

# Geostatistic Inversion Study on Reservoir Prediction in MMC Oil Field

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## ***Abstract***

The major reservoir in MMC oil field includes several features, for example, the reservoir is very thin, and the heterogeneity is very strong, vertical overlapping is very common, distribution is very complicate, and litho-faces and thickness variation are very strong. Reservoir distribution and characterization are the major difficulties. Due to the reasons mentioned above, reservoir prediction was implemented by using the geostatistic inversion. Through the analysis of the inversion results, the inversion result has both high vertical resolution and horizontal resolution; thin layer sandstone can be identified; and the inversion result has been well fit the data.

**Keywords:** *Heterogeneity; Rreservoir prediction; Geostatistic inversion; High resolution*

## **1 INTRODUCTION**

Geostatistic inversion was firstly used by Hass<sup>[1]</sup>, developed by Dubrule<sup>[2]</sup> and Rothman<sup>[3]</sup>. It integrates high vertical detail of well log data with the high lateral detail of 3D seismic to produce multiple highly detailed, unbiased and geologically plausible 3D realizations of P-impedance, lithology, and engineering properties such as porosity<sup>[4-9]</sup>. These realizations accurately capture the heterogeneity of the subsurface and together also give valuable insight into the underlying uncertainties of the predictions given all known soft and hard input data.

MMC oil field is located in central Melut basin South Sudan, the oil bearing layer is Yabus Formation in Paleogene. The sedimentary environment of Yabus Formation is braided river and meandering river, the type of reservoir is fault block reservoir controlled by lithology and structure. Sandstone in the reservoir is very thin, with bad continuity, great lateral variation, vertical overlapping. The key issue is the distribution of reservoir is unclear. So, geostatistic inversion was implemented in major oil bear layers from Yabus Formation in order to solve the problems met in the oil field development.

## **2 MAJOR STEPS GEOSTATISTIC INVERSION**

Geostatistic inversion integrates the conventional deterministic inversion and statistic method. The major steps are as follows.

### ***2.1 Synthetic Seismogram Calibrations and Wavelet Extraction***

The same as deterministic inversion such as constraint sparse spike inversion (CSSI), it is also very important in Geostatistic inversion(GI).

#### **(1)Wavelet extraction**

An appropriate wavelet which can be used in convolution with the reflection coefficient for making the synthetic seismogram is the key factor for the inversion.

Principles of wavelet extraction and evaluation are shown as follows:

- a) Choose seismic traces with the stable reflection features for wavelet extraction in order to make the wavelet

stable.

- b) Time window should include the target layer in order to make the consistency of dominate frequency between wavelet and seismic data in the target layer.
- c) Time window had better be 3 times longer than the wavelet length to make sure the extracted wavelet can characterize the seismic features.
- d) The wavelet should be the minimum phase, the spectrum should be similar to the seismic data, the phase should be stable in the seismic data spectrum range.
- e) Synthetic seismogram should match very well with the seismic, S/N ratio should be high.

In this study, firstly, single-well wavelets (amplitude and phase spectrum wavelets) are extracted from initial time-depth relation through seismo-statical method. At last the average wavelet of wells with good wavelet and synthetic seismogram is calculated. Because it is the average wavelet finally used in the inversion, each well should be respectively calibrated again through the average wavelet, the wavelets should be extracted again, and the average wavelet should be calculated again continually and repeatedly until an optimal wavelet is obtained. It is shown that for the average wavelet, energy is concentrating on the main lobe (Fig. 1). It means the average wavelet is of good quality for further study.

## (2) Synthetic seismogram calibration

Integration of well and seismic data is critical for a good inversion, which is usually made by synthetic seismogram calibration. The synthetic seismogram making is very fundamental in seismic inversion, which is the bridge between seismic and well data and has direct impact on seismic well tie and wavelet extraction. During the process of the calibration, the forward modeling and the inversion results can be improved by modifying time-depth relation and wavelet extraction, and meanwhile, the time-depth relation has been modified gradually through matching up the forward modeling results and the inversion results. Finally the best calibration result can be obtained through the iterative processes (Fig. 2).

Synthetic seismogram calibration and wavelet extraction are actually iterative processes. Wavelets have been extracted and optimized by modifying the synthetic seismogram gradually, and synthetic seismogram can be verified and improved through optimizing the wavelets. Based on synthetic seismogram calibration, time-depth relations of the wells have been established and seismic well ties have been built up.

