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Delineation of Permeability Zoning of Asmari Reservoir based on Mud Loss Data using Fractal Models in Gachsaran Oilfield, SW Iran

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Concentration-volume

Number-size

Permeability

Abstract

An important work for fractured reservoir modeling and development of oilfields is the delineation of geomechanical attributes such as permeability. The main aim of this research work is detection of permeability zones in the Asmari reservoir of Gachsaran oilfield (SW Iran) based on mud loss data. The mud loss was 3D estimated by ordinary kriging method. Then, fractal number-size, concentration-volume, and concentration-distance to fault models were applied for permeability zone classification. The concentration-distance to fault fractal model shows three permeability zones, and the concentration-volume fractal modeling represents eight zones with an index multifractal behavior. Moreover, the number-size fractal analysis presented that a multifractal behavior with five societies. The correlation between the results obtained by these fractal methods reveals that the obtained zones have a proper overlap together. High value permeability zones based on the concentration-distance to fault and concentration-volume fractal models are began from 501 Barrel Per Day (BPD) mud loss, and 630 BPD obtained by the N-S modeling. Fractal modeling indicates that the permeability zones occur in the SW, NW and southern parts of the Gachsaran oilfield which can be the fractured section of the Asmari reservoir rock. Main faults from this oilfield are correlated with the permeability zones derived via fractal modeling.

1. Introduction

Modeling of geological specifics is an essential task for different oil and gas fields [1]. The permeability is a critical parameter, which specifies the reservoir rock's quality. This character presents the production potential for a borehole, which depends on the parameters of a reservoir rock, especially tectonic setting and structures [2, 3]. This parameter can be calculated based on other related parameters such as effective porosity or mud loss. Modeling/simulation of this parameter based on mathematical methods is an important work for interpretation of reservoir data, e.g. fractal modeling [4-8].

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 geological zones. These problems are solved by structural mathematical methods such as fractal methodology [5, 9].

Fractal geometry can express the complexities in nature based on self-similarity and real geometrical dimensions [9-12]. It is useful for interpretation of geological particulars such as geophysical, geochemical, petrophysical, and geotechnical/geomechanical data [13-17]. 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) [9], Cheng et al. (1994) [18], Cheng (1999) [19], Afzal et al. (2011; 2012) [20-21], and Sadeghi

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(2021) [22], respectively. The fractal models have been utilized for hydrocarbon reservoir modeling/simulation because hydrocarbon reservoirs data can be interpreted with fractal/multifractal models [23-24]. Geostatistical and fractal modeling are applied to define and recognize properties of reservoir rock such as permeability and permeability [6, 25-26].

The mud loss data from 179 drilled boreholes related to the Gachsaran oilfield in SW Iran was investigated in this work for permeability zoning. Separation of permeability zones of reservoir rock was carried out based on ordinary kriging geostatistical modeling of mud loss data and concentration-volume, number-size and concentration-distance to fault fractal models. The zones with high values of permeability is correlated with faults.

2. 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 [3]. 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 are produced from the Asmari formation within carbonate rocks [27] (Figure 1).

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 [6]. The Asmari formation in this oilfield contains conductive, clustered, and opening mode fractures with various patterns in forelimb and backlimb [28]. 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 [29]. Main faults have NW-SE and W-E trends in this oilfield based on the faults' map and rose diagram (Figure 2).

