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RESEARCH PAPER

Detection of effective porosity zones utilizing fractal modeling in an oilfield reservoir, NW Iran

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Abstract
An essential work for reservoir modeling specifically fractured reservoirs and development of oil and gas fields is the delineation of geological and geomechanical attributes such as rock type, e.g., effective porosity and permeability. The purpose of this investigation is delineation of effective porosity zones in an oilfield reservoir at the southern Iran for detection of fractured reservoir rocks. First, this parameter was estimated in 3D environment of the Asmari reservoir. Next, fractal number-size (N-S) and concentration-volume (C-V) models were utilized for categorization of the effective porosity zones. The C-V fractal model represents three effective porosity zones, and the N-S fractal analysis shows six zones with an index multifractal feature for the effective porosity data. The correlation between the results obtained by these fractal models presented that the obtained zones have a proper overlap together. High value porous zones based on these fractal models are commenced from 11% and 12.5%, respectively. Fractal modeling indicates that the porous zones happened in the SE and NW parts of the study oil field that presents the fractured part of the Asmari reservoir rock. Main faults from this oilfield are correlated with the porous zones derived via fractal modeling.

Keywords: Fractal Modeling, Concentration-Volume, Number-Size, Fault, Effective Porosity.

Introduction

Modeling of geological characteristics, e.g., effective porosity, is important task for an oilfield. The effective porosity is an essential parameter which indicates the quality of reservoir rock. This character reveals the potential of production for a borehole, which depends on the parameters of a reservoir rock especially tectonic setting and faults (Bahroudi and Koyi, 2004; Rastegarnia et al., 2018; Shamszadeh et al., 2022). Modeling/simulation of this parameter based on mathematical methods, e.g., fractal modeling, is an important work for interpretation of reservoir data.

The conventional mathematical methods derived via classical statistics has several problems such as basis on the normal distribution, absent of the data spatial distribution and the not paying to attention of geometrical shape of the anomalies/zones. These problems are solved by methods based on fractal geometry (Agterberg, 1995; Turcotte, 1997; Davis, 2002; Afzal et al., 2017; Farhadi et al., 2022).

The Fractal geometry can express of the complexities in nature based on self-similarity and

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real dimensions in nature (Mandelbrot, 1983). It is useful for interpretation of geological particulars such as geophysical, geochemical, petrophysical and geotechnical/geomechanical data (Goncalves et al., 2001; Saadati et al., 2020; Shamseddin Meigooni et al., 2021; Afzal et al., 2022; 2023; Nabilou et al., 2022a,b; Bazargani Golshan et al., 2024). The fractal methods have been introduced and improved for this aim, e.g., number-size, concentration-area, spectrum-area, concentration-volume, spectrum-volume and concentration-concentration, which are proposed by Mandelbrot (1983), Cheng et al., (1994), Cheng (1999), Afzal et al. (2011; 2012) and Sadeghi (2021), respectively. The fractal models have been utilized for hydrocarbon reservoirs modeling/simulation because their data can be interpreted with fractal/multifractal models (Ebrahim et al., 2018; Kianoush et al., 2022). Geostatistical and fractal modeling are applied to recognize properties of reservoir rock such as effective porosity and permeability (Amanipoor, 2013; Kianersi et al., 2021; Afzal et al., 2023).

The effective porosity data from 179 drilled boreholes based on well logging related to the Gachsaran oilfield in SW Iran was used in this study. Separation of effective porosity zones of reservoir rock was carried out based on ordinary kriging geostatistical modeling and concentration-volume and number-size fractal models. These zones with high values of effective porosity is correlated with faults.

Geological setting

The Gachsaran oilfield is located at Khuzestan province, SW Iran which consists on the Bangestan and Asmari fractured formations. This formations occurred at the NW-SE trend of anticlines oilfields in the south section of Iran (Shamszadeh et al., 2022). The eastern part of the Gachsaran Anticline indicates a smaller wavelength and angular fold in the Asmari formation. The Gachsaran oilfield contains more than 45 billion in-situ oil barrels as a main oilfields in the SW Iran. Most of the oil have been produced from the Asmari formation within carbonate rocks (Alizadeh et al., 2018; Fig. 1).

