Conditional Grid-Free Object-based Modeling of IHS Facies

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The grid-free facies modeling approach was presented in the 2010 CCG Annual Meeting (paper 107 and 203 in Report 12). In this paper, a methodology is presented to condition the grid-free model to the well data. This method works based on the rejection algorithm. Geometrical operations (rotation and translation) are performed on the rejected channel to decrease the computation time by avoiding iterations. The developed methodology was applied on two different data set to illustrate the methodology.

1. Introduction

The McMurray Formation was deposited within the fluvial-estuarine environment (Carrigy, 1959; Flach, 1984; Smith, 1987). Carrigy (1959) subdivided the McMurray Formation into three stratigraphic units. The Lower McMurray unit mainly contains massive or high angle fine to coarse pebbly sands and considered to be deposited within the fluvial environment. The Upper Unit of the McMurray Formation is known by horizontal strata which are often in sharp contrast to Inclined Heterolithic Strata (IHS) beds of the middle McMurray. The middle unit of the McMurray Formation is thickest and contains the best reservoir sands that were deposited within a tidally influenced middle to outer estuarine system (Ranger and ginger, 2003).

Beside the abandoned channel-fill facies which are predominated by mud and considered as permeability barriers, there are two distinct reservoir facies associations available in the middle McMurray unit (Ranger and ginger, 2003); the large scale cross-stratified sand and the inclined heterolithic stratification.

The cross-stratified sand is characterized by excellent porosity and permeability and high bitumen saturation. Ranger and Gingras (2003) suggested considering this facies in the lower (outer) estuary proximal to the estuary mouth. The clean sand of this facies association is the most desirable reservoir facies.

The IHS is the main reservoir facies in the McMurray Formation. IHS packages consist of inclined repetitive sets of decimeter to meter thick couplets of sand and mud. IHS varies in contents from those dominated by clean sand to those composed almost of mud. It has been proven that the majority of IHS deposits are generated as a result of point bar lateral accretion within meandering channel of freshwater rivers, tidally influenced rivers and creeks draining intertidal mudflats (Thomas et al., 1987). IHS facies association has very complex geology and is the cause of most of the heterogeneities in the McMurray Formation. The IHS deposited as part of tidal channels contain centimeter scale features. These tidal channels are common and interrelated over many square kilometers. The geological complexity of IHS exists at many scales.

Modeling the detailed facies in estuarine systems that contain multi-scales geological features requires a methodology that captures heterogeneity over multiple scales. Pyrcz and Deutsch (2004) presented a stochastic event-based methodology that generates IHS models based on the lateral migration of meandering channels. Mud drapes are modeled separately and incorporated into the IHS model. Wen (2004) presented a surface-based modeling approach to generate 3D IHS beds. Patruyo et al. (2009) modeled IHS set by analyzing the high quality seismic reflection time slices.

The grid-free modeling of IHS facies (Hassanpour and Deutsch, 2010) can produce realistic models of IHS facies including the small scale shale drape features. The unconditional facies models can be used as training images in multiple point simulation. Conditioning the object-based models to the well data can provide models that both geologically and statistically valid. In this report a methodology to condition grid-free model to the well data is presented.

2. Conditioning Data

Well log data are the most useful data in reservoir modeling and treated as hard data. Conventional well logs measure the electrical, radioactive and acoustic properties of reservoir rocks. The petrophysical properties such as porosity, water saturation and volume of shale are calculated from well logs reading. Core plug data and well log data are the smallest hard data available for reservoir modeling. The well log data provides porosity, water saturation and volume of shale at every 10 to 15 cm vertically.

Electro-facies are usually defined, at the same resolution of well logs, by using the multivariate analysis of conventional logs or based on the volume of shale. Core plugs which are sampled at specific portion of the reservoir provide measured porosity, permeability and water saturation. Facies are normally identified in cores and classified based on the microscopic and small scale features such as lithology, grain size, texture, sedimentary structure and color (Coll et al., 1999).

