

Modeling Lateral Accretion in McMurray Formation Fluvial-Estuarine Channel Systems: Grizzly Oil Sands' May River SAGD Project, Athabasca*

Duncan Findlay¹, Thomas Nardin¹, Alex Wright¹, and Raheleh Salehi Mojarad¹

Search and Discovery Article #51014 (2014)

Posted September 8, 2014

*Adapted from extended abstract prepared in conjunction with oral presentation at CSPG/CSEG/CWLS GeoConvention 2014, (Adopt, Refine, Sustain) Calgary TELUS Convention Centre, Calgary, AB, Canada, 12-16 May 2014, AAPG/CSPG©2014

¹Grizzly Oil Sands ULC, Calgary, Alberta, Canada (tom.nardin@grizzlyoilsands.com)

Abstract

Large-scale fluvial-estuarine point bars and other laterally accreting channel systems in the McMurray Formation represent the most important reservoirs in the Athabasca oil sands region of Alberta. For SAGD (steam-assisted gravity drainage) developments, steam chamber growth, steam/oil ratios, production rates and recovery efficiencies are strongly dependent on sand body thickness, connectivity and heterogeneity. As a result, an industry goal has long been the construction of geologic models and reservoir simulations that realistically represent the reservoir architecture and flow units in these complex systems (e.g., Deschamps et al, 2012, Su et al, 2013). However, until recently, computing power and software limitations necessitated the broad use of “flat” layered models that exhibit simple “follow top” or “follow base” layering geometries.

The purpose of this paper is to present a geologic model that captures the geometries of inclined heterolithic stratification (IHS), inclined sands (IS) and their associated basal channel sands. The model integrates McMurray Formation outcrop observations with core, log and 3D seismic data from Grizzly Oil Sands' May River SAGD Project. The methodology used to construct the model wherein lithofacies, petrophysical properties, and conditioning parameters are distributed chronostratigraphically are discussed. The model has been upscaled for simulation so the potential effects of IHS on steam chamber development can be investigated.

Location and Stratigraphy

The Grizzly Oil Sands May River property is located in Township 77, Ranges 8 and 9 W4M, approximately 14 km northwest of Conklin, Alberta ([Figure 1](#)). Grizzly has submitted an application to the Alberta Energy Regulator in December 2013, to develop 12,000 bpd of bitumen from the McMurray Formation using SAGD technology. At May River, the McMurray is divided into three stratigraphic units whose boundaries are defined by unconformities or flooding surfaces ([Figure 2](#)). In ascending stratigraphic order, these units are the Lower McMurray, McMurray B and McMurray A, respectively, using terminology adopted from the Alberta Energy and Utilities Board Report 2003-A (2003). The Lower McMurray directly overlies the sub-Cretaceous unconformity and consists of thin sands, carbonaceous mudstones and rooted

horizons interpreted to have been deposited in a floodplain setting. The McMurray B is incised into the Lower McMurray over most of the area, contains single-story, and amalgamated multi-story channel sand bodies that are the reservoirs proposed for SAGD development. The McMurray A consists of basal mudstones and an upward-coarsening succession of very fine-grained sands characterized by wave ripples and swaley to hummocky cross stratification. This unit is interpreted to be an offshore to shoreface succession deposited in a brackish bay setting. The Wabiskaw C, a glauconitic and argillaceous sand at the base of the Clearwater Formation, overlies the McMurray A.

Sedimentary structures, ichnofacies, vertical grain size trends, stratal stacking patterns, dip meter logs and seismic data indicate that the McMurray B is comprised of laterally accreting channel deposits and associated overbank sediments. The succession is similar in vertical scale (40 m) to the large-scale point bar deposits documented elsewhere in the Athabasca oil sands region (e.g., Hubbard et al, 2011; Jablonski, 2012; Nardin et al, 2013). The basal section is characterized by thick, cross-bedded channel sands. The succession generally fines upward transitioning to current rippled IS, sandy IHS and more mud-prone IHS toward the top. The degree of bioturbation also tends to increase up section. Core examples of lithofacies used in the geologic model are shown in [Figure 3](#).