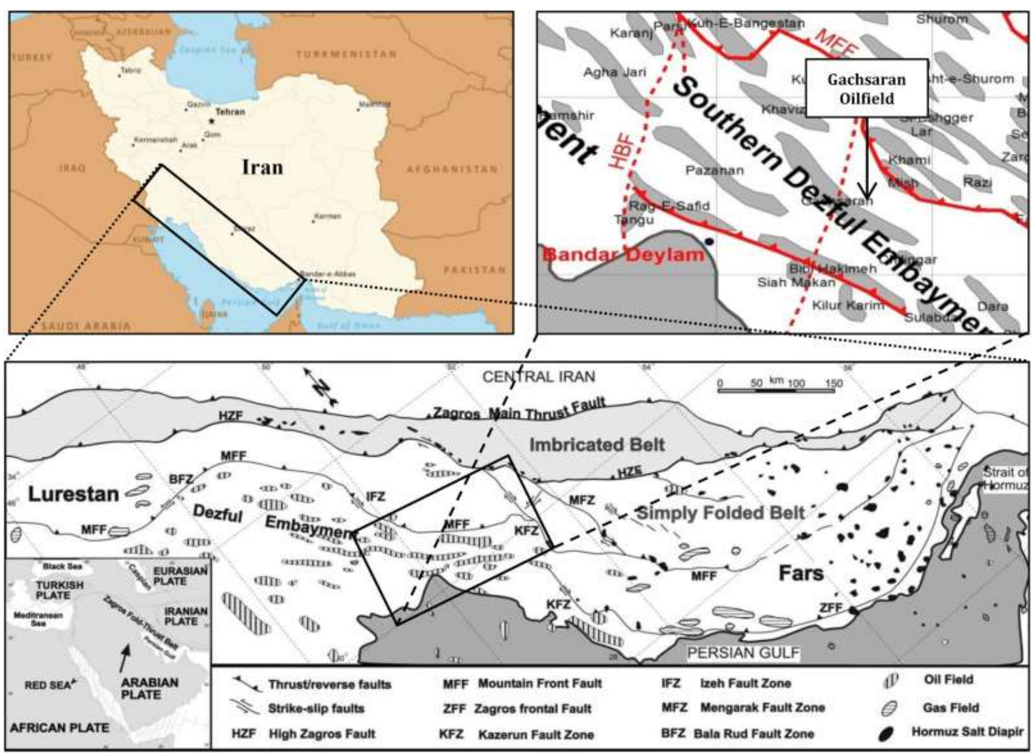

Figure 1. Situation of Gachsaran oilfield and related structures and faults (Alizadeh et al., 2018)

The Oligo-Miocene Asmari formation as main reservoir of Gachsaran oilfield is included of limestone and dolomite. Moreover, this is one of the well-known oil and gas fractured reservoirs in the world. The length and width variation of the Asmari is about 56 km and 1-13 kilometers, respectively. The Asmari formation stratum thickness is 633 meters. The subsurface data from the drilled boreholes present that the compact lithology of the NE part of the Gachsaran oilfield are more widespread. Furthermore, rate of production of numerous sections of this oilfield shows the expansion of cracks in these parts (Afzal et al., 2023). The Asmari formation in this oilfield contains conductive, clustered and opening mode fractures with various patterns in forelimb and backlimb (Afroogh et al., 2023). There are several faults with an approximate NNW-SSE trending. This presents the seismic data of a high dip angle reverse fault in the SE of this oilfield (Motamedi et al, 2012). Main faults have NW-SE and W-E trends in this oilfield based on the faults' map and rose diagram (Fig. 2).

