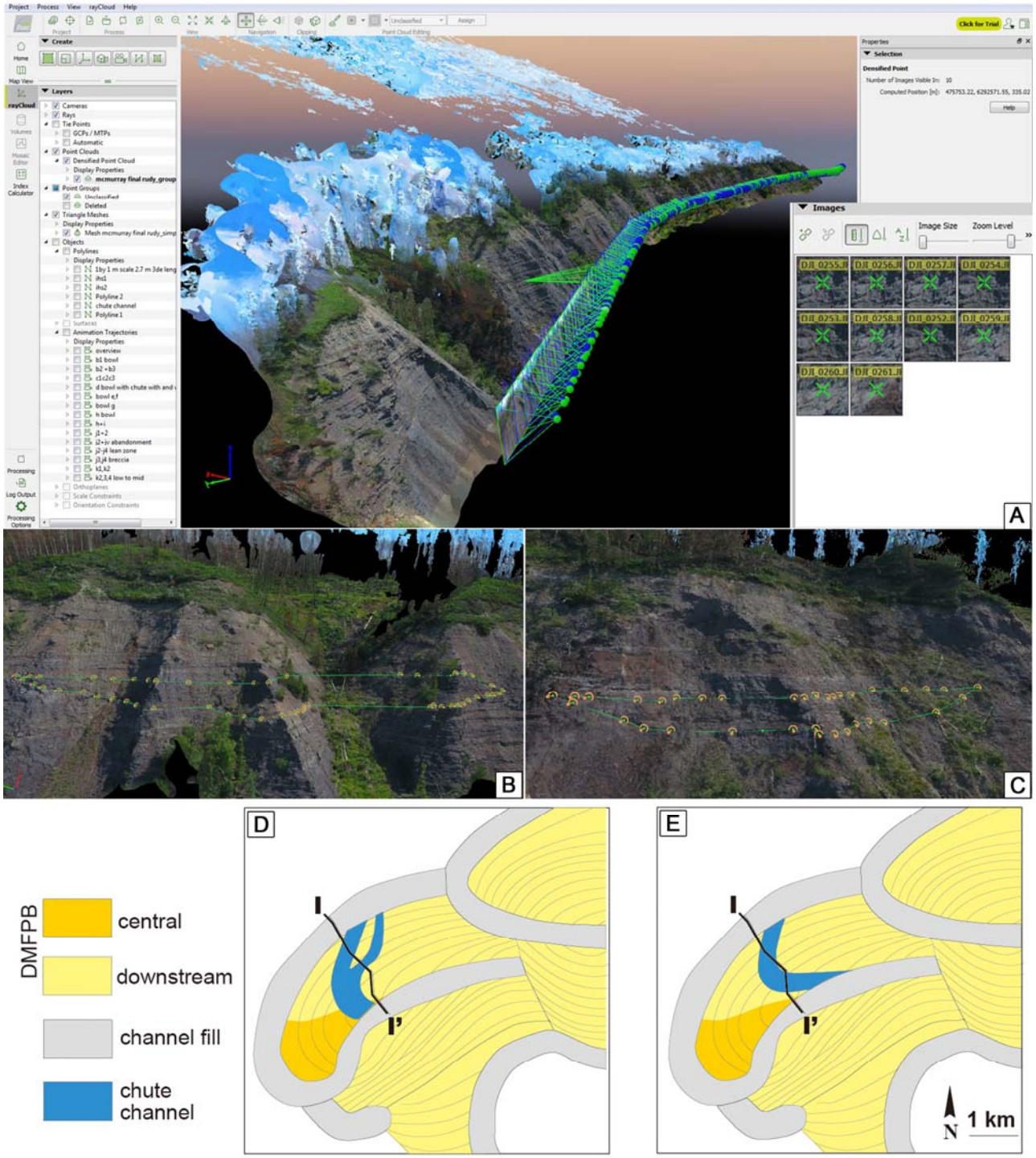

Figure 1. (A) Three-dimensional outcrop model (Pix4D Mapper) of McMurray Formation Type Section created from 195 photos at the distance of 70-80m from the outcrop. Drone location (green dots) and individual photo coverage (blue rectangles) of each used photo. Blue areas above the outcrop are processing artifacts. Inset shows 10 photographs used to georeference a single point in 3D mesh (multiple merging green lines); (B) Chute Channel 1 model created from 26 images. (C) Chute Channel 2 model created from 20 images. (D-E) Depositional model scenarios: (D) Two contemporaneous chute channels. (E) Single chute channel exposed at two different locations. I – I' hypothetical position of McMurray Formation Type Section outcrop. (D-E) modified from Ghinassi et al., 2016.