Mudstone clast beds may occur anywhere in the succession and the ability to correlate them between wells depends largely on their origin (Nardin et al, 2013). Where tabular clasts have characteristics (thickness and lithology) identical to those of associated in-place IHS mudstones, the clasts are interpreted to have been derived from erosion of IHS. In this case, outcrop analogues suggest that the clast beds are oriented along the dip length of the lateral accretion surfaces ([Figure 2](#)). As the lengths of the beds in the dip direction are typically shorter than the well spacing, these clast beds cannot be correlated. In contrast, where thick clast intervals occur near the base of a channel fill and the clast lithologies are dissimilar to associated in-place mudstones, the clasts are interpreted to be the product of cutbank erosion. These clast beds commonly mark the amalgamation of multi-story channel sands and can be correlated between wells. Matrix-supported clast facies and discontinuous clast-associated IHS are considered baffles to steam rise, as pathways exist for bitumen drainage.

Methodology and Results

The geologic model encompasses the entire development area (2.6 sections) and is controlled by 27 core holes (480 m average spacing) tied to 3D seismic. The following first-order stratigraphic surfaces are represented in the model: sub-Cretaceous unconformity, base McMurray B, base McMurray A, base Wabiskaw B, base lower Clearwater Shale, and Clearwater Marker. The McMurray B stratigraphy is further divided into three amalgamated channel units and a superjacent unit comprised of overbank deposits. With the exception of the McMurray B, the cells are layered to conform to the top of each zone.

Although the 3D seismic data proved useful in interpreting the top and base of the McMurray B and the boundaries of individual channel trends, the pattern of lateral accretion could not be consistently determined. As a result, dipmeter data were used to identify the dominant lateral accretion dip azimuth and angle at each well location within each channel trend. These data were then used as a guide to construct curvilinear dip surfaces and inclined grids, which served as the stratigraphic framework for conditioning the reservoir portion of the model.

Lithofacies were upscaled and modeled in Schlumberger's Petrel 2013.3 software using the Sequential Indicator Simulation algorithm and following a vertical proportion curve established from lithofacies analysis. Where the areal extent of IHS lithofacies is less than the well

spacing, the construction of variograms based on well data is not appropriate for two reasons. Firstly, variogram dimensions tend to converge on the average well spacing rather than on the actual lithofacies extent. Secondly, as IHS lithofacies are distributed chronostratigraphically along lateral accretion bedding, layers within the inclined grid rarely intersect more than a single well. In the May River model, variograms are based on McMurray mudstone bed length and clast distributions observed in similar facies exposed at Syncrude Canada's Mildred Lake mine (Figure 4; Nardin et al, 2013). This approach results in more realistic stratal geometries and lithofacies distributions as illustrated in Figure 5. The pay interval is characterized by high net/gross lithofacies (S, S15, SIHS and C; Figure 3). The net/gross tends to decrease up section, reflecting an increase in the proportion of more mud-prone IHS near the top of the section.

Reservoir properties were introduced using the Sequential Gaussian Simulation algorithm keyed to each lithofacies and honoring vertical reservoir trends observed in the data. The cells are 7 m × 7 m × 0.3 m in size and are populated with porosity, permeability, and oil saturation values. Porosity values are determined from logs. Oil saturations are calculated from Dean Stark mass weight data and log porosities. The horizontal permeability data are populated following the porosity model as a secondary attribute.

A representative block within the completed model was selected for simulation and upscaled to a resolution of 7 m × 0.9 m × 0.9 m. The cells in the upscaled grid are layered parallel to producer-injector well pairs in an interval from the base of the McMurray B to a height of 5 m above the injector. Above that to the top of the McMurray B, the cells are inclined parallel to the geomodel. The resulting CMG STARS simulation shows that the shape and rate of steam chamber growth is strongly influenced by the distribution of IHS lithofacies. If wells are drilled perpendicular to the direction of lateral accretion, steam tends to rise along permeable sands between muddy IHS beds (Figure 6). Predicted steam-oil ratios and recovery factors average 2.7 and 60%, respectively. Peak oil rates per well pair range from 130-180 m³/day.

Conclusions

The described methodology allows for the construction of geologic models of laterally accreting channel systems that closely mimic the stratal architecture observed in McMurray Formation outcrops and 3D seismic volumes. Variograms based on field measurements of the areal extent of IHS lithofacies are preferable to using well data alone. Models that capture lateral accretion geometries and distribute lithofacies and petrophysical properties chronostratigraphically will result in more realistic representations of flow units and improved prediction of steam steam-oil ratios, recovery efficiencies and the pattern of steam chamber growth and bitumen drainage.