One of the most useful image log tools is Formation Micro Imager (FMI). It measures the micro-resistivity of the formation throughout the borehole and generates an electrical image which has vertical resolution of about 5 millimeters. The application of FMI logs is to define important reservoir geometries and petrophysical reservoir parameters. They can also be used to identify the dip angle of the small scale features such as shale drapes in the IHS facies.

Seismic data are exhaustive and provide extensive lateral coverage but with limited vertical resolution. Seismic attributes do not directly measures the reservoir properties. Seismic can be used to delineate the boundary of IHS point bars. They can also provide an approximate facies proportion in the large coverage area.

Combination of all available information should be used to generate a reasonable data set for grid-free conditioning. Data at the well log resolution are not suitable for the OBM conditioning. Well data should be interpreted to define the desirable facies in terms of intervals. Each interval is defined with a base and top elevation and a facies code.

3. Architectural Elements

The architectural elements are defined as components within the depositional system that have distinct facies content. Each depositional environment may have unique architectural elements and geo-objects. For example, fluvial systems contain crevasses and levees that may not exist in turbidite systems.

Thomas et al. (1987) provide an extensive review of the architectural element and geometry of IHS deposits in the estuarine system. Description provided here is mostly based on their work. Figure 1 shows the architectural elements of a single IHS set. Five architectural elements are considered; (1) cross stratified sand, (2) point bar sand, (3) shale drapes, (4) breccia, and (5) channel fill. Specifications and general geometry of each are described as follows.

The cross-stratified sands facies (CSS) is the best reservoir sand. This facies has as strong tidal indicators and suggested to be part of outer estuarine system (Pemberton et al., 1982; Ranger and Gingras, 2003). Main estuarine and the associated tributary channels are incised into this facies. Several incisions may remove or re-arrange this facies. The geometry of cross stratified sand in fluvial setting, as described in Bridge (1993), is generally interpreted as curved-crested ripples and dunes. Here, for the application of McMurray Formation, this element is considered as the background facies and no specific geometry is assumed.

The basic lithological building blocks of the IHS set are inclined units that comprises of alternating sand and mud. The point bar sands (PBS) is the sand member of this unit that has been seen in the majority of outcrops to be homolithic (Thomas et al., 1987). Point bar sands are deposited on the inner bank of meander channels as a result of channel migration. Lateral accretion of several point bars during a long geological period generates lobe-shaped area (shaded areas in the top of Figure 1). We called this area as the IHS volume that encompasses both inclined sand and shale units. Here we assumed that the PBS element fills entirely inside of each single IHS set volume. Shale drapes and breccia element are represented as separate elements placed inside an IHS volume.

The shale member of the inclined unit is called shale or mud drapes (SH). Individual shale drapes are known from outcrops to be laterally continuous from the top of a facies unit to near the base with decreasing thickness. There is a general fining-upward trend inside this facies that make it heterolithic; however, for simplicity it will be assumed that the shale drapes are considered to be homolithic. IHS set are usually capped by a sheet layer of shale that has the same facies characteristic (top shale). Here top shale is modeled as a separate element that contains the same facies type as the shale drapes.

The mud clast breccia (BR) can be found at the bottom of a channel succession as a result of erosion of previously deposited muddy point bars and overbank collapse. Although this element comprises of several muddy clasts randomly distributed in background sand matrix, here for simplicity, this element is assumed to be a thin layer positioned at the bottom of the IHS volume. For more detail modeling, each centimeter scale clasts can be considered as an object and placed at the bottom of IHS volume.

The channel fill element (CHF) is the channel geometry that bounds the IHS set and is filled with mud and sand but usually acts as a permeability barrier. If channel abandonment occurred, the channel is filled mostly by mud in a fining-upward trend.

4. Unconditional Simulation Algorithm

The simulation engine is a stochastic object/event based technique. Objects are generated based on some geological rules and stored in a grid free format. Vertical and lateral channel stacking are the two main geological rules implemented. Only the location and the key parameters of objects are stored in the output file. Objects are recorded based on their geological time (older to younger).

