Training Image Library for Estuarine System

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A training image library for the fluvial and deepwater reservoir has been developed previously in CCG. This paper presents a supplementary training image library for estuarine system of the McMurray Formation based on the grid-free facies modeling algorithm presented in papers 107 and 203 and two developed programs (`IHSSIM` and `IHSRAST`) discussed in paper 413 of this report.

1. Introduction

Variogram-based geostatistical facies modeling techniques such as sequential indicator simulation generate facies models that do not capture the complexity in the reservoir geology. Because they only account for the two-points statistics between data and ignore non-linear relationship. Multiple point statistics (MPS) has received much attention recently and relies on higher order statistics. This technique was first proposed by Journel and Alabert (1989) and then used in simulation (Deutsch, 1992; Streblle and Journel, 2000; Lyster, 2009). In this method, higher order statistics are extracted from training images.

Training image (TI) is an important input for multiple point simulation algorithms. A training image is a conceptual geological model that provides information about the facies structures and geometry. Information that can be used to understand the facies structure of a study area is generally provided from well data, outcrop images or geological interpretations. A digitized outcrop photo or a conceptual geological map can be used directly as a training image but they only provide information in two dimensions. It is difficult to integrate available information to construct 3D conceptual models. Process-based forward simulation (Tetzlaff and Harbaugh, 1989; Boisvet, 2007), event-based modeling (Pyrcz, 2004), and unconditional object-based simulations (Pyrcz, 2004, Maharaja, 2008) have been used to generate 3D training images.

Since all the critical information that are used in MPS is extracted from TI, using an appropriate TI that represents the geology of area of interest has a large impact on the result of facies modeling. A training image library (TIL) provides sets of categorized training images that can be used for MPS. TIL for fluvial and deepwater reservoirs (Pyrcz, 2004) has been developed before in CCG. The training images represent a range of NTG ratios and a variety of depositional styles. The fluvial training image library includes 498 TIs that are generated based on the marked point processes, FLUVSIM (Deutsch and Tran, 2002), surface based models and bank retreat fluvial models. Each TI in this library represents a volume of about 4000 m x 4000 m x 20 m that are discretized by 256 x 256 x 128 grids.

An unconditional grid-free object-based facies modeling technique is presented in paper 107 and 203 of this report with the application in the estuarine environment of McMurray Formation. Two GSLIB type programs were developed to generated unconditional grid-free facies model and to rasterized the grid free model. These tools can be used to generate multiple training images of estuarine system for the McMurray Formation. This training image library can be used in different applications. Training images can be used as the input to the MPS or they can be directly used as a facies model. Different scenarios of IHS deposits are considered and grid free training images are generated and rasterized in cross sections. This paper discusses details of generating estuarine training image library.

2. Methodology

`IHSSIM` program can be used to generate training images of estuarine system. TIs generated with `IHSSIM` are grid-free models and represent the large scale geometry of IHS sets as well as the small scale shale drapes inside the IHS volume. In general, Generating estuarine training image involves following steps:

1. Defining different scenarios
2. Generating grid-free TIs
3. Rasterizing TIs

A detail explanation of each step is discussed in the following sections.

Scenarios for Training Image Generation

To generate a library of TIs that realistically represents the estuarine system of the McMurray Formation different possible scenarios should be defined. Figure 1 shows six different IHS sets morphotypes for different depositional environment. Among those, number 2 and 5 are representing possible IHS scenarios for the McMurray Formation. Number 2 illustrate a low to moderate energy meandering rivers of Athabasca upper delta plain (Calverley, 1984). Number 5 shows rhythmic IHS couplets of moderate energy mesotidally influenced meandering river of McMurray Formation (Smith, 1985). Both cases can be generated by selecting appropriate parameters in IHSISM program.

Five important factors are selected; IHS set size, similarity of IHS sets, channel stacking pattern, shale content of IHS, and the amount of breccias. Each factor is represented by a letter ranging from a to e. Since there is not any control on the net to gross (NTG) ratio of training images in the grid-free mode, the factors are selected so that the resulting TIs represent variety of NTG ratios. This was mostly controlled by shale content in the training image.