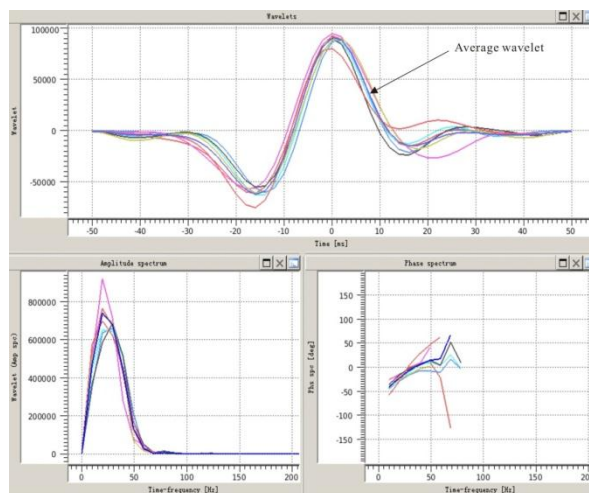


FIG.1 WAVELET ANALYSIS

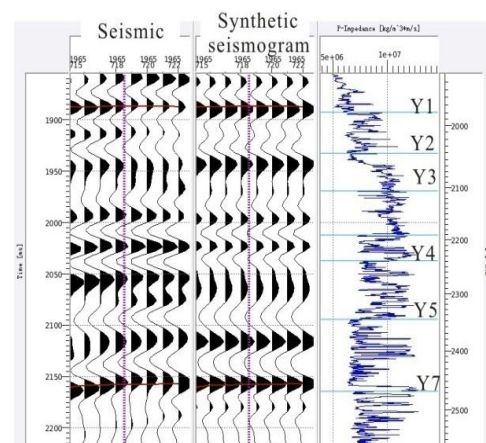


FIG.2 SYNTHETIC SEISMOGRAM CALIBRATION OF WELL MMC-1

## 2.2 Geological Framework Building Up

After synthetic seismogram calibration and wavelet extraction, high precision framework has been built up through

high resolution correlation by integrating logging data and seismic data. The deposition model, structure model, and relations between layers and their inside textures have been defined base on horizons and faults through seismic interpretation. 3D grid has been created following the interpreted stratigraphy of the earth model framework.

Faults developed very much in the study area, and the fault throw variation is great. So the fault association should be taken seriously when building up the framework. In this study, the framework was built under the sequence stratigraphy theory and based on the detailed 3D seismic data interpretation.

### 2.3 Geostatistic Inversion

In this study, the approach of geostatistic inversion can be summarized as follows:

- (1) 3D grid has been created following the interpreted stratigraphy of the earth model framework.
  - (2) Continuous petrophysical properties have been discredited on the 3D grid mentioned above.
  - (3) On the same 3D grid, a discrete property representing lithotypes has also been defined.
  - (4) All available evidence and assumptions as a series of probability density functions (Pdf) have been defined over the property volumes.
- a) Variograms: The variogram is a geostochastic tool that quantifies and models the spatial continuity of the property. Expectations are that the properties vary smoothly in space within each lithotype and that the lithotypes are arranged in spatially continuous bodies. These beliefs have been captured by using spatial Pdfs parameterized by geostochastic variograms. Variogram is usually computed from logging data vertically and seismic data laterally. Variogram model for impedance and porosity of sand in Yabus IV layer is taken as an example as shown in Fig.3.

