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Three-Dimensional Geostatistical Modeling of Oil Reservoirs: A Case Study From the Ramin Oil Field in Iran

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Abstract: Three-dimensional numerical earth models play an increasingly central role in the engineering and petroleum industry. They are routinely used to plan new wells, calculate hydrocarbon reserves and when coupled to a flow simulator, predict production profile. In the reservoir modeling subject there are different methods for 3D-reservoir modeling. Of these methods in the present study the geostatistical method is used for 3D-modeling of the Asmari reservoir in the Ramin oil field, South-West of Iran. Structural and petrophysical models were also provided using RMS (Reservoir Modeling System) software. The out put data of the project, indicating the trend of the oil field similar to Zagros range. Its structure is smooth and there are two culminations with different depth. It should be noted that these structural morphologies have different reservoir properties. The model is also predicted that the upper part of the Eastern culmination is a good candidate to do well drilling program due to higher reservoir quality than lower part.

Key words: 3D-modeling, geostatistic, oil reservoir, Zagros

INTRODUCTION

Generally, models are expressions of our ideas about the encountered problems. Models may be classified as:

Conceptual models (qualitative models)
Physical models (experimental models) for example:

- Flum-operated simulations of sedimentologic or stratigraphic
- Phenomena at scals ranging from bedforms to basins

Mathematical models (computer models)

- Deterministic models (physically-based or process-based) have one set of input parameters and therefore yield one unique outcome
- Stochastic models have variable input parameters, commonly derived from probability-density functions (Pdf's) and therefore have multiple outcomes; as a consequence model runs must be repeated many times (realizations) and subsequently averaged

In reservoir modeling subject there are different methods for 3D reservoir modeling. In each of these methods using geological information, mathematical or statistical sciences and different software, properties of the reservoir are modeled. There are some publications in different aspects of the reservoir modeling such as dynamic reservoir simulations (Labourdette *et al*., 2006; Jackson *et al*., 2005), fracture intensity (Wong, 2003; Masaferro *et al*., 2003), 3D stratigraphy, 3D structural model (Mitra and Leslie, 2003; Mitra *et al*., 2006; Hennings *et al*., 2000).

Geostatistical method is a powerful tool in modeling now. As a historical review the quantification of geology has always been a fascinating topic and of the first pioneering efforts may be noted those of Vistelius (1992) and his many followers using Markov chain analysis (Ethier, 1975) to quantify one-dimensional lithological sequences along well. Many successes were encountered with this approach, but it appeared difficult to generalize to the second and third dimension. Then, in the mid sixties, the giant Hassi Messaoud field in Algeria was the object of pioneering application of quantitative reservoir description techniques. The distribution of sand lenses and shale break was modeled in a vertical cross-section with the goal of understanding their impact on effective permeability. This model was used as a basis for reservoir simulation and it was observed that, because heterogeneities were modeled in a realistic way, a satisfactory history-match could be achieved more easily (Dubrule, 1998; Clevis *et al*., 2006).

Three realizations are different; such a model often consists of hundreds of thousands of grid cells. Current reservoir simulators are not able to handle such large data set and scaling-up of heterogeneity models is required before they can be handled by flow simulators. These models will represent the spatial distribution of petrophysical parameters such as porosity and water saturation (Dubrule, 1998).

Generally, geostatistics is study of phenomena that vary in space and/or time. Geostatistics can be regarded as a collection of numerical techniques that deal with the

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characterization of spatial attributes, employing primarily random models in a manner similar to the way in which time series analysis characterizes temporal data. In other word, geostatistics offers a way of describing the spatial continuity of natural phenomena and provides adaptations of classical regression techniques to take advantage of this continuity.

Basic component of geostatistics are:

- **Variogram analysis:** Characterization of spatial correlation.
- **Stochastic simulation:** Generation of multiple equiprobable image of the variable also employs semivariogram model. In geostatistics variables are random. A random variable is a variable whose value is a numerical outcome of a random phenomenon (Corstanje *et al*., 2008). Dataset that use in stochastic are tow types. Soft data that measured indirect such as geophysics petrophysics data and hard data that measured direct in laboratory.

Geostatistics is applied to geological modeling, air pollution, water pollution, mining, biological species. Geostatistical routines are implemented in the major reservoir modeling packages like petrel and Roxar Irap RMS; used in the generation of grids of facies, permeability, porosity, etc. for the reservoir.

Software for representing geology in 3D is routinely used to model subsurface reservoir The 3D geological modeling or static reservoir modeling technology continues to advance. Software includes some or all of the following capabilities.

- Seismic interpretation, Petrophysical evaluation, Data analysis, Deterministic and geostatistical fault modeling, Deterministic and geostatistical facies/property models, Uncertainty analysis, Flow based upscaling.

These capabilities allow better integration of seismic data, conceptual geological model, static and dynamic well data into one common earth model.

In the present study the geostatistical methods is used for 3D modeling of Asmari reservoir in Ramin oil field, in Iran. Structural and petrophysical models for this reservoir were provided using RMS software.