Vertical stacking starts from the base of the model. The number of aggradation levels is provided to the simulator to control the vertical stacking. This information may be provided by the well logs, outcrops or analogue data. More aggradation level leads to generation of complex cosets that are superimposed and overlap. Within each vertical stacking level, several lateral stacking occur. The lateral stacking of IHS sets are controlled with the number of meandering channels in each aggradation level. More channels leads to generation of more amalgamated IHS sets.

The meandering channels are not generated, instead, a channel line which represents the general orientation of the meandering channel is considered. The channel line is represented by a source location and an azimuth angle and IHS sets are attached to the line in such a way as to generate a realistic meandering channel pattern. Channel meandering wavelength, amplitude to wavelength ratio, and IHS width to the wavelength ratio are required for IHS generation. These variables are used to calculate the top key points of the IHS body discussed previously and the location of IHS's anchor point. Other required parameters for the IHS set are picked from the associated Gaussian distribution. Once the IHS volume is generated, other associated architectural elements are placed.

The number of shale drapes in each aggradation level is controlled with the shale frequency parameter. Higher shale frequency results in muddier IHS packages. Generation of IHS sets along the channel line halts when the new IHS set anchor point falls outside the modeling area.

5. Conditional Simulation Algorithm

We only consider three main facies for the conditioning; cross-stratified sand as the background, IHS set, and mud-filled channel. Conditioning the grid-free model to the small scale shale drapes seems to be impossible due to the complexity and lack of input data. Once three facies of CSS, IHS, and mud-filled channel are appropriately placed in the model, the shale drapes, top shale, and breccia facies can then be simulated inside the IHS facies.

The first step is to prepare the data for conditioning. Thickness of each data point that is provided as interval is checked first. If the thickness is more than possible IHS thickness, then the interval is divided into several reasonable intervals. Then all data are sorted based on their top elevation. Simulation starts from the bottom of the model so the lower elevation data gets priority for simulation. All data are assigned to the appropriate aggradational level based on their top elevations. Data are also sorted based on the proximity to the source line. Data point which are farthest from the source line gets higher priority. This is only because the closer data to the source may have better chance to intercept a random channel line.

There are several different methods that can be used for conditioning an object-based model. The algorithm that we used here is based on the rejection algorithm. Simulation starts by generating a random channel line using the user-defined parameters. If the thickness of the generated channel line is less than the well data, another channel is generated. This process is really fast because only the basic structures of the architectural elements are generated.

The next step is to check if the well data matches the generated channel line. In this step the data point is checked against the IHS box to see if it is inside. If the well data falls inside any of IHS boxes of the generated channel line, then the next step is to check previously conditioned data with this channel line and count the number of good or bad intercepts. When the generated channel line matches a previously conditioned data, it is counted as a good intercept and if it does not it is counted as a bad intercept. If there is no bad intercept then the channel line is accepted and we move to the next data. If there is any bad intercept, the parameters of channel line and its associated good and bad intercepts are stored and another channel line is generated. This process is repeated many times until we either find a channel line with no intercepts or reach the maximum number of try.

When we reaches the maximum number of try and could not find a channel line with no bad intercept, the best case that had the lowest number of bad intercepts is selected. The channel line is updated by performing some geometric operations to reduce the number of bad intercepts. Since the IHS sets are parameterized based on the hierarchy levels to the channel line, rotation or transformation of channel line can simply be done by changing the starting point coordinates of channel or changing the channel line angle. This process can be done several times to get a channel line with no bad intercept. After this process if still no channel line is achieved, the best case will be considered.

When all the data in the current aggradation level is honored, the simulation proceeds by generating new channel lines until we get the maximum number of channels at the current level. Note that, after each channel generation or modification, the previously honored data should be checked for violation. Figure 2 shows the flowchart of the conditioning algorithm.

6. Examples

Two examples are presented to show the proposed conditioning algorithm. In the first example, nine wells are considered with a single aggradation level. Figure 3 shows the location of well data and the model in plan and cross section view. In the second example, 4 well data with 4 aggradation levels are considered. Figure 4 shows the results of conditional model. In both cases all well data were matched perfectly. More examples are provided in the paper 204 in this report.