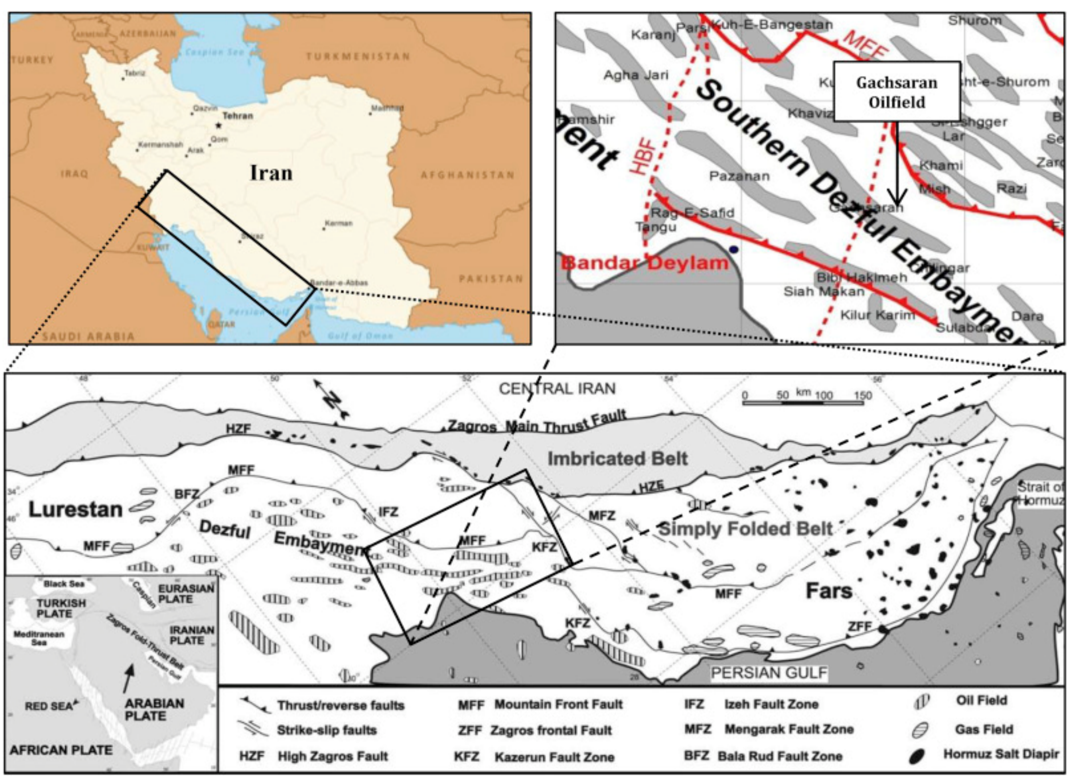

Figure 1. Situation of Gachsaran oilfield and related structures and faults [27].

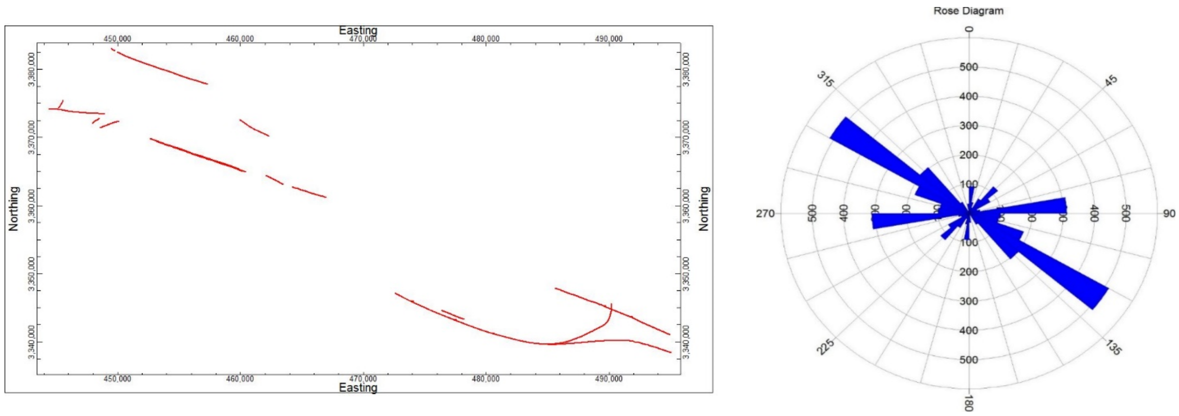

Figure 2. Fault map and rose diagram of the Gachsaran oilfield

3. Methodology

Dataset includes about 92800 data of the mud loss in Asmari formation related to 179 drilled boreholes of the Gachsaran oilfield. Statistical parameters of the mud loss data is depicted in the Table 1. Next, distribution of the permeability is 3D modeled in Asmari by ordinary kriging method as an applicable geostatistical estimation. Then the permeability block model were classified based on number-size (N-S), concentration-distance to fault (C-DF), and concentration–volume (C-V) fractal technics. However, permeability zones were delineated, and these zones were correlated with faults in the Gachsaran oilfield. Flowchart of this methodology is depicted in Figure 3.