These models also make possible better planning of horizontal well pair trajectories. At May River, the orientations and shapes of the drainage patterns and the trajectories of the producer-injector well pairs are designed to maximize bitumen recovery based on pay trends, base of pay structure, and lateral accretion dip azimuths. Where possible, the wells are aligned at high angles to IHS dip azimuths in order to maximize bitumen drainage from pay higher in the section.

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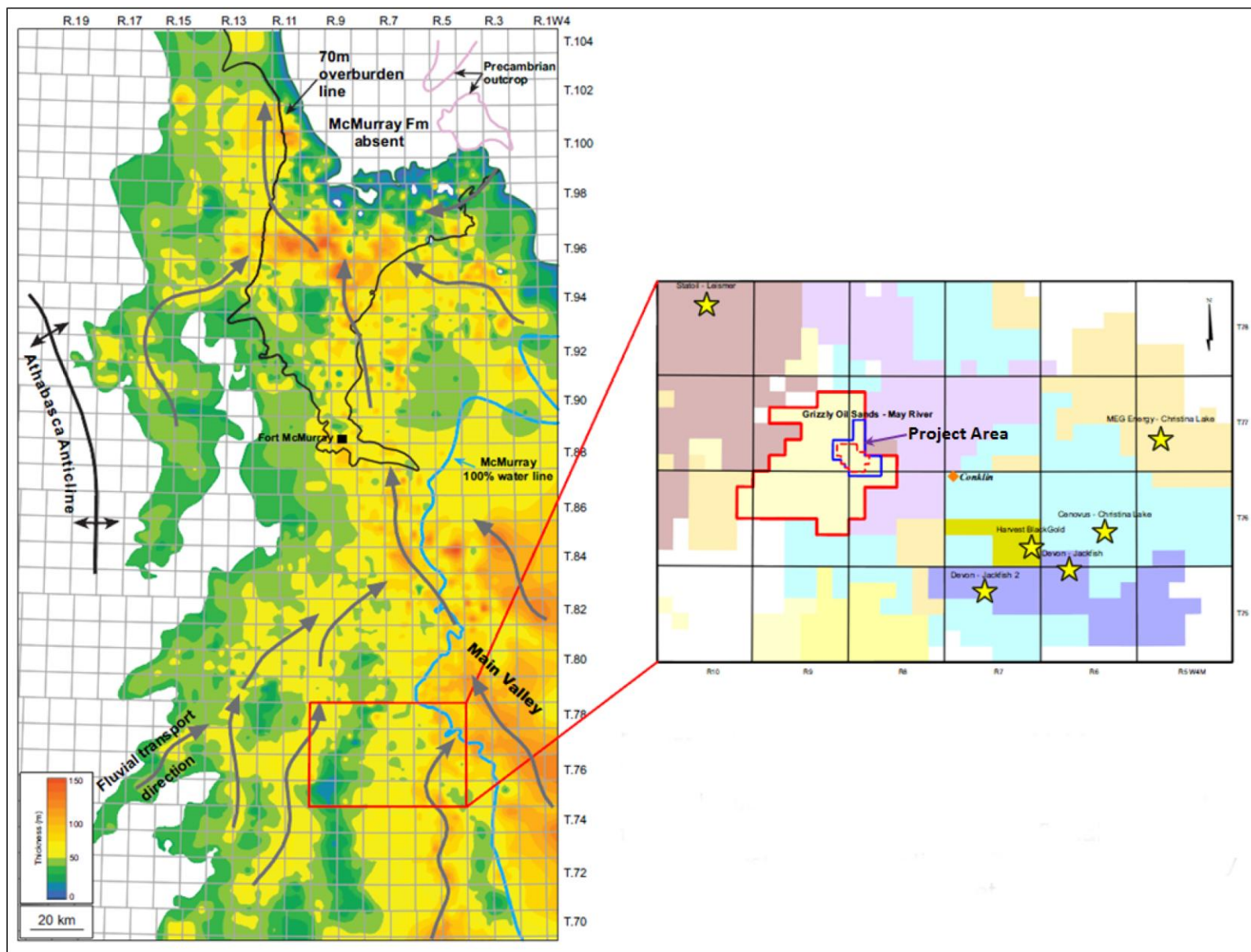


Figure 1. Isopach of Athabasca area McMurray-Wabiskaw succession (Modified from Nardin et al., 2013). Isopach values less than 40 m have been omitted to enhance visualization of the Aptian fluvial-estuarine drainage system. The location of Grizzly Oil Sands' May River Project is shown in the inset.