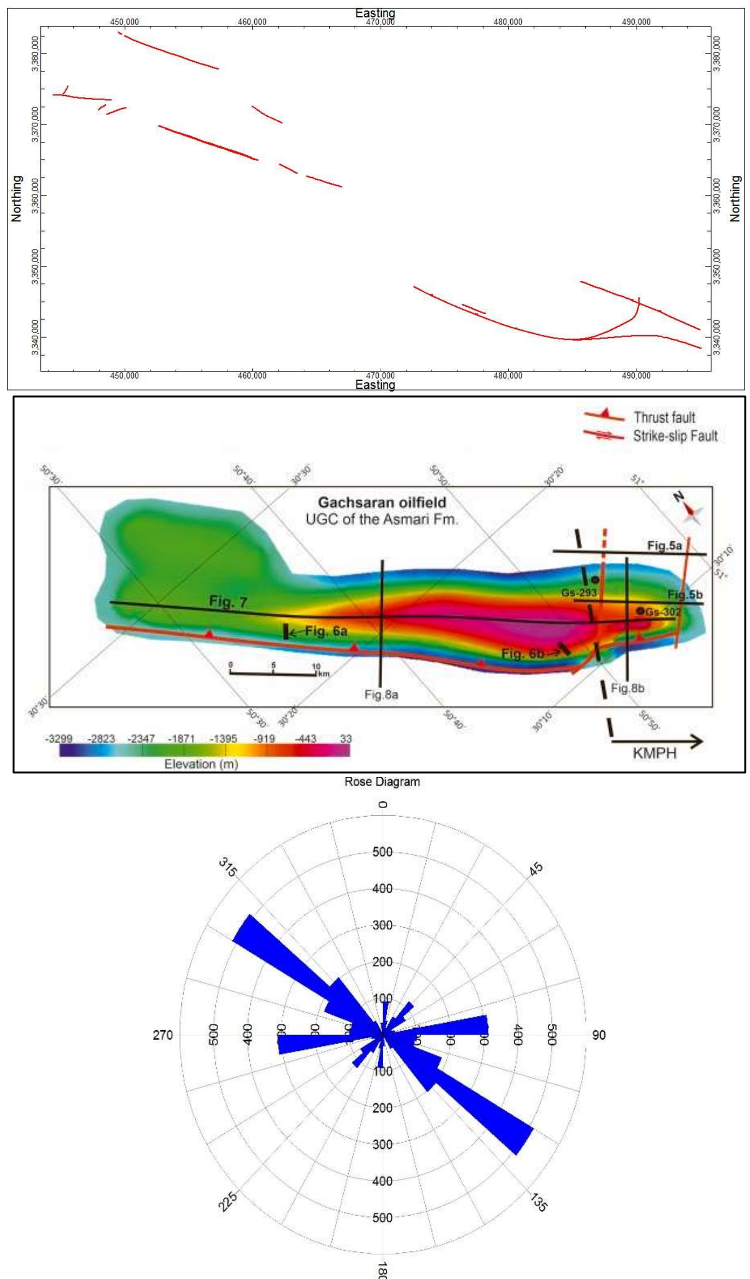

Figure 2. Fault map (based on Shamszadeh et al., 2022) and rose diagram of the Gachsaran oilfield

Methodology

Dataset includes about the effective porosity 700000 data from well logging operation in Asmari formation in related to 179 drilled boreholes of the Gachsaran oilfield. Next, distribution of the effective porosity is 3D modeled in the Asmari formation by ordinary kriging method as an applicable geostatistical estimation.

Then, the effective porosity block model derived via the ordinary kriging estimation, were classified based on number-size (N-S) and concentration-volume (C-V) fractal methods. However, various effective porosity zones were delineated based of the log-log plots derived via both of them. Finally, different effective porosity zones were correlated with faults in the Gachsaran oilfield.

Fractal models

Mathematical methods are available as proper tools for description of natural processes specifically geological features. Conventional mathematical methods based on Euclidean geometry is not proper to explain the nature's complexities. For solving of this problem, Mandelbrot (1983) presented fractal geometry as a suitable implement. Different models have been resulted from the fractal geometry have a basic criteria. This is a reverse relationship between regionalized variables (effective porosity and permeability in this scenario) and their occupied geometrical spaces (Afzal et al., 2010; Daya and Afzal, 2015; Nazarpour, 2018; Koohzadi et al., 2021; Shahbazi et al., 2021; Pourgholam et al., 2022). These main geometrical spaces includes area, perimeter, volume and distance to a geological feature such as fault (Malaekeh et al., 2021; Nabilou et al., 2022a; Mahdizadeh et al., 2022).

C-V Fractal methodology

The C-V model was proposed by Afzal et al. (2011) based on the volume occupied by each value of the studied attribute (effective porosity in this research). It is a useful model to show the parameter's distribution grade in a volume, which is generation a block model of the corresponding character's values. If the concentration of each sub-cell is revealed ρ, a C-V power equation can be indicated as follows:

$$V(\geq \rho) \propto \rho^{-D} \tag{1}$$

The D indicates the fractal dimension related to different ρ classes. The breaking points in a C-V log-log plot depict changing from one zone to another according to exchanging geological conditions in a studied reservoir. For example, high value obtained effective porosity zones show effect of structures specifically faults for the effective porosity increasing in a reservoir rock (Torshizian et al., 2021; Adib et al., 2022; Abdideh et al., 2023).