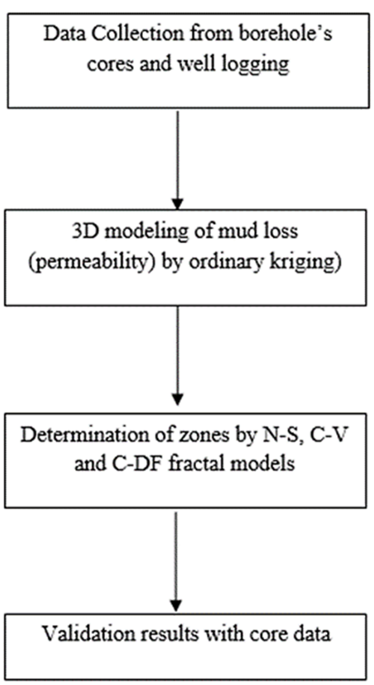

Figure 3. Flowchart of this methodology

4. Fractal Models

Mandelbrot (1983) [9] introduced fractal geometry as a suitable implement for better interpretation of geological features. Different fractal models have a basic principle as a reverse relationship between regionalized variables (permeability in this case) and their occupied geometrical spaces especially area, perimeter, volume and distance to a feature [30-34].

4.1. C-V

The C-V model was presented by Afzal et al. (2011) [20] according to the volume occupied by each value of the target attribute (e.g. mud loss or permeability). It is an applicable model to demonstration the parameter's distribution in a volume is to create a block model. If each sub-cell's concentration is revealed ρ, a C-V power law can be presented as follows:

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

The D reveals the fractal dimension of various ρ classes. The breaking points in a C-V log-log plot represent the change from one to another zone based on exchanging geological and petrophysical conditions in a petroleum reservoir or an ore deposit [6, 35-36].

4.2. N-S

The N-S fractal is based on the inverse relationship between a variable, and it's cumulative frequency [9, 37-38]. This methodology is proposed as the following formula [9]:

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

The C is equal to the threshold value for the target variable. The N(≥C) is number of samples, which values are the equal as or higher than C. Furthermore, β is the fractal dimension, and ρ is equal to value of the parameter [37]. Advantage of this model is independent from estimation and simulation.

4.3. C-DF

The C-DF fractal model has the following formula, which is proposed by Nouri et al. (2013) [39]:

$$DF(\geq \rho) \propto F\rho^{(-D)} \quad (3)$$

The ρ is parameter concentration such as value of mud loss. Furthermore, the DF(≥ ρ) is cumulative distance from faults of sampled sites with concentration values equal or greater than ρ. F and D are constant and is the scaling exponent or fractal dimension, respectively [11, 16].

The faults which were extracted from magnetic survey data as main basement faults. The distances to these faults are named DF and the mud loss (permeability) were classified based on ρ, and DF. The C-DF model were carried out based on the mud loss data form the drilled boreholes and the 2D fault map of the Asmari reservoir to determine the relationship between permeability zones and faults.

5. Results and Discussion

In this study, permeability obtained by well logging operation in the drilled boreholes of the Gachsaran oilfield was modeled for separation of related zones in the Asmari reservoir rocks of this oilfield (Figure 4). First, the distribution of the permeability in the oilfield was estimated, and modeled based on a usual geostatistical method as named Ordinary Kriging (OK). This is a method with proper and unbiased estimation based on variogram and anisotropic ellipsoid. The anisotropic ellipsoid and permeability variograms show that the NW-SE main trend which is similar to rose diagram (Figure 5). Moreover, the minor direction is NW-SE in the Gachsaran oilfield, as depicted in Figure 5. Then, the 3D model of the Asmari reservoir was modeled in Gachsaran oilfield, as shown in Figure 6. It is important for generation of the 3D block model for mud loss (permeability) distribution.