7. Conclusions

A methodology for conditional grid-free simulation of IHS sets in the McMurray Formation is presented. The methodology was very fast for the two examples presented in this paper(less than a minute). However, more mismatches and more computational time are expected when a dense data set is used. Multi-scale conditioning can be considered as a future work in which IHS sets are honored in the large scale model and then small scale features are conditioned inside the IHS packages.

8. References

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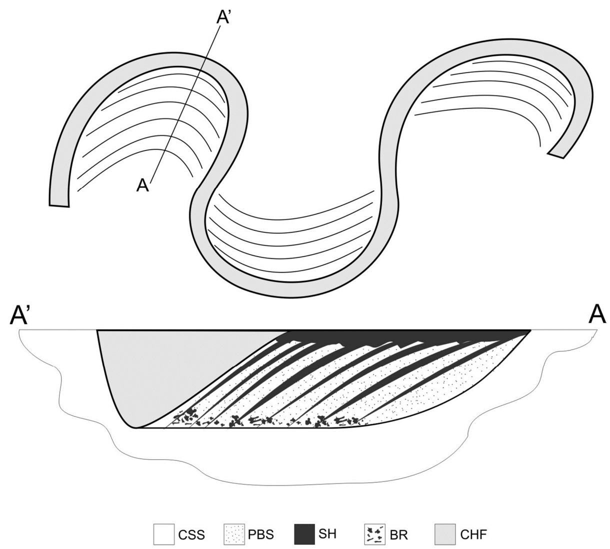

Figure 1: Architectural elements of the IHS packages in estuarine system of the McMurray Formation.

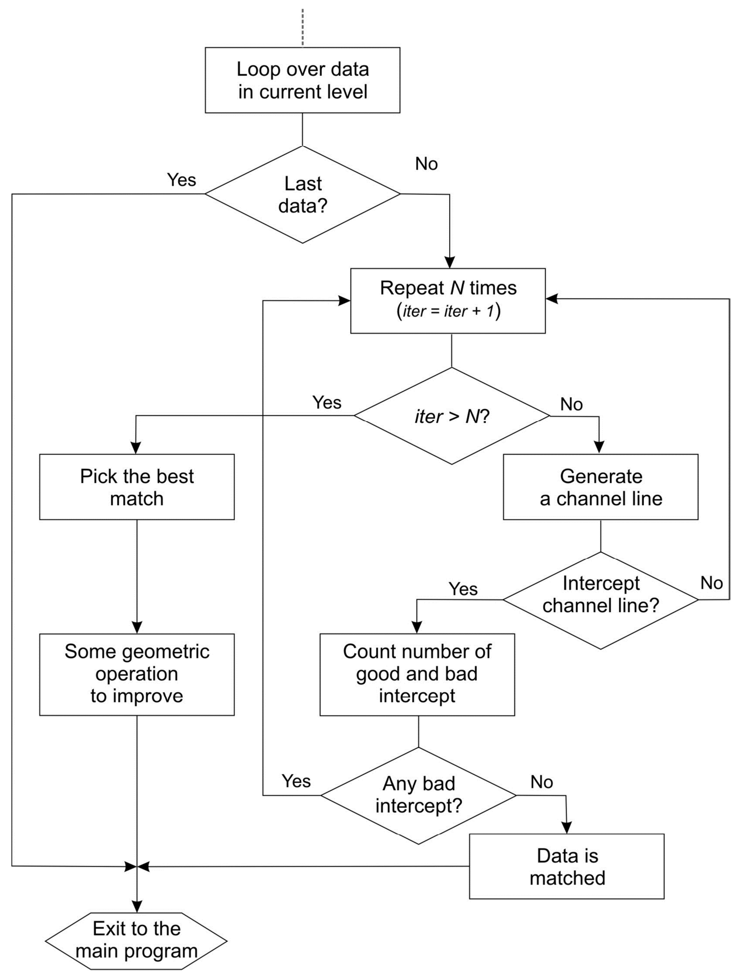

Figure 2: Flowchart of well conditioning for the grid-free simulation with `IHSSIM`.