N-S Fractal model

The N-S model is derived via the inverse relationship between a parameter and the cumulative frequency of this and higher values of the studied attribute (Mandelbrot, 1983; Hassanpour and Afzal, 2013; Shahbazi et al., 2021). This model is introduced based on the following formula (Mandelbrot, 1983):

$$N(\geq C) \propto \rho^{-\beta} \tag{2}$$

In the above relationship, C is equal to the threshold value for the studied parameter. The $N(\geq C)$ are number of samples which values are equal to and higher than C. Furthermore, β is the fractal dimension and ρ is equal to value of the parameter (Shahbazi et al., 2021). Main advantage of this method is independent from estimation and simulation.

Results

In this study, the effective porosity obtained by well logging data was modeled for separation of related zones in the Asmari reservoir rocks of the Gachsaran oilfield (Fig. 3). First, the distribution of the effective porosity in this oilfield was estimated and modeled based on a conventional geostatistical method as named Ordinary Kriging (OK). This is a method with proper and unbiased estimation based on variogram and anisotropic ellipsoid. The effective porosity anisotropic ellipsoid and variograms indicate that main trend for extension of this parameter is N-S (Fig. 4). Moreover, the minor direction is W-E in the Gachsaran oilfield, as depicted in Fig. 4. Then, the 3D model of the Asmari reservoir was created in Gachsaran oilfield, as shown in the Fig. 5. It is important for generation of the 3D block model.