Table 1. The statistical parameters of the mud loss data (BPD) in the Gachsaran oilfield

Number of data	Mean	Median	Maximum	Minimum	Standard Deviation
92823	132.5	58.5	3584.2	0	234.1

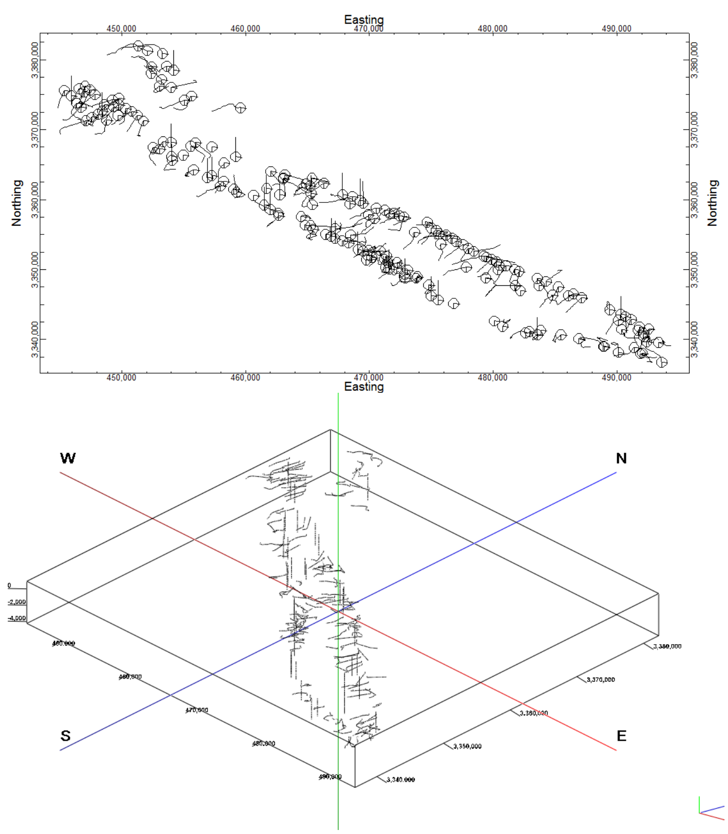

Figure. 4. The location of drilled boreholes in the Gachsaran oilfield as 2D map (a) and 3D model (b).

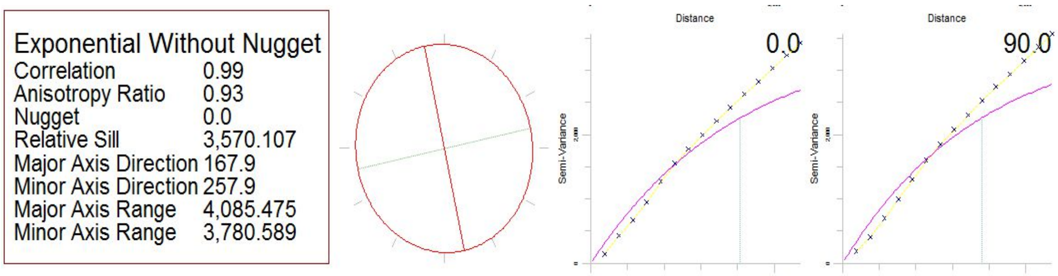

Figure. 5. Variogram and anisotropic ellipsoid for mud loss (permeability).

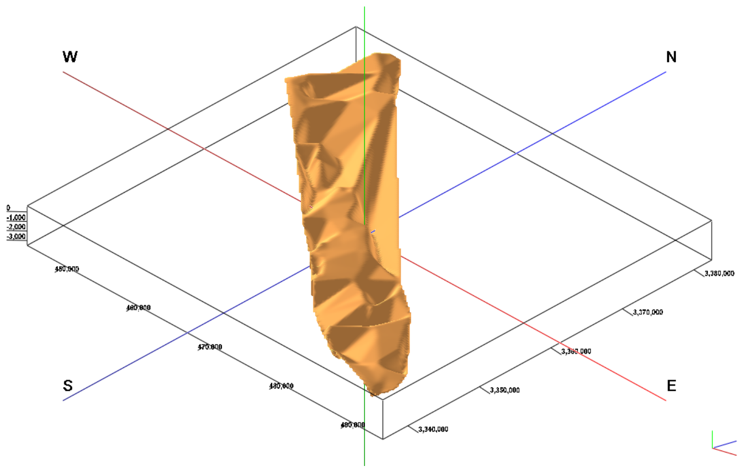

Figure 6. 3D model of the Asmari formation in the Gachsaran oilfield.