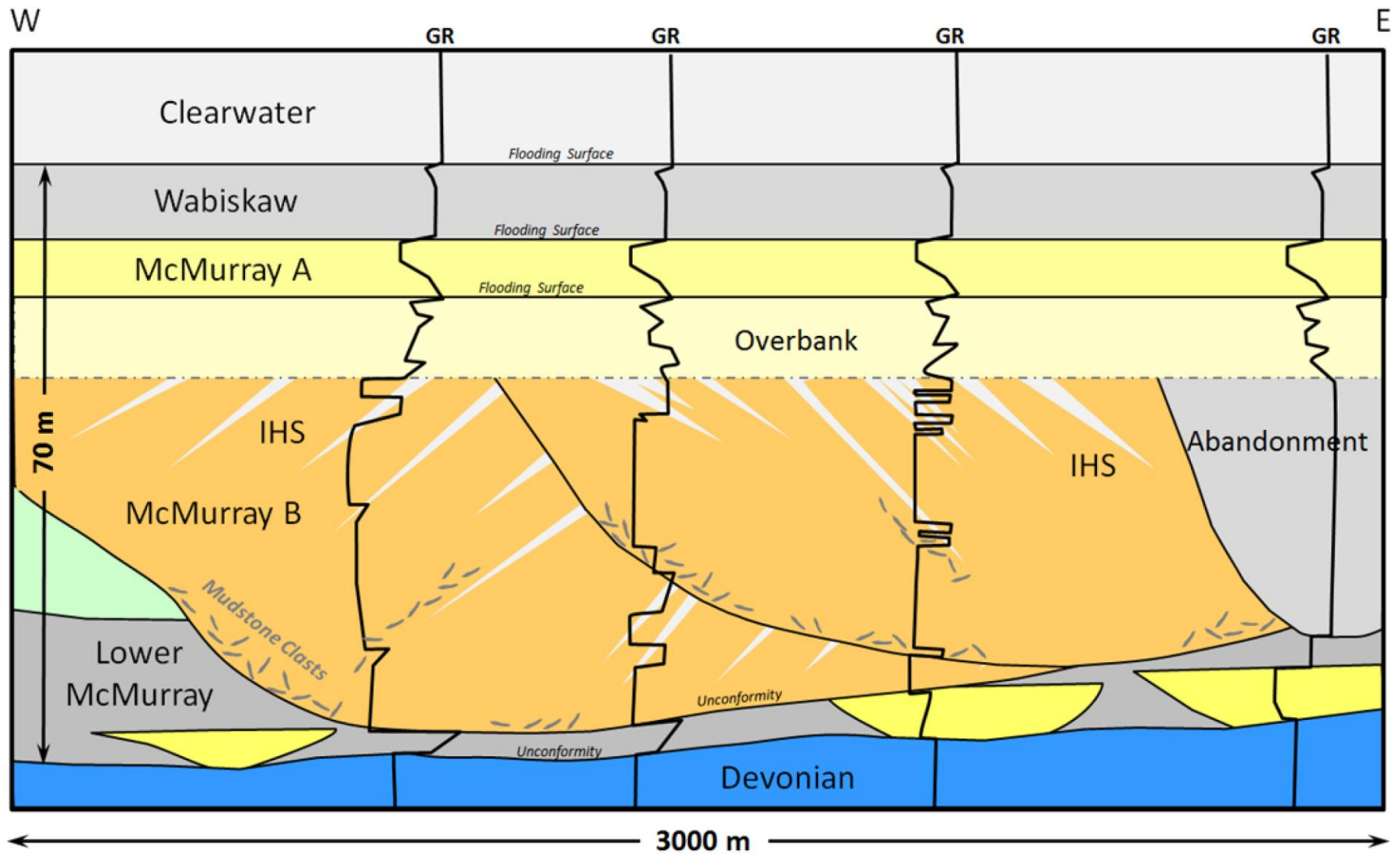


Figure 2. McMurray Formation sequence-stratigraphic framework illustrating McMurray B amalgamated sand bodies in laterally accreting channel systems.