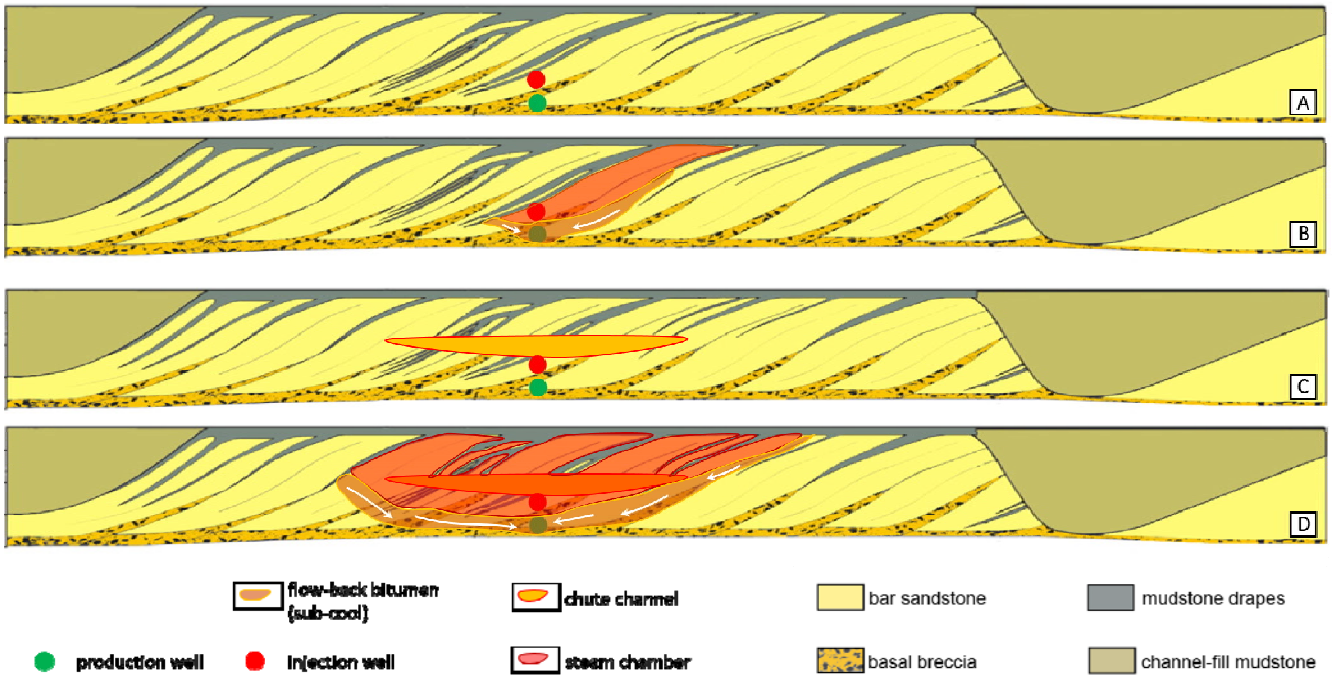

Figure 2. Schematic presentation of the impact of sand-filled chute channel deposit on steam growth in SAGD developments. (A-B) The placement of SAGD well-pair within point bar deposit and inferred steam chamber growth; (C - D) inferred production by SAGD well-pair in point bar with encased sand-filled chute channel. McMurray Formation point-bar model (background) modified from Ghinassi et al., 2016.

Chute Channel 1						
		Thickness (m)	**Width (m)**	**Area (m^2)**	**Base (m)**	**Top (m)**
entire		7.46	111.91	640.97	112.75	110.26
		Thickness (m)	**Width (m)**	**Area (m^2)**	**Number of beds**	
lateral accretion		na	12.5	36.4	4	
breccia		3.73	107.8	221.63	na	
vertical	**period1**	na	8.69	50.81	3	
accretion	**period2**	4.26	101.25	310.98	7	
Chute channel 2						
		Thickness (m)	**Width (m)**	**Area (m^2)**	**Base (m)**	**Top (m)**
thinner		3.62	51.31	138.7	53.43	51.55
thicker		4.24				
		Thickness (m)	**Width (m)**	**Area (m^2)**	**Number of beds**	
lateral accretion		na	3.95	7.31	3	
cross-beds	**thinner**	0.97	19.93	13.83	na	
	thicker	1.45				
vertical accretion		2.88	51.31	117.72	5	

Table. Chute 1 and Chute 2 measurements. Note: limited lateral accretion and predominance of sand-dominated vertical accretion fill in both channels.