All five selected factors are related to the parameters of the `IHSSIM` program. For example, IHS size can be fully controlled with the meander wavelength, width to wavelength ratio, amplitude to wavelength ratio, thickness, and dip angle in the `IHSSIM`. Amount of shale in the TI is related to the maximum number of accreationary surfaces, shale drape frequency and top shale thickness. Channel stacking patter is related to the number of aggradation level and number of channels in each level.

Several studies have been done on the geology of the middle McMurray Formation and different IHS deposit parameters are reported. Mossop and Flatch (1983) reported a meander wavelength of 2750 m in their study area. This number was 1600 m for the study area of Crerar and Arnott (2007). The average range of dip of heterolithic strata forming McMurray Formation is reported to vary between 8° to 15° (Mossop and Flach, 1983; Langberg et al., 2002; Rangers and Gingras, 2003; Crearar and Arnott, 2007).

Three levels are considered to capture range of variation of each factor. For IHS size, level 1 refers to the small, level 2 refers to medium, and level 3 refers to large. Level 1 of similarity means IHS sets are more similar in shape. For channel stacking pattern, level 1 is related to loosely amalgamated, level 2 refers to moderately amalgamated, and level 3 refers to highly amalgamated channels. For Shale content and breccias, level 1, 2, and 3 refers to low, medium, and high amounts respectively. Table 1 shows all factors and their associated parameters and levels.

Table 1: Factors and the associated parameters considered for generation of estuarine training image library.

	Factors	**Associated `IHSSIM` Parameters**	**Level 1**	**Level 2**	**Level 3**
a	**IHS Size**	Meander Wavelength (mean)	1600	2400	3600
		Width/Wavelength (mean)	0.55	0.55	0.55
		Amplitude/Wavelength (mean)	0.55	0.55	0.55
		Thickness (mean)	15	20	25
		Dip (mean)	15	12	8
b	**Similarity**	Meander Wavelength (stdev)	100	200	300
		Width/Wavelength (stdev)	0.05	0.1	0.2
		Amplitude/Wavelength (stdev)	0.05	0.1	0.2
c	**Channel Stacking**	Number of levels	3	5	7
		Elevation	48-32-15	48-40-35-28-15	48-35-30-28-20-15-10
		Number of channels in each level	3-3-3	3-3-5-5-7	5-5-7-7-7-10-10
d	**Shale Content**	Max. no. of accreationary surfaces	50	55	60
		Shale drape frequency	0.1-0.2-0.3	0.4-0.5-0.6-0.7-0.8	0.5-0.6-0.7-0.7-0.7-0.8-0.9
		Top shale thickness	0	5	10
e	**Breccia**	Breccia thickness	0	5	10

Grid-free Training Image Generation

Considering five factors and three levels, $3^5 = 243$ training images are generated. Each grid-free TI represents a volume of 5000 m by 5000 m by 50 m. This is a reasonable size for a typical reservoir study. The total number of objects involved in each training image varies from hundreds to thousands of objects. A training image with thousands of objects occupies couple of MB memory and can be compressed to tens of KB easily. Generating grid-free training images with IHSSIM is really fast and construction of TI library took only 10 minutes. Grid-free TIs are named in the format of "TI_a-b-c-d-e.gfm" where a-e representing different factor's level. For example, TI_1-2-2-3-1 refers to the training image generated for level 1 of factor a, level 2 of factor b, level 2 of factor c, level 3 of factor d, and level 1 of factor e. Main advantage of grid-free training images is that they can be rasterized to any desired grid resolution.

Training Image Rasterization

Grid-free TIs cannot be used or visualized unless they are rasterized with the IHSRAST program. Parameters and tips to use IHSRAST program is presented in paper 413 of this report. Training images in the estuarine TI library can be rasterized to any grid resolution. However, the resolution should be selected so that the small scale features are adequately characterized with the selected grid size. Rasterization of TI with large grids result in missing very important small scale feature of IHS sets, however rasterizing with very small grids may not be possible because of very long computational time and memory shortage. There is also a possibility to rasterized only a specific part or a cross section of a grid-free training image.