MATERIALS AND METHODS

The Ramin oilfield is located at Dezful Embayment in the Zagros ranges of Iran (Fig. 1). The oil field consisted of the Asmari formation as a petroleum reservoir. It is limited by the Gachsaran evaporate formation at the top

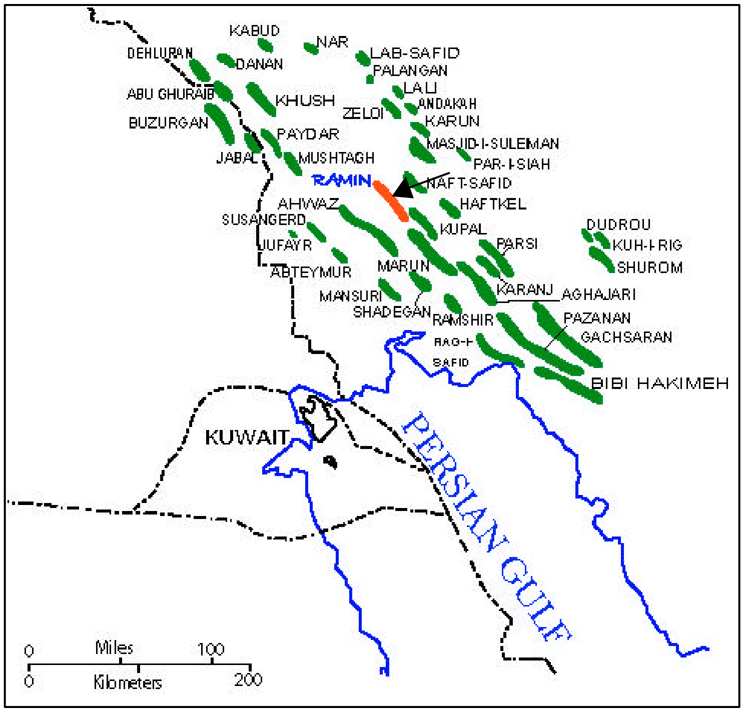

Fig. 1: Situation of Ramin oil field in SW of Iran

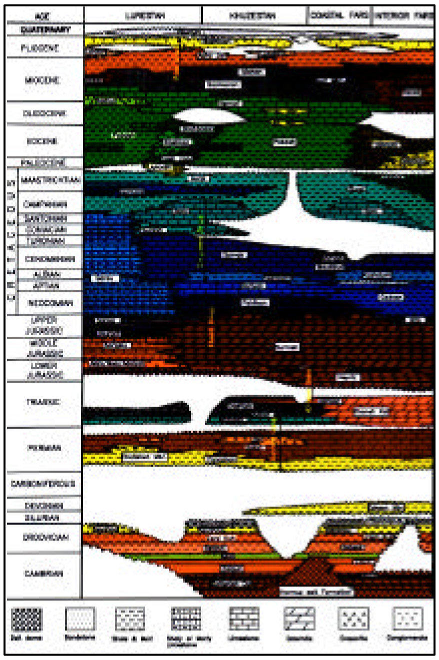

Fig. 2: Simplified table of rock units in Zagros areas

and the Pabdeh Formation at the base (Fig. 2). Gachsaran Formation is considered as the cap rock for all reservoirs in Zagros area. The Asmari reservoir is the main pool in this field and divided into 4 zones.

The definition of the geological model of the reservoir seems to be one of the most important phases in the workflow of a typical reservoir study based on core material, cuttings, outcrop evidences and logs. To generate this model, we have passed three important phases:

- **Structural study:** Reviewing the available literature about the regional setting, tectonic evolution of the region, 2D seismic surveys and well information to evaluate the structure top map, its extension and fault pattern.
- **Stratigraphic study:** reviewing all the available geology and core reports to infer the sedimentological settings of the Asmari reservoir in Ramin field which will help to find out the extension of the depositional bodies in the reservoir and building a reliable stratigraphic framework. A 3D-model of structure shall be constructed using the results of previous step.
- **Petrophysical properties study:** Study all the available petrophysical evaluations for the field and data analysis to build the best experimental variogram for stochastic simulation.

3D-geological modeling was made using IRAP-RMS software which is supported by NISOC (National Iranian South Oil Company). All needed data to construct 3D geological model include seismic map (contours), well data, (e.g., location, deviation, logs etc.), well picks (entry point to each horizon) imported to IRAP-RMS data engine (Fig. 4). The workflow for geological modeling shall be at least put through following steps (Fig. 3).

- Structural modeling
- Fault modeling (in this field there is no fault)
- Stratigraphic modeling (Construction of layer model)

The isochores, representing true vertical thickness information, were calculated by combining the TST maps and the dip information from the top surface:

$$\text{Isochore} = \text{TST}/\cos(\text{dip})$$

The next reservoir zone surface below the seismically defined Top Asmari (interpreted top) is calculated by adding the calculated isochore to the smoothed Top Asmari surface (Fig. 5). Then this process was repeated down to the top Ilam surface (next interpreted top). Between each zone-surface generation the surface was corrected to the well points. Well adjustment was used for each zone to fit the horizons to well point.