Figure 3. Core examples of the McMurray B lithofacies used in the May River geologic model.

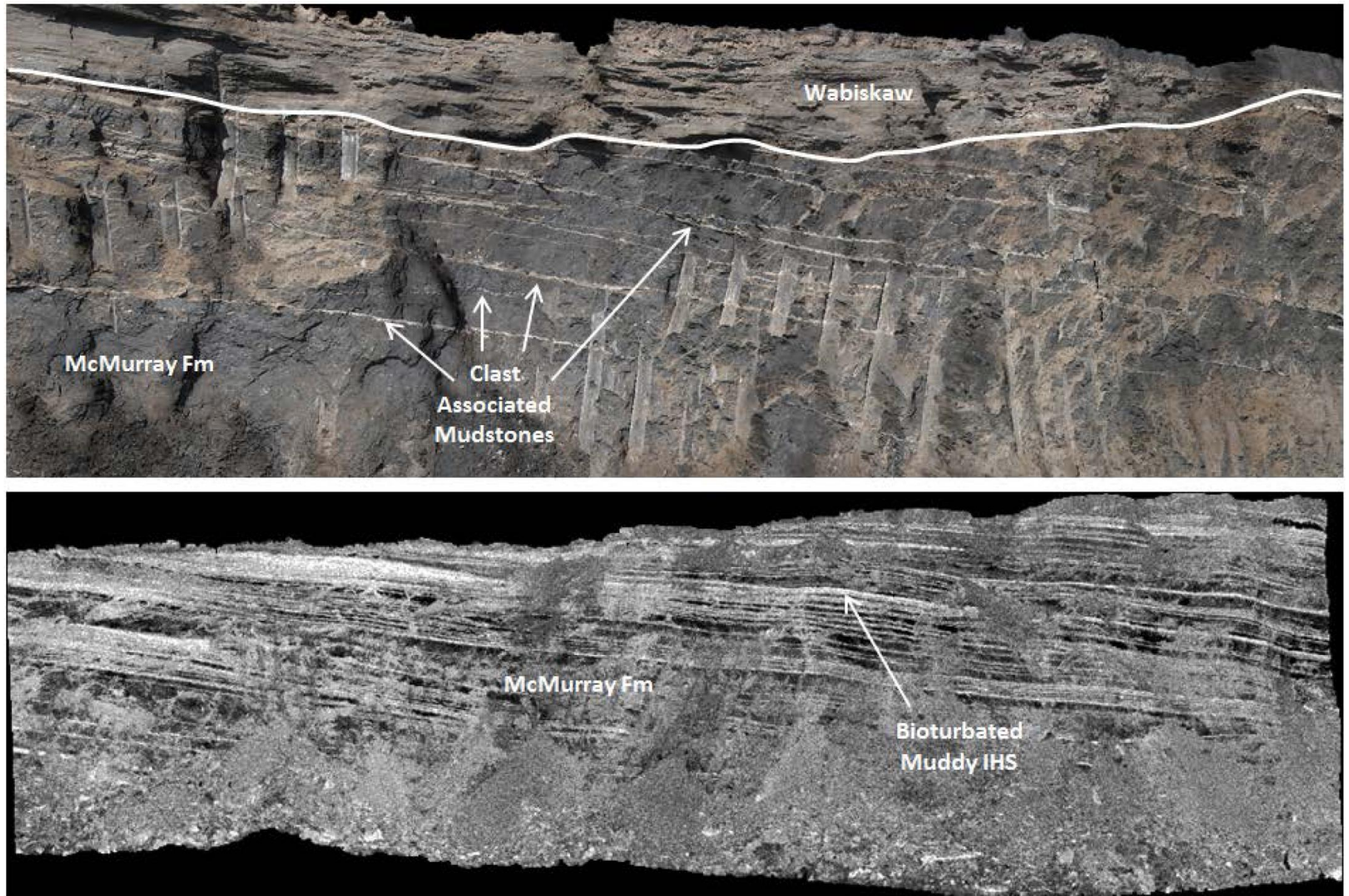


Figure 4. Examples of McMurray IHS lithofacies from Syncrude's Mildred Lake mine. The upper panel shows discontinuous clast-associated mudstones truncated beneath the basal Wabiskaw unconformity. Bioturbated continuous mudstones and interbedded sands are shown in the lower panel. Bed length and frequency distributions for these lithofacies are documented in Nardin et al. 2013.