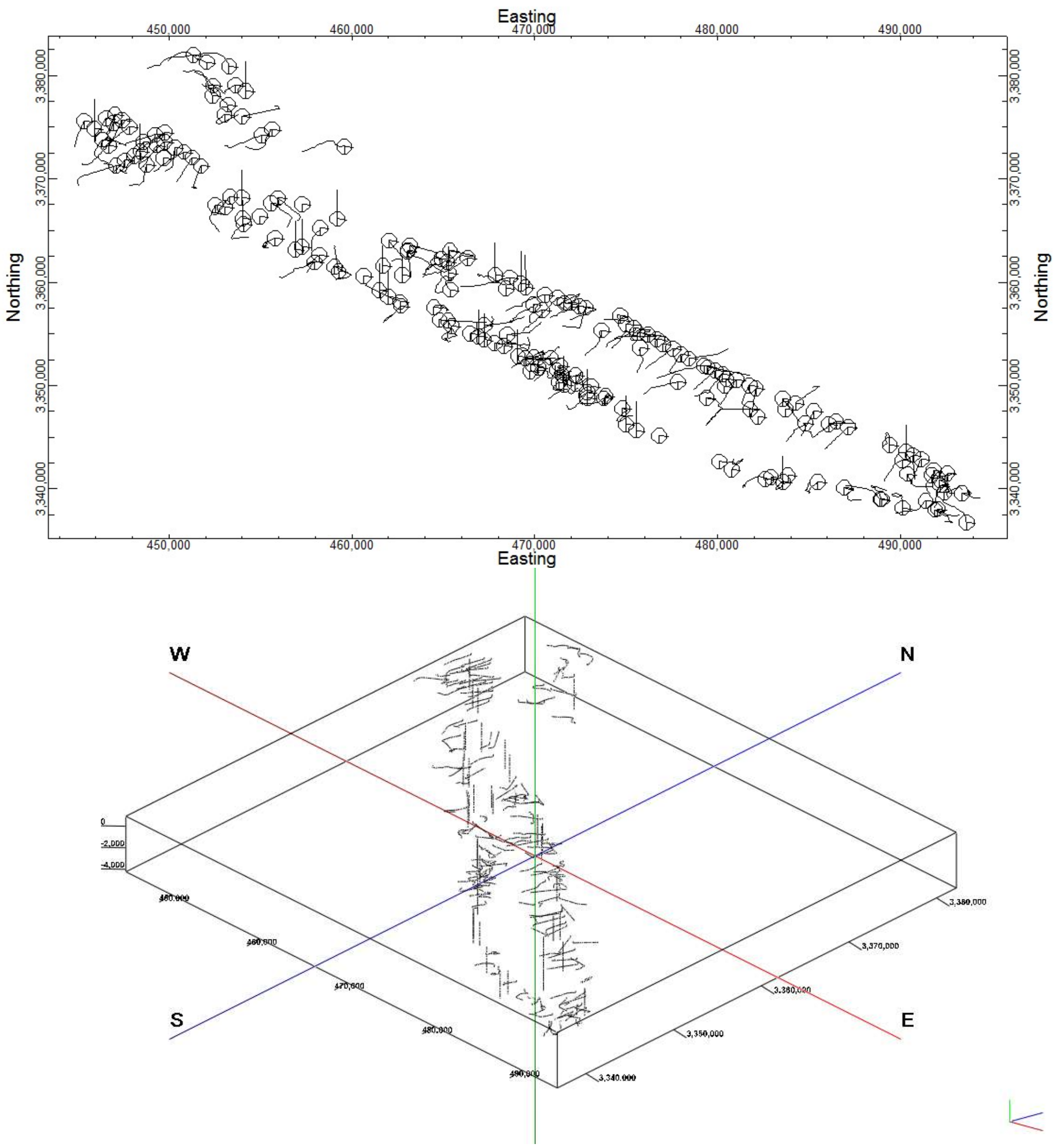

Figure 3. The location of drilled boreholes in the Gachsaran oilfield in 2D map (a) and 3D environment (b)