Several zones for permeability are defined based on the C-V, C-DF, and N-S log-log plots (Figures 7, 9, and 11). Based on the C-V log-log plot, eight zones were separated as seven thresholds with an index multi-fractal behavior that can reveal two genesis for permeability in this reservoir. High intensity zones have mud loss values higher than 501 Barrel Per Day (BPD) and moderate zone contains 252-501 BPD, as depicted in Figure 7. A block model of the permeability was classified based on the C-V fractal model, as depicted in Figure 8. Based on this model, a high value permeability zone has a NW-SE trend which is correlated with fault's directions. On the other hand, zones with high value mud loss are located in the SW, NW, central and southern parts of the Asmari reservoir.

Separation of permeability zones derived via the N-S model represents five zones, as depicted in Figure 9. Furthermore, there is a multi-fractal behavior. The main thresholds are 141, 631, and 3548 BPD for moderate, high and extreme permeable zones. There is a NW-SE trend for the moderate, high and extreme value zones in the Asmari reservoir (Figure 10). Also, main permeable zones with values ≥ 631 BPD are situated in the southern, central, and SW parts of the Asmari reservoir (Figure 11).

Based on the C-DF fractal modeling, three zones were distinguished (Figure 12). The main value for threshold is 501 BPD which is equal to the high value zones achieved the C-V fractal modeling. Moreover, the moderate zone is between 31 and 501 BPD based on the C-DF model, as presented in Figure 11. Based on the classified 3D model, a high value permeability zone has a NW-SE trend which is correlated with fault's directions. The permeable zones with high value mud loss are located in the SW, NW, central and southern parts of this reservoir, as shown in Figure 12.

Results obtained by these three fractal models is shown a main thresholds high value for major permeability zones, which is 501 BPD in the Asmari reservoir. High value mud loss zones are located in a NW-SE trend in the southern, SW, and central parts of the Gachsaran oilfield as a similar location for all of these models, as depicted in Figures 8 and 10. These permeable zones are correlated with faults in this reservoir, as depicted in Figure 2.

The reason for the presence of index multifractal behavior for permeability in this carbonate reservoir can be effect of the fractures, specifically reverse faults for increasing permeability. Many parts of the Asmari reservoir are fractured zones in the Gachsaran oilfield. It has been dolomitized and replaced by a diagenesis happening in relation to tectonic events [40]. One of the suitable approaches to recognize fractures in reservoir rocks 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 (Figure 13). Consequently, open fractures in the Asmari reservoir of the Gachsaran oilfield have been observed the image logs, as depicted in Figure 13. These fracture networks are correlated in the high permeable zones derived via these fractal models.

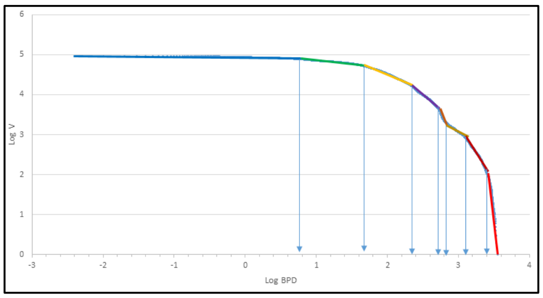

Figure 7. The C-V log-log plot of permeability and related threshold values.

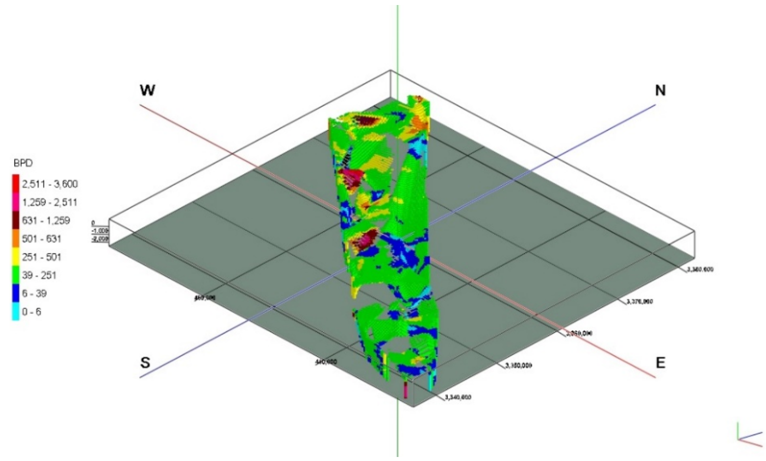

Figure 8. Permeability zones' distribution map of the permeability via the C-V model in the Gachsaran oilfield.