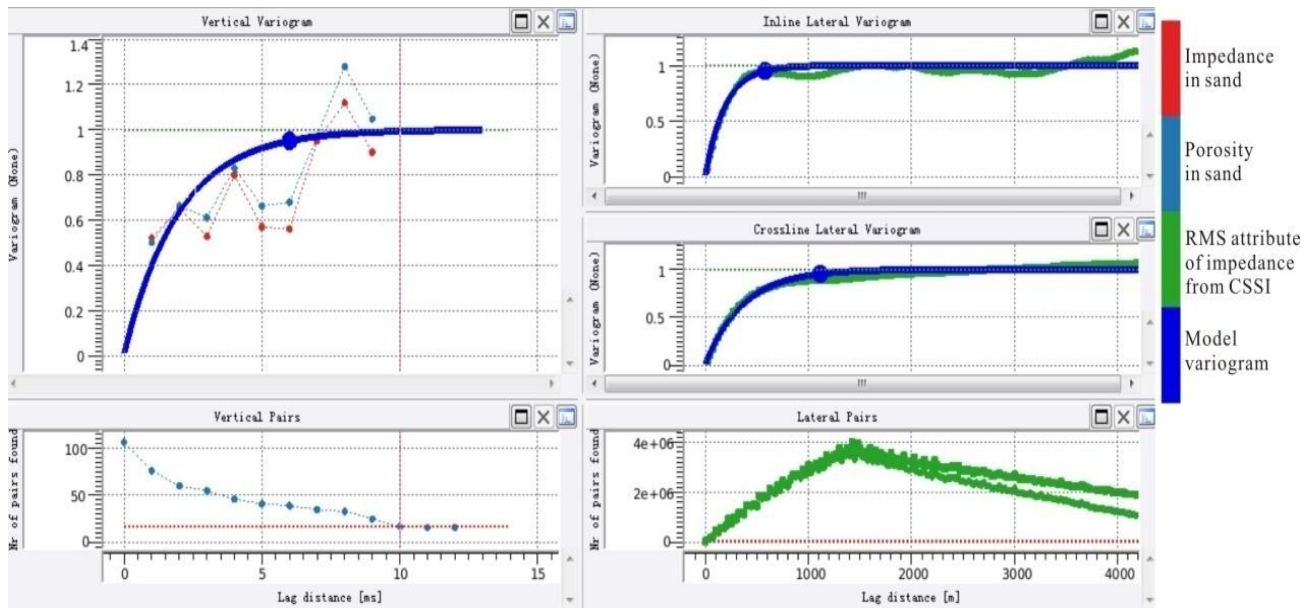


FIG. 3 VARIOGRAM MODEL FOR IMPEDANCE AND POROSITY OF SAND IN YABUS IV LAYER

- b) Property Distributions: The crossplots of all properties observed for each lithotype along with the crossplots believed to arise from petrophysical considerations have been expressed as multivariate joint Pdfs. Impedance and porosity probability density distribution in Yabus IV layer taken as an example as shown in Fig.4.
- c) Seismic: The seismic data has also been modeled as a noisy, blurred version of a 3D reflectivity image, which is in turn related (in the full stack case) to the P-impedance via the standard contrast convolutional model. An explicit Pdf for the noise to account for the random uncorrelated differences between the seismic and the synthetics.
- d) Well Logs: Direct log measurements of properties at points along the well tracks are also incorporated in Pdf

form (to account for inherent measurement noise).

- (5) Pdfs arising from the various data sources described above have combined to yield a Bayesian posterior distribution over the 3D reservoir property and lithology volumes (Fig. 4). The advantage of having this global or ensemble posterior Pdf is that it is a true multivariate Pdf and thus fully describes the statistical dependencies of all scales- from the micro scale on a few micro layers to macro scale on a group of traces.
- (6) Then, the Markov Chain Monte Carlo algorithm has been customized to obtain a fair sample of realizations from the Pdf. The realization usually consists of a 3D image of each reservoir property, and of lithology, discredited on a high resolution stratigraphic grid.