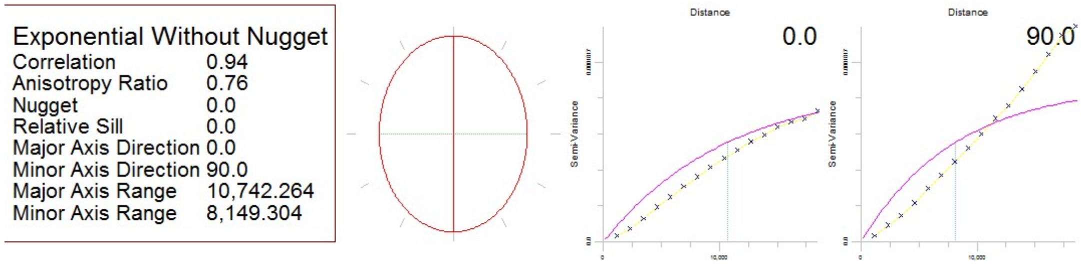

Figure 4. Variogram and anisotropic ellipsoid for effective porosity

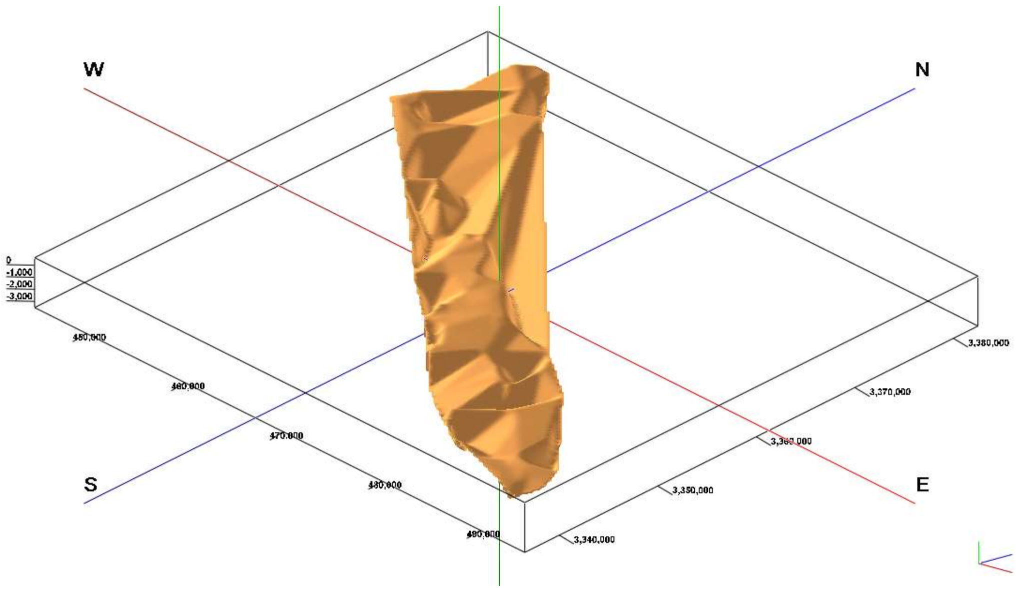

Figure 5. 3D model of the Asmari formation in the Gachsaran oilfield

Several zones for effective porosity are detected based on the C-V and N-S log-log diagrams as depicted in Figs 6 and 8. Based on the C-V log-log graph, three zones were separated as two thresholds equal to 6% and 11%. High intensity zone have effective porosity values higher than 11% and moderate zone contains 6-11% effective porosity values (Fig. 6). A block model of the effective porosity was classified based on the C-V fractal model (Fig. 7). Based on this model, a highly effective porous zone has a NW-SE trend which is correlated with fault's directions.

Separation of effective porosity zones via the N-S model represents six zones, as depicted in Fig. 8. Furthermore, there is an index multifractal behavior which can reveals two genesis for the effective porosity. Two main thresholds are 6.3% and 12.5% for moderate and high intensity zones for effective porosity. There is a NW-SE trend for the highly zone in the Asmari reservoir (Fig. 9). This is similar to the high value zones achieved the N-S fractal method. Also, main effective porous zones with values ≥ 6.3% are situated in NW, southern, northern and SE parts of this reservoir (Fig. 9).

Discussion

Results obtained by the both fractal model are shown two main thresholds for highly porous zone which are 11% and 6% in this oilfield. Highly porous zones are located in a NW-SE trend in the central part of the Gachsaran oilfield as a similar location for both C-V and N-S models, as depicted in Figs. 7 and 9. These main porous zones are correlated with faults in this reservoir, as depicted in Fig. 2.

The reason for the presence of index multifractal behavior for the effective porosity in this carbonate reservoir can be effect of the fractures specifically reverse faults for increasing effective porosity.

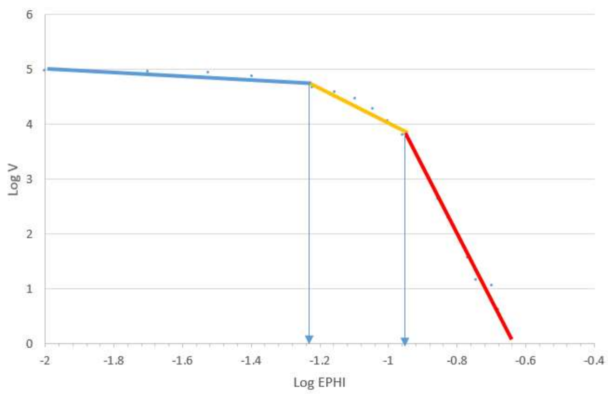

Figure 6. The C-V log-log plot of effective porosity and related threshold values

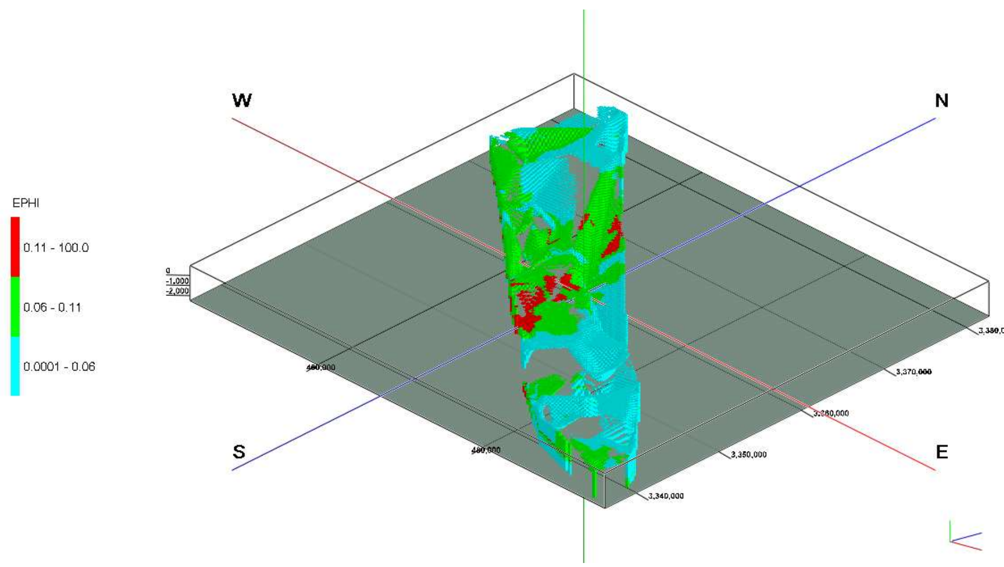

Figure 7. Effective porosity zones' distribution map of the effective porosity via the C-V model in the study oilfield