Total stratigraphic modeling steps:

Step 1: Calculate dip and azimuth from Top Asmari structural map.
Step 2: Calculate True Stratigraphic-Thickness (TST) in all zones for the available wells.
Step 3: Calculate isochore maps; Isochore = TST/cos (dip)
Step 4: Create next map; next surface = Above surface+isochore
Step 5: Exact adjustment to well picks.
Step 6: Repeat step 1-5 for all zones.

Establish a structural model with 4 zones. Dip and azimuth data from Top surface were used to calculate True-Stratigraphic-Thickness (TST) in all 7 wells.

- 3D fine geological grid
- Block wells and data analysis

Property modeling (stochastic petrophysical modeling) shall be performed using stochastic method. For this purpose simulation method will be used on the basis of actual well data. Quality control of property models will be secured by comparing the statistical results from the model with those of the actual well data.

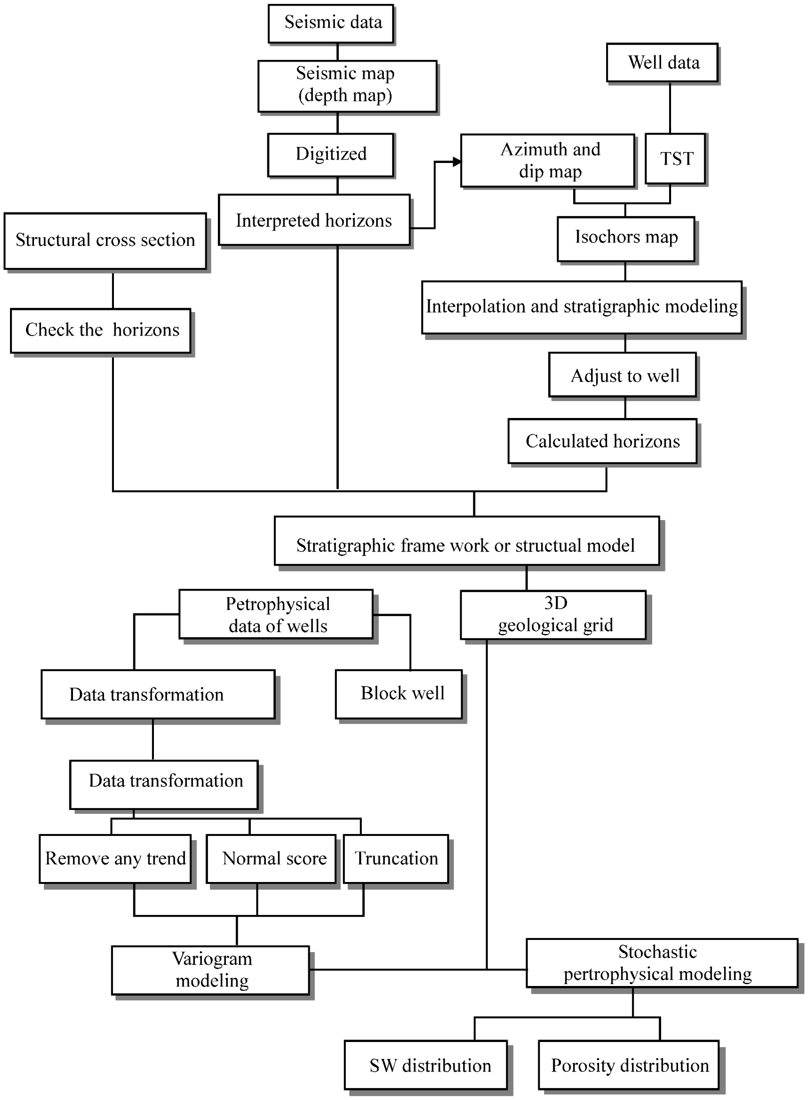

Fig. 3: Schematic flow chart of the modeling steps of the Asmari reservoir in Ramin oil field

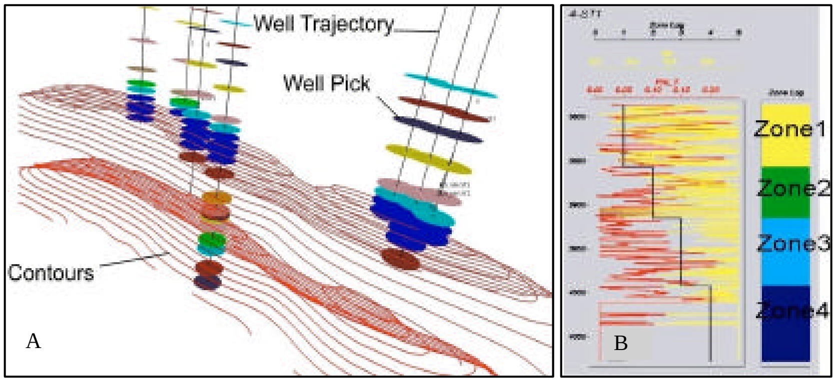

Fig. 4: Primary data imported to the software for modeling. Well trajectories, Well picks and contours line (A), well logs (B)