Since full rasterization of training images with small grids is not possible all of the 243 training images in the estuarine library are rasterized in plan, long and cross sections. Plan section of TI is rasterized with 1024 by 1024 grids with size of 4.88 m by 4.88 m. Long sections and cross section are rasterized with 1024 by 128 grids with size of 4.88 m by 0.39 m. Figure 2 shows training image size and specifications. Figure 3-5 show some examples of training images in the training image library.

3. Selecting Appropriate Training Image

Training images in the library have different statistical and spatial properties such as facies proportion, variograms, and multiple point statistics. Choosing an appropriate training image from the grid-free training image library may be challenging. Based on the application that the training image will be used for, different options are recommended to select from the estuarine training image library.

Training images may be used qualitatively as a conceptual geological model. In this case, the appropriate training image may be chosen from visualized cross sections provided as a part of the training image library. If enough information about the geology of the reservoir is available, data provided in Table 1 can be used to select the most relevant training image.

Training images may be used directly as facies model in geostatistical modeling of petrophysical properties such as porosity and permeability. If the resource estimation is the goal of property modeling, appropriate TI should be chosen based on the net to gross ratio (NTG). In this case, NTG ratios of all training images in the library are calculated and the most appropriate TIs are selected. Since fully rasterized training images are not available in high resolution, cross sections can be used to calculate NTGs.

If training image is going to be used as an input to the MPS, some statistical measure of training image must be considered. Using inappropriate TI that does not represent the geology of area of interest has a large impact on the result of MPS. Multiple point histograms, transition probabilities, distribution of runs, and connectivity functions can be considered as a measure to rank training images (Pyrcz, 2004; Boisvert, 2007).

4. Conclusion

A library of training images is generated for the estuarine system of McMurray Formation. This library contains grid-free training images with variety of IHS deposit structure. Training images have not been tested in a real application yet and the geological realism of them should be assessed. More complicated geological scenarios may be defined and the library can be updated with new training images.

The grid-free training images contains sets of large scale IHS set volumes and very small scale shale drapes and can be rasterized in any grid resolutions. Full rasterization of grid-free TIs is not possible with small grids but one major advantage of presented method is that a selected part of a training image can be rasterized in a high resolution. For example, in SAGD applications an area related to a well pairs can be selected and rasterized with very small grids (1m x 1m x 0.1 m).

One future work for this research is to provide a tool to select the most appropriate training images from the library. TIs should be ranked based on different parameters such as NTG, and multiple point statistics.

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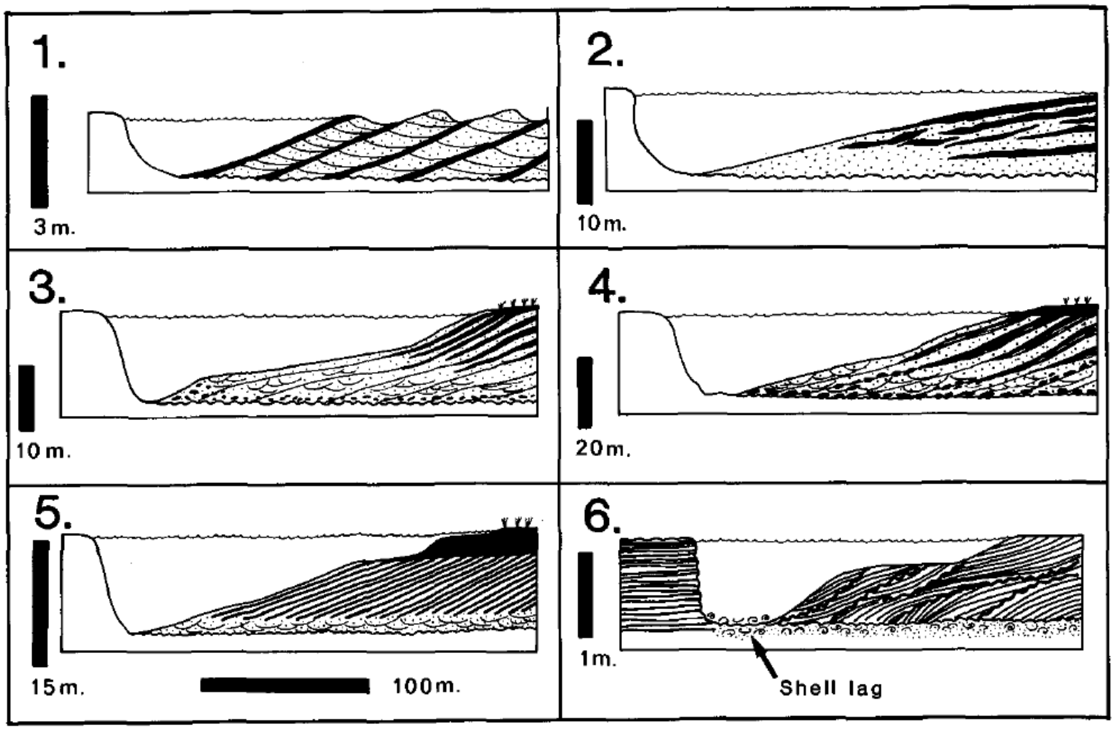