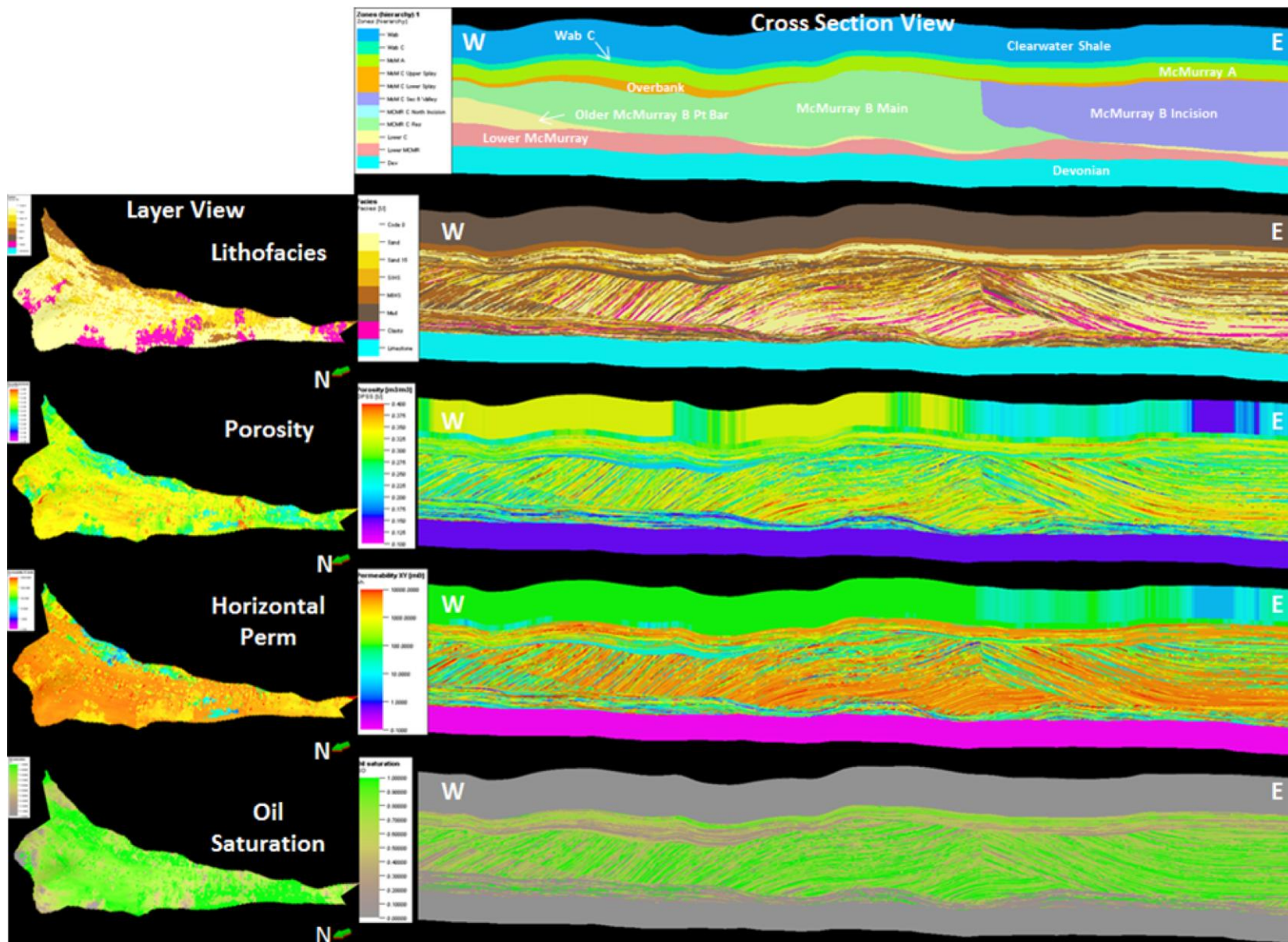


Figure 5. Layer and cross section views at 5X vertical exaggeration from the May River geologic model. From top to bottom, the panels illustrate the stratigraphic framework and the distribution of lithofacies, porosities, permeability and oil saturations. Note the discordant channel boundaries and the distribution of IHS lithofacies, clast intervals and reservoir parameters along lateral accretion bedding within each channel fill.