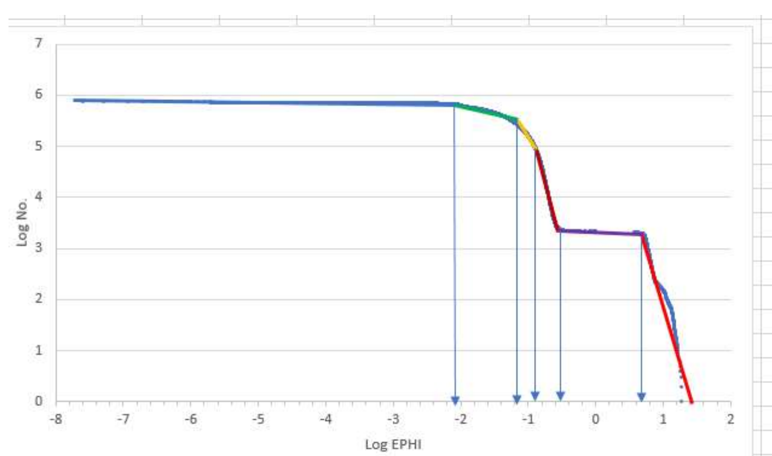

Figure 8. The N-S log-log of effective porosity

The many parts of the Asmari reservoir are fractured zones. It has been dolomitized and replaced by a diagenesis happening according to tectonical event (Bahroudi et al, 2004). One of the appropriate approaches to recognize fractures in reservoir rock is to utilize image logs obtained by the well logging. The Asmari formation in this oilfield has an open fractures network which is controlled the high rate of oil production (Fig. 10). Consequently, open fractures in the Asmari reservoir of the Gachsaran oilfield have been observed the image logs, as depicted in Fig. 10.

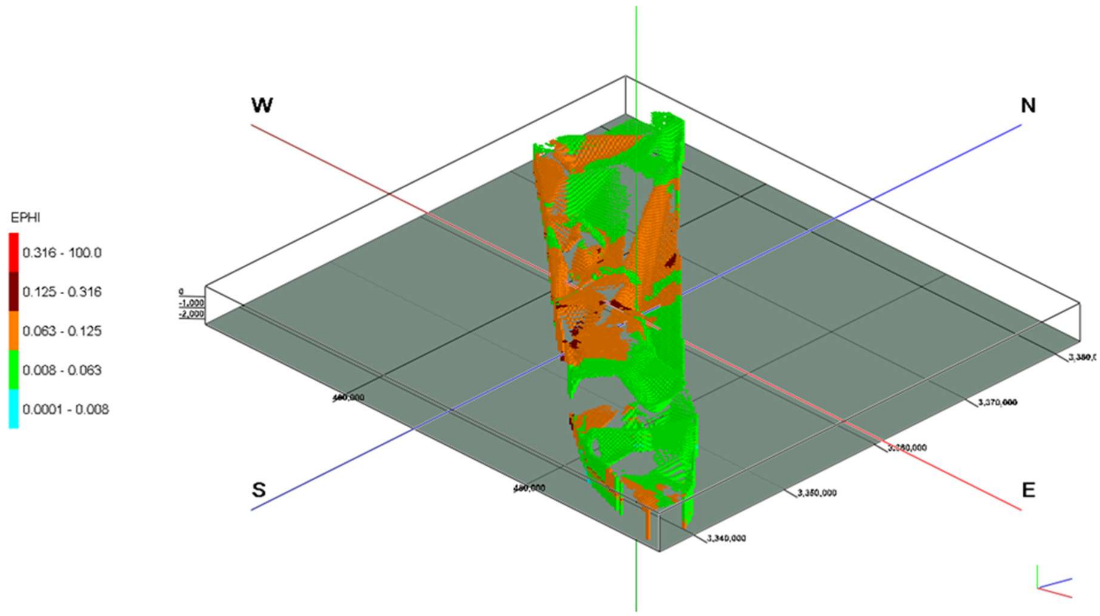

Figure 9. Effective porosity zones' distribution map of the effective porosity obtained by the N-S method in the study oilfield