Figure 1: Schematic illustration of six idealized IHS set for different depositional environments (Thomas et al., 1987). Case number 2 and number 5 show possible IHS sets types for McMurray Formation.

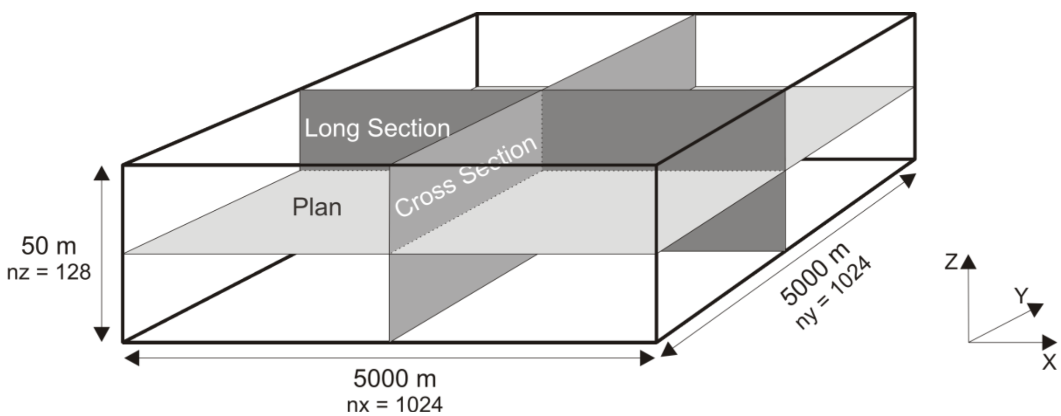

Figure 2: Training image size, rasterized sections, and specifications considered for estuarine training image library.

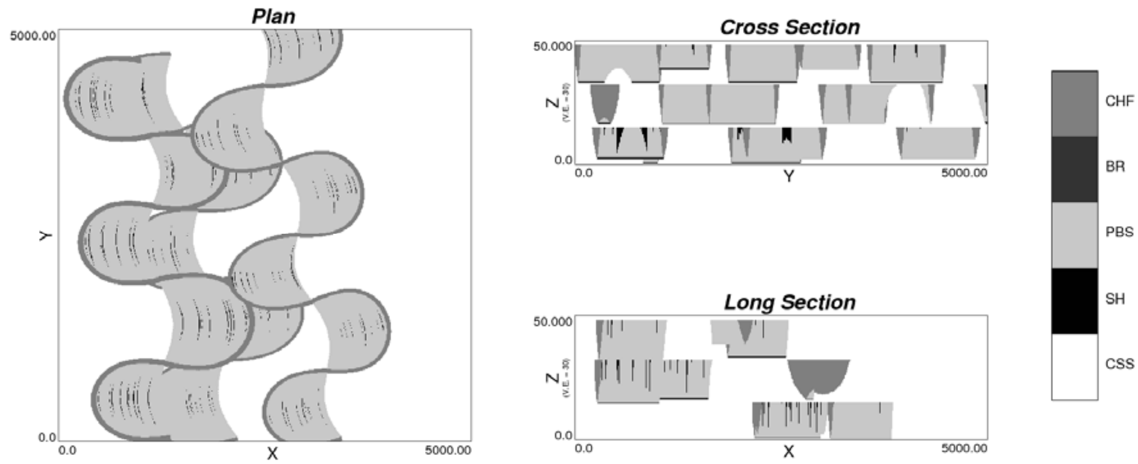

Figure 3: Three rasterized sections of training image for case 1-1-1-1-1 (vertical sections are exaggerated 30 times).