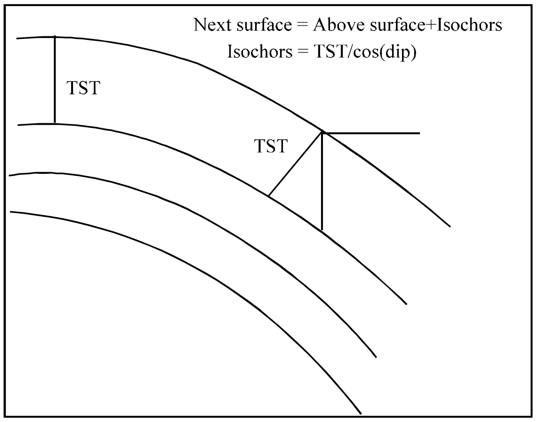

Fig. 5: Schematic image, use of isochors in create layer model

RESULTS AND DISCUSSION

Generating a high quality structural framework is an essential first step in the 3D-modeling workflow. The approach used include seismic data, well data and construction of a series of structural cross sections to understand the evolution of the structure (Mitra and Leslie, 2003; Mitra *et al*., 2006) and provide a structural framework for property (petrophysical) modeling.

Primary data needed to modeling of the Ramin oil field was taken from all information available for this field and import to the RMS (Reservoir Modeling System) software. These data consisting contour lines that provide from digitizing of the tops of the Asmari and Ilam formations in underground maps (UGC), well trajectories, well markers (well picks) and well logs. Underground maps were provided from 2D-seismic interpretations provide interpreted horizons in structural model. Calculated horizons as intermediate horizons, derived by combining interpreted horizons and thickness data (Isochors maps), dip map and azimuth map of top Asmari formation were plotted (Fig. 6-8). we have used geostatistics method to interpolate and extrapolate the values of reservoir variables at unsampled locations. Then the contour maps were built by the estimated value (Kelkar and Perez, 2002). Stratigraphic modeling between two interpreted surfaces was done by interpolation method (Fig. 9A) which is computed intermediate values or estimated between measured values, usually using a mathematical function (local B-spline). Local B-Spline is the algorithm that calculates the amplitude to a family of bell shaped functions (B-splines) using a local heuristic approach. The sum of these functions defines a function in (x, y) which approaches the input data. Spatial interpolation as a method of constructing new data points from a discrete set of known data points was applied to estimate values on maps. A series of cross sections was made for model to check the horizons they have to be (1) sorted in depth order, (2) not intersect each other and (3) should not have holes or spikes (Fig. 9B).

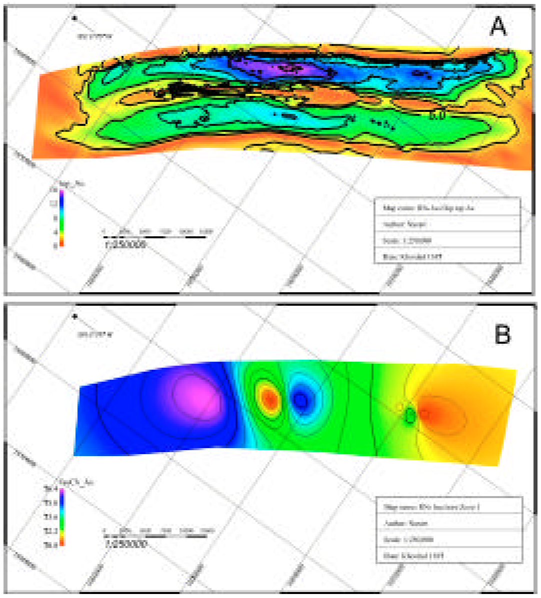

Fig. 6: Dip map of top Asmari (A) and Isochore map for zone 1 (B)

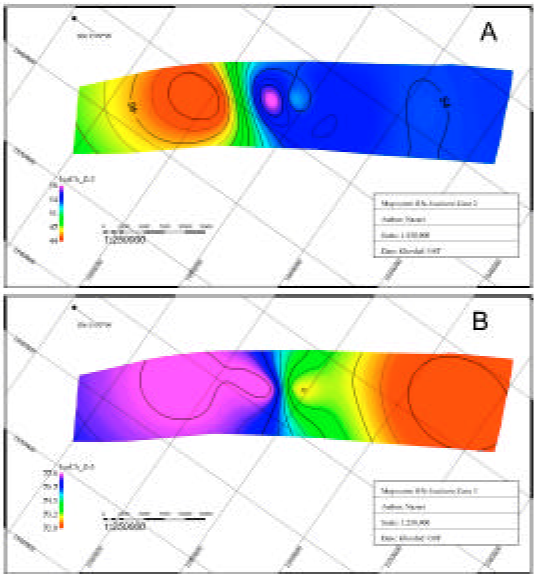

Fig. 7: Isochore map for zone 2 (A) and zone 3 (B)

After these stages, to attain the model, the next phase was to build a 3D grid which is the cellular framework to take place all other geological modeling within Irap RMS.