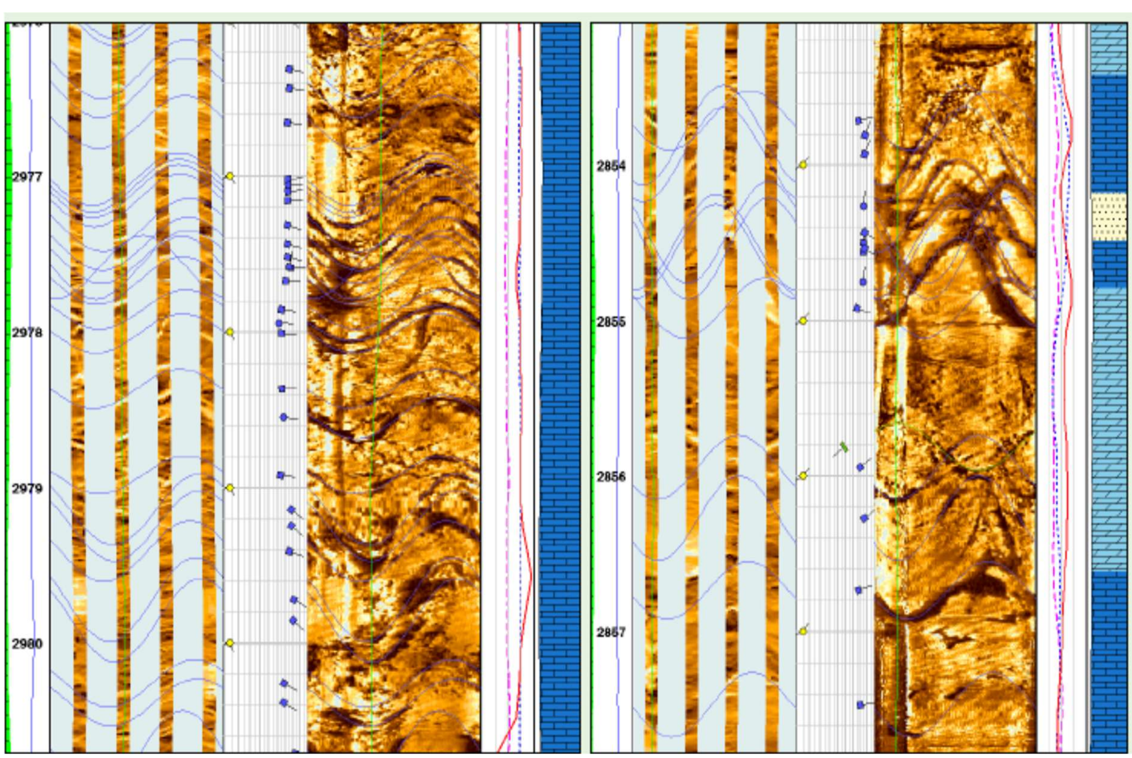

Figure 10. Open fractures in the Asmari reservoir of the Gachsaran oilfield in two image logs

Conclusions

This research presented that the both fractal models are appropriate models for delineation of different porous zones in a reservoir rock. The conclusions are itemized as follow:

The index multifractal behavior in this oilfield is an evidence for effect of faults for increasing of the effective porosity. Furthermore, the index multifractal in the N-S log-log plot can be presented two source for the effective porosity. The effective porosity lower than 12.5% can be shown a diagenetic (dolomitized) source but the effective porosity more than the 12.5% can be represent a source related to faults and fractures. This part of effective porosity is located in the central part of the reservoir with the NW-SE trending.

The obtained zones are recognized for the effective porosity with these techniques. These results are approved by geological particulars, specifically the effect of fractures and faults in the Asmari reservoir. The main zones are correlated with faults and fractures especially in the central part of this reservoir.

Based on these model results, main porous zones (≥6%) occurred based on tectonic event and overlap with faults. Moreover, trend of highly porous zone (≥12%) is correlated with the faults' rose diagram in the Asmari reservoir of the Gachsaran oilfield.

As a future challenge, interpretation of reservoir rock's characteristics specifically structural features can be better by fractal modeling.

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Declarations

Conflict of interest None.

List of symbols

V Volume
C Threshold value for concentration
D Fractal dimension
N Number of data
β Fractal dimension of concentration
ρ Concentration

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