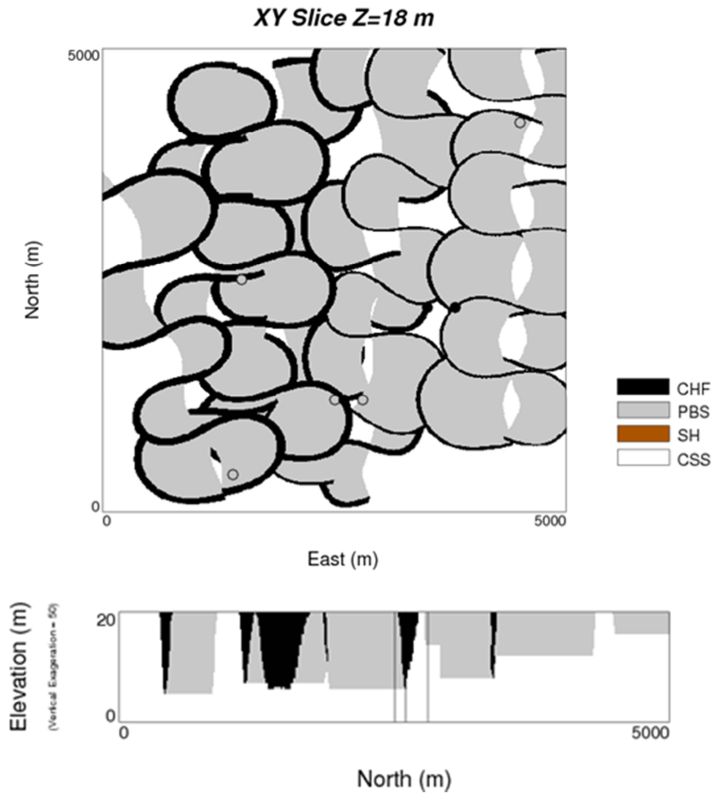

Figure 3: Example of conditional grid-free modeling of IHS facies with nine conditioning well data.

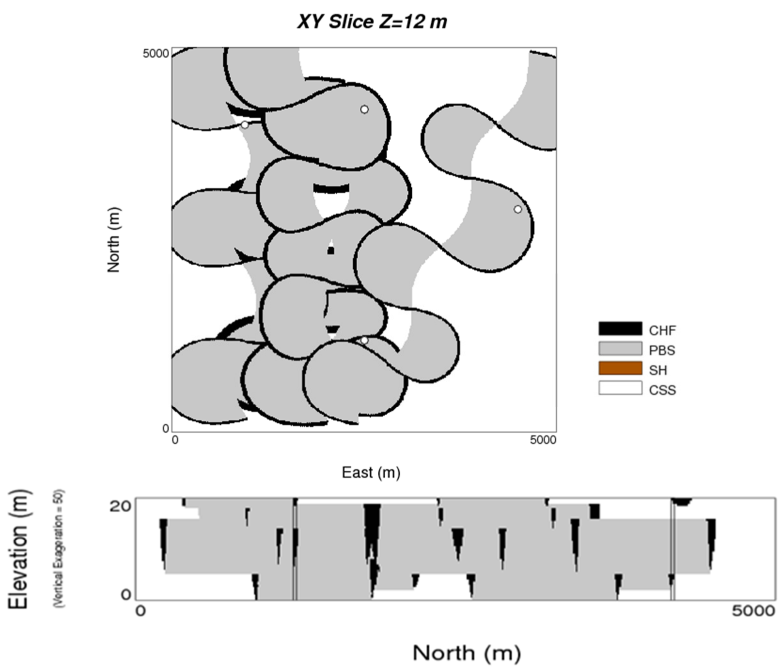

Figure 4: Example of conditional grid-free modeling of IHS facies with four conditioning data and multiple levels.