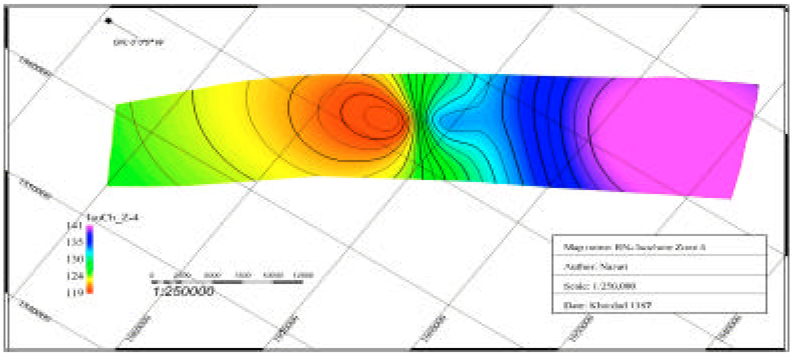

Fig. 8: Isochore map for zone 4

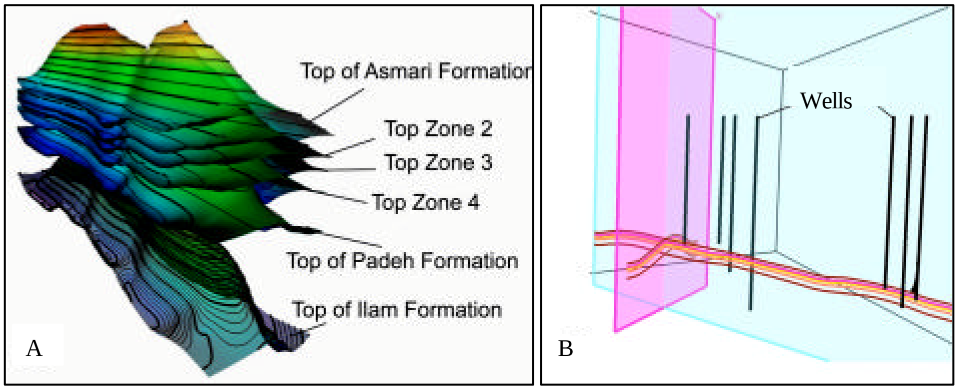

Fig. 9: Stratigraphic model of Asmari reservoir in Ramin oil field (A), cross sections that use for check the structural framework (B)

Table 1: The average thickness of 4 zones and grid cells dimensions in 7 wells of the Ramin oil field

	Zone 1	Zone 2	Zone 3	Zone 4
Average thickness (m)	72	54	72	120
Dimension of cells in Z direction (m)	6	6	12	12
No. of cells in Z direction	12	9	6	10

In each cell of a 3D grid all parameters (continuous or discrete), can be defined (e.g., porosity or water saturation). Such parameters are a key control on hydrocarbon production, including sweep efficiency (Pringle *et al*., 2004; Larue and Friedman, 2005). In this study 4 zones of the Asmari reservoir are gridded. In x and y directions the increment of cells is 100 m. In Z direction, the increment of cells in zone 1 and 2 is 6 m and in zone 3 and 4 is 12 m. The cells in zone 1 and 2 are finer because these two zones are important than zone 3 and 4 in view of hydrocarbon production. In other words in zone 1 and 2 the dimensions of cells are 100×100×6 m and in zone 3 and 4 are 100×100×12 m (Table 1, Fig. 10A).

In the last stage in entering the model, the well data were scaled up to the vertical resolution of the 3D grid. The cells intersected by the well tracks identified and each cell was given an average value for the various log properties. Each cell in this new blocked well was then assigned values based on the log data that had been selected to get the average. The geometry of block well will depend on that of the 3D grid (Fig. 10B).