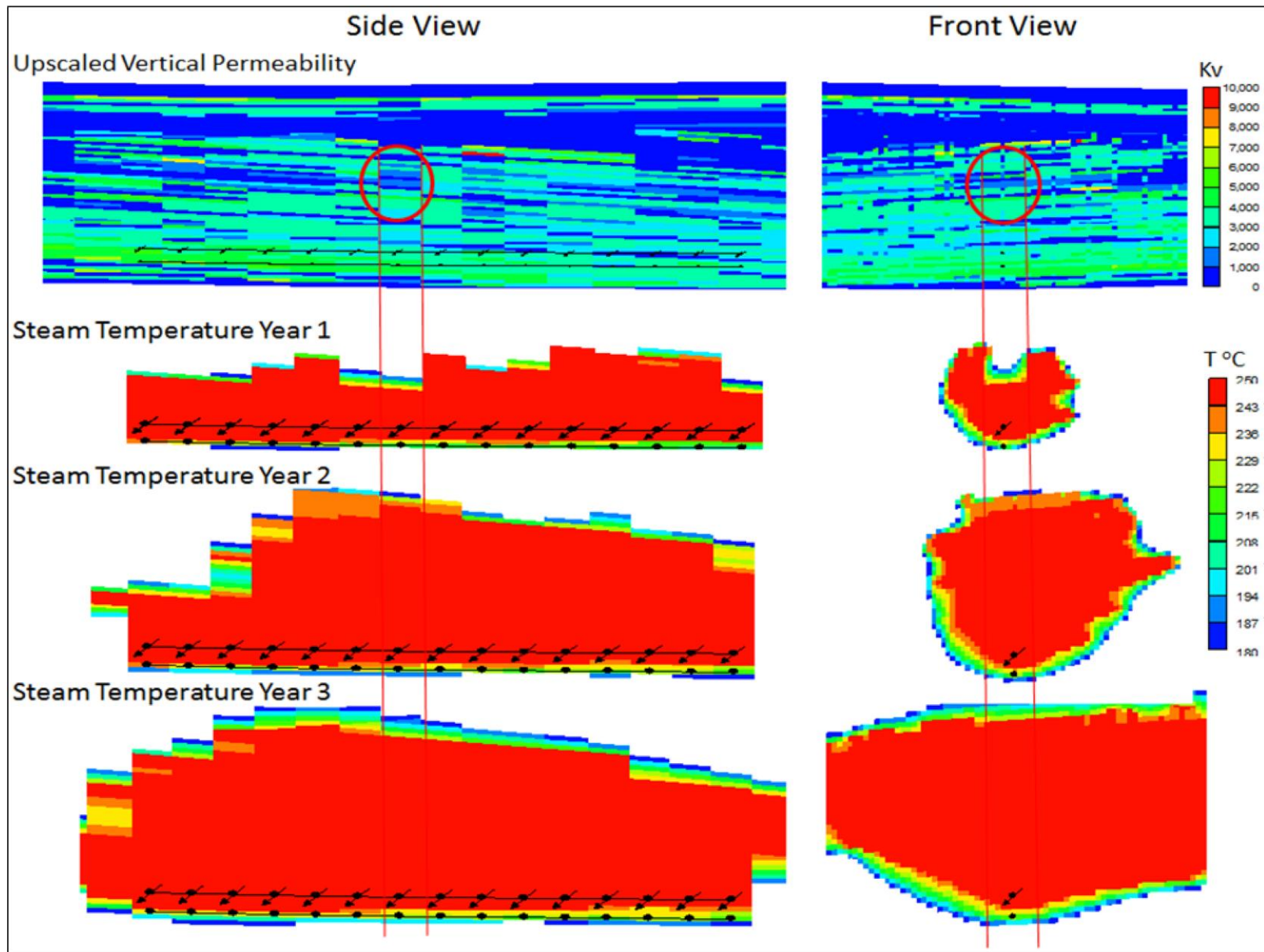


Figure 6. Results from reservoir simulation showing upscaled vertical permeability model and tortuous steam rise through IHS. Note the influence of low permeability baffles indicated by red circles.