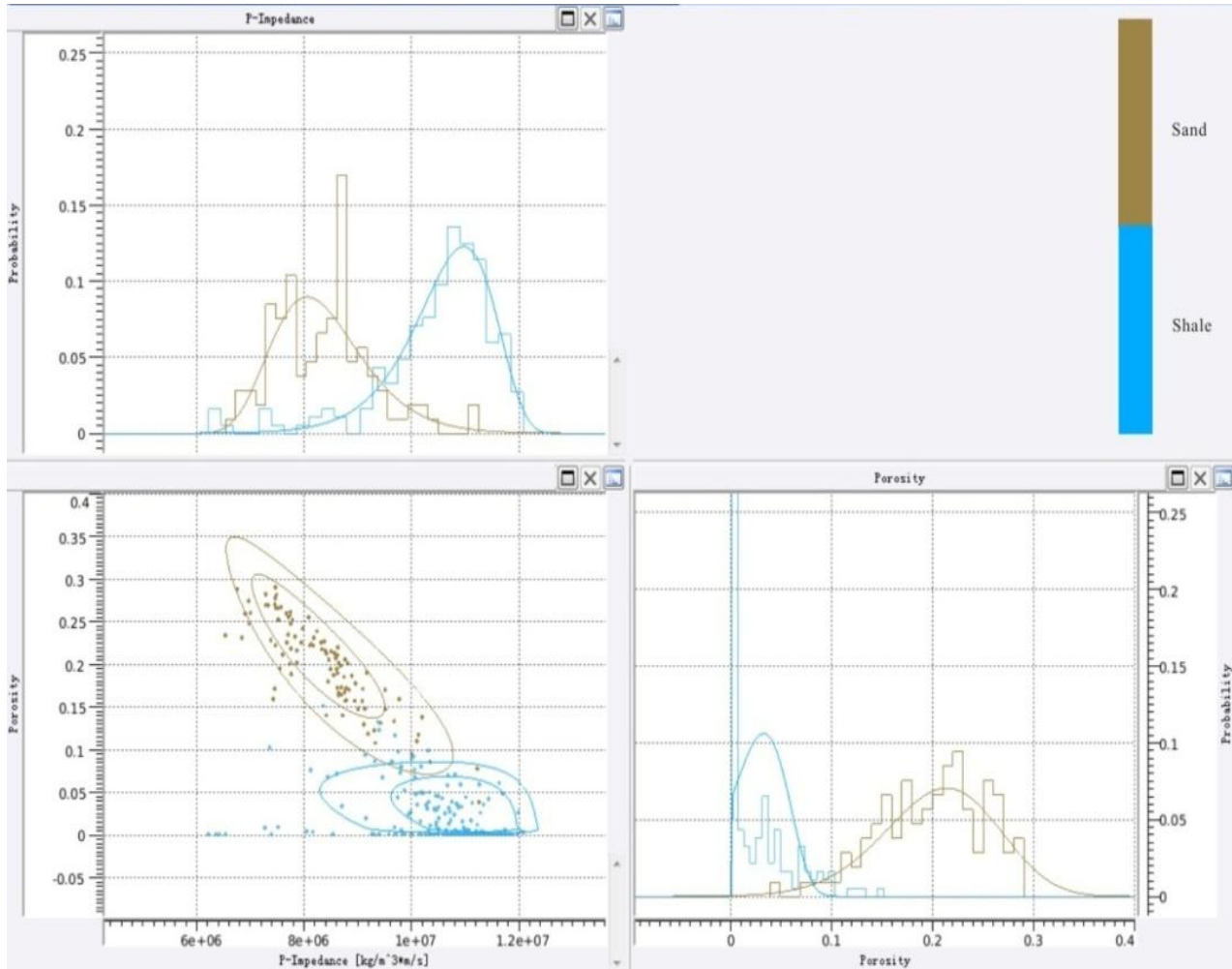
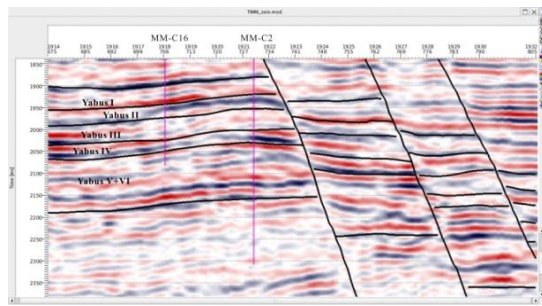


FIG. 4 IMPEDANCE AND POROSITY PROBABILITY DENSITY DISTRIBUTION IN YABUS IV LAYER

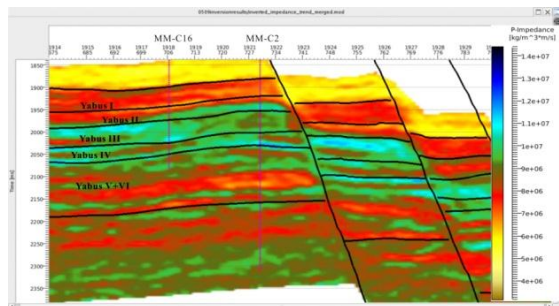
### 3 ANALYSIS AND INTERPERTAION OF THE GEOSTATISITCAL INVERSION RESULTS

Based on the parameter analysis mentioned above, the geostatistic inversion was implemented. The inversion results include impedance volume, lithology volume and porosity volume. It is the same as CSSI constrained by both seismic data and logging data, but has much higher vertical resolution (Fig.5). The results of geostochastic inversion honor the seismic trend, have a good spatial relationship with the seismic data, are of good lateral continuity and match the well data very well (Fig. 5). In this study, ten times of realization have been achieved, and the best one has been used for analysis and interpretation. The probability data of the sandstone have been done in order to make the uncertainty analysis (Fig. 5F).

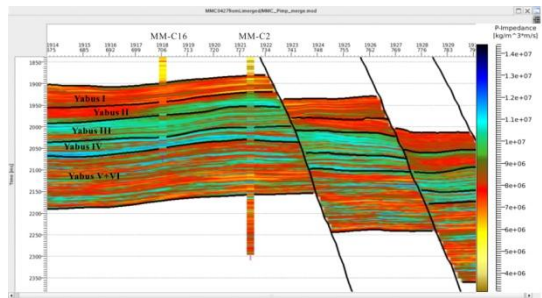
Based on the analysis of geostochastic inversion results, sandstone thickness distribution, reservoir thickness distribution have been extracted, and the contour maps of which have been made in different layers. Here in this report, taking Yabus 4 layer as an example, both types of contour map are shown in Fig. 6 and Fig. 7.