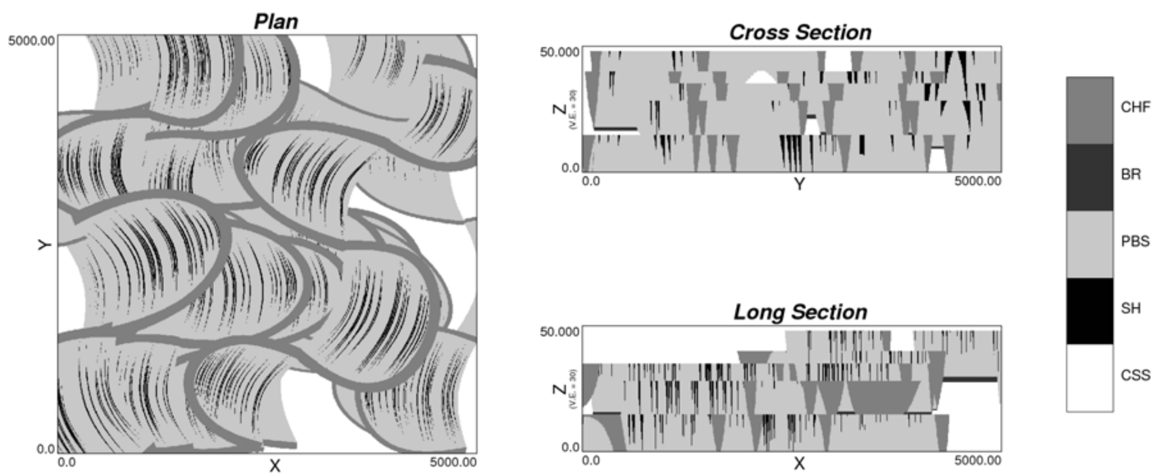

Figure 4: Three rasterized sections of training image for case 2-2-2-2-2 (vertical sections are exaggerated 30 times).

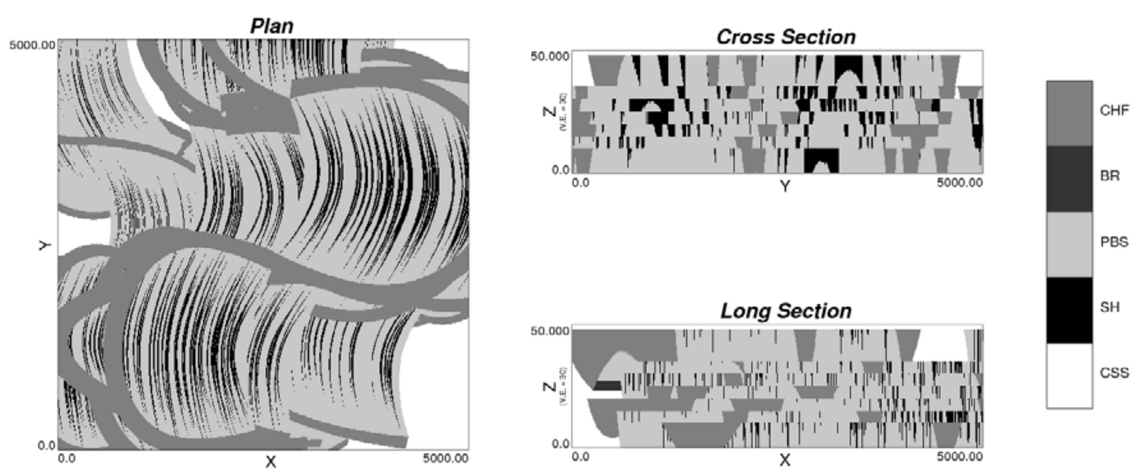

Figure 5: Three rasterized sections of training image for case 3-3-3-3-3 (vertical sections are exaggerated 30 times).