Data analysis and petrophysical modeling-geostatistical models have this advantage than other methods to compare data from different sedimentary basins, formations and horizons. They also enable geologist for example, to put their valuable information in a format in that can be used by reservoir engineers (Journel and Stanford, 1990). Fortunately, however, a full range of deterministic and stochastic modeling techniques is available, but the techniques used will depend on the data available and the project aims it is also kept in our mind that geostatistical methods are optimal when our used data are:

- Normally distributed
- Stationary (mean and variance not vary significantly in space)

It is therefore a requirement that the input well data must be transformed to remove any trends (Fig. 12A, B) and to create a normal distribution (Fig. 11A, B). These

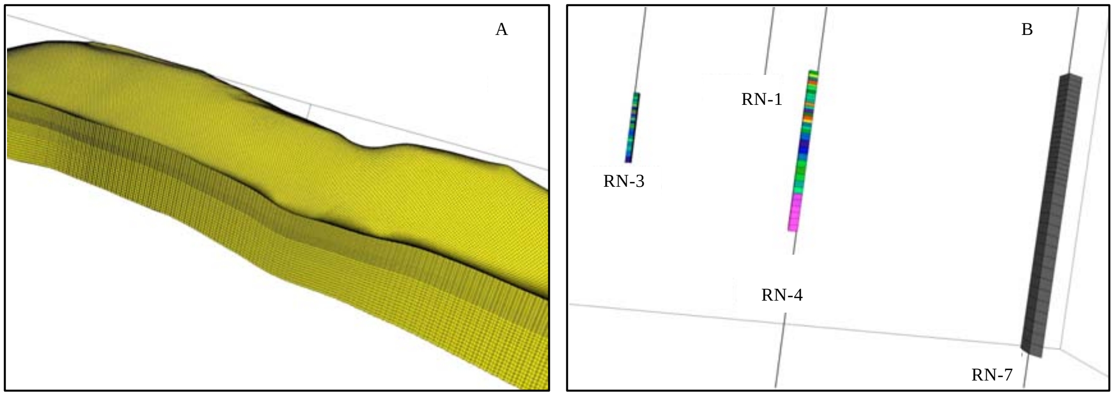

Fig. 10: The 3D geomodel grid in Ramin oilfield (A) and block wells (B)

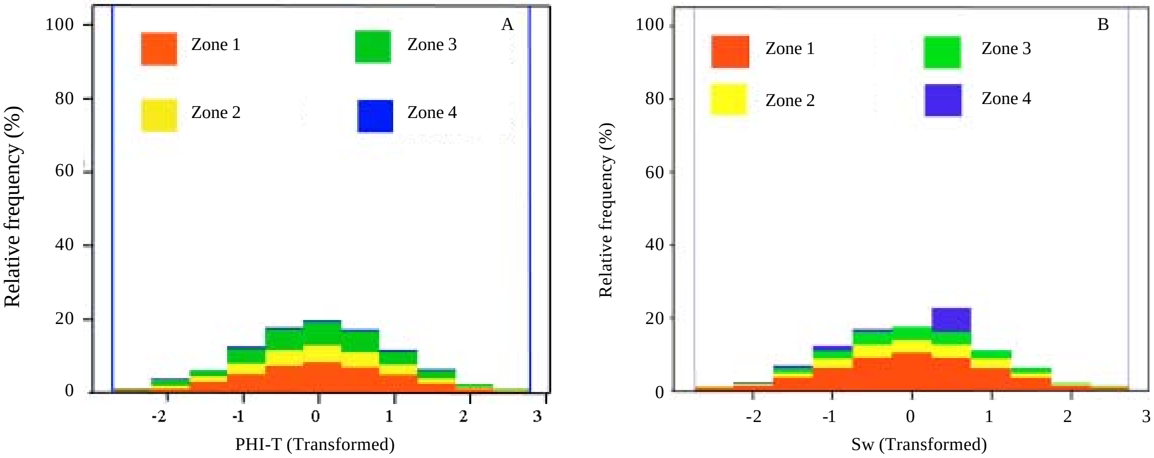

Fig. 11: Histogram of porosity data (A) and water saturation data (B) in 4 zone

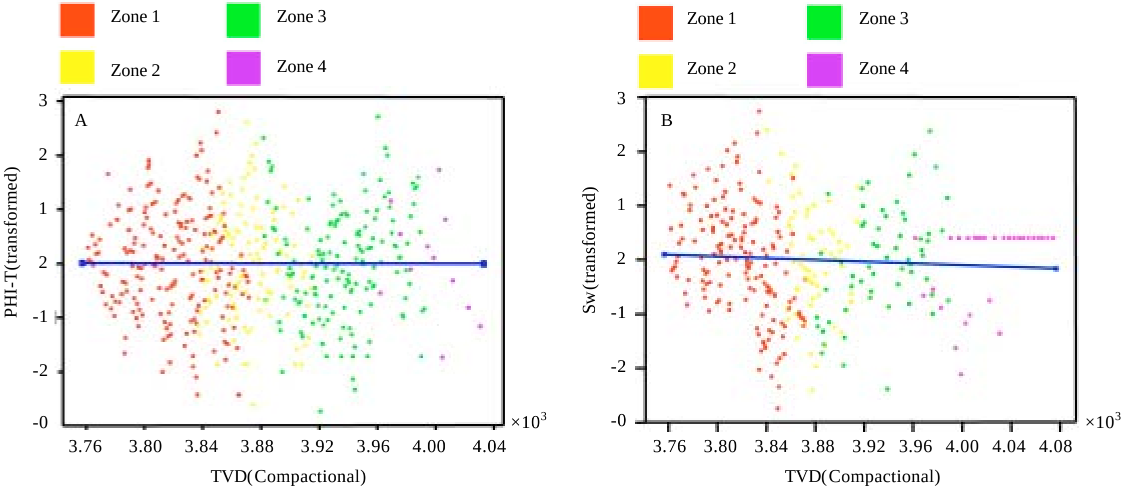

Fig. 12: Scatterplot of distribution porosity (A) and water saturation (B) in 4 zone

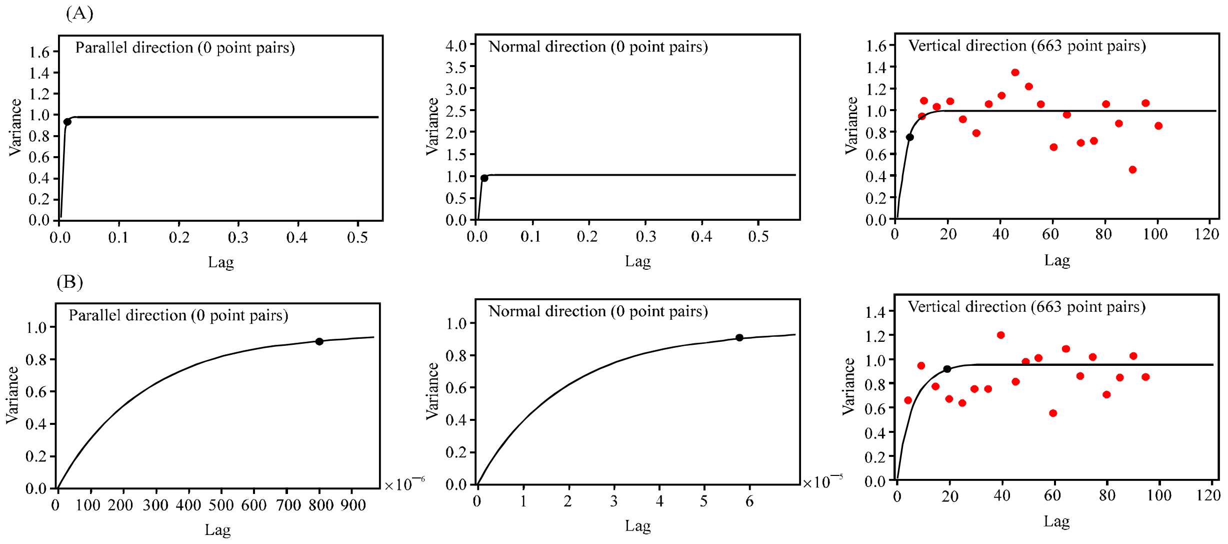

Fig. 13: The variogram models of parameters for Asmari reservoir in Ramin oil field, (A) the variogram model for porosity in 3 directions, (B) the variogram model for Sw in 3 directions

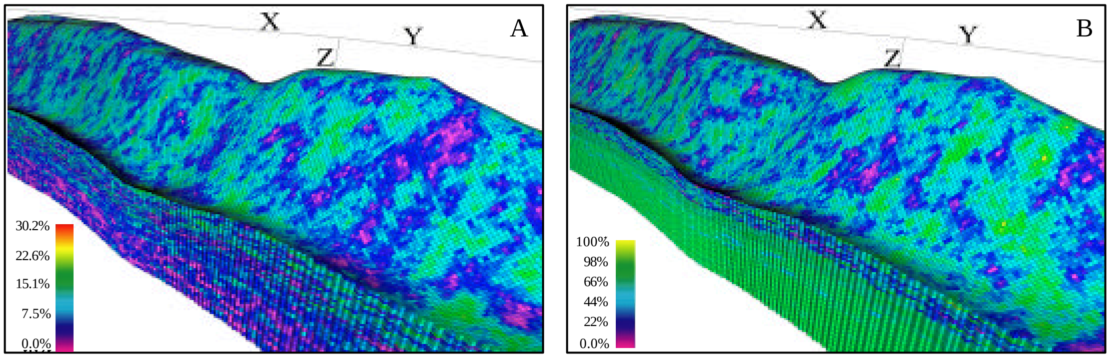

Fig. 14: Distribution of porosity (A) and water saturation (B) in 3 dimension in Ramin oil field and distribution of porosity and Sw in 4 zones

transformations can be carried out in the data analysis and then applied to the stochastic petrophysical modeling. Data analysis is crucial to understanding the property distribution within the reservoir. Much of the petrophysical modeling work is carried out during the data analysis stage. In this stage, the data is investigated for trends and transformed to a normal (Gaussian) distribution. The variogram analysis also takes place as a part of data analysis. The trend is modeled and removed and residual variograms are computed (Li and White, 2003). The variogram shows the increase in dissimilarity between sample values versus increasing separation distance (Journel and Stanford, 1990). A variogram illustrates the spatial statistics of a variable. It measures the variability between sample points (well locations) as the distance between the points increase.

The values defining the experimental variogram are calculated by computing the squared difference between all pairs of sample values. The resulting points are plotted against the separation distance between the points (lag). The dissimilarity between the points is a function of the heterogeneity of the reservoir. Normally, the average dissimilarity between points increases as the distance between samples increases.

The variogram model was provided in three directions: (1) Main, (2) Perpendicular in the horizontal and (3) Vertical. The vertical variogram will normally be well defined due to the quantity of data available from the well logs. The variogram model was created based on knowledge of the geology (Fig. 13). In the next stage of stochastic petrophysical modeling, 3D distribution of porosity and water saturation in reservoir was generated (Fig. 14).

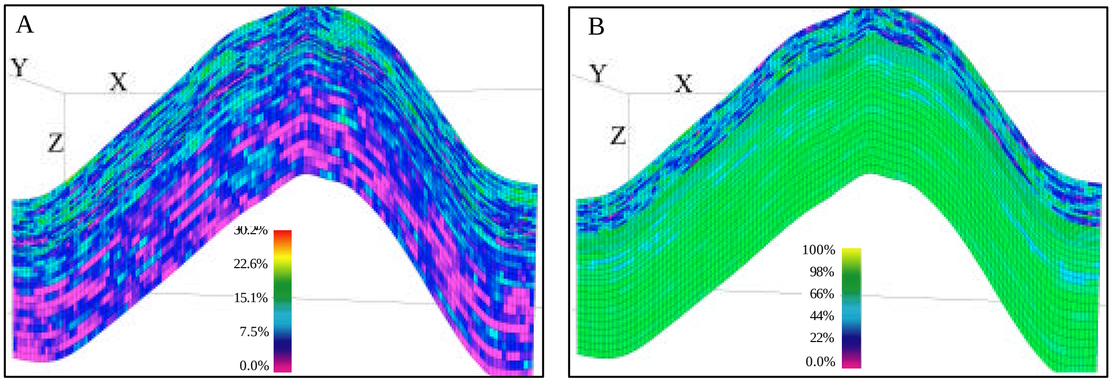

Fig. 15: Distribution of porosity (A) and water saturation (B) for all 4 zones in a cross section of upper culmination

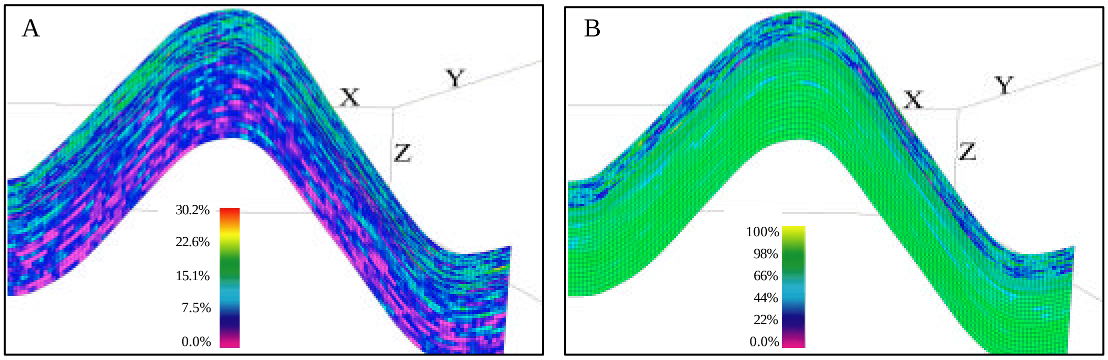

Fig. 16: Distribution of porosity (A) and water saturation (B) for all 4 zones in a cross section of lower culmination

Plotting the main reservoir parameters (porosity and water saturation) in Ramin oil field present that zone 1 and 2 (the upper parts of reservoir) have higher porosity and lower water saturation from zone 3 and 4. It means that zone 1 and 2 have higher oil saturation and are most important parts in hydrocarbon production of the field.

Also petrophysical model (Fig. 14-16) indicate that water saturation in the upper culmination is higher than lower culmination; therefore zone 1 and 2 of the lower culmination are the best situations of reservoir for future drillings.

CONCLUSION

Stochastic modeling method allows more control on the spatial statistics of the model. This method has great potential for identification best locations for drilling with reduced risks.

The structural model of the Ramin oil field indicated that the Ramin anticline has the same trend as the Zagros Mountains (NW-SE) and exhibits a smooth structure. This anticline showing two culminations that the east one is dipper than the west one.

Plotting the main reservoir parameters (porosity and water saturation) in the Ramin oil field presented that the two first zones, 1 and 2, (the upper parts of reservoir) have the higher porosity and lower water saturation the two last zones 3 and 4. It means that zone 1 and 2 have higher oil saturation and are most important parts in hydrocarbon production of the field.

Also petrophysical model indicated that the water saturation in the upper culmination is higher than the lower culmination; therefore, zone 1 and 2 of lower culmination are the best situation of the reservoir for future drillings project.

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