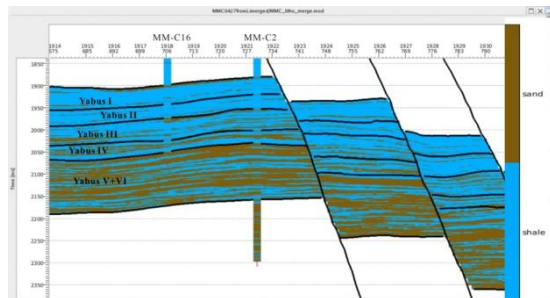
A SEISMIC CROSS-SECTION



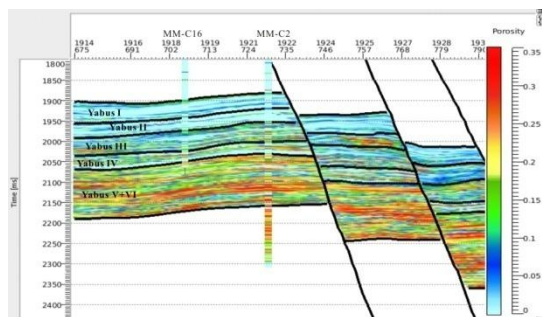
B IMPEDANCE CROSS-SECTION FROM CSSI RESULTS



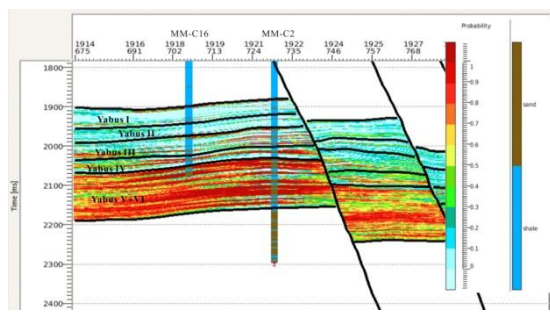
C IMPEDANCE CROSS-SECTION FROM GI RESULTS



D LITHOLOGY CROSS-SECTION FROM GI RESULTS



E POROSITY CROSS-SECTION FROM GI RESULTS



F PROBABILITY CROSS-SECTION OF SANDSTONE FROM GI RESULTS

FIG. 5 ANALYSIS OF INVERSION RESULTS

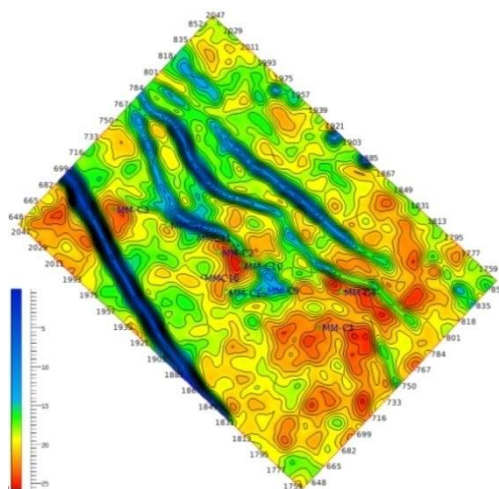


FIG. 6 SANDSTONE THICKNESS MAP IN DIFFERENT LAYERS

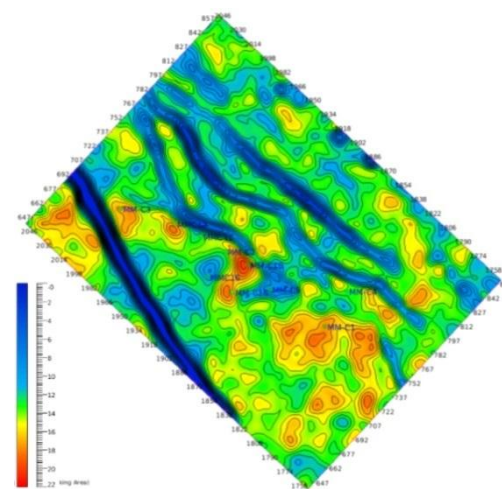


FIG. 7 RESERVOIR THICKNESS MAP IN DIFFERENT LAYER (POROSITY VALUE OF 15% AS THE CUTOFF VALUE)

## 4 CONCLUSIONS

Geostatistic inversion can provide impedance, lithology and porosity results with high resolution. The inversion results honor the seismic data and constraint by well data, can provide more accurate and detailed lithological and physical information for further study. Through the application of the geostatistic inversion in MMC area, it is proved that this method is efficient and accurate for reservoir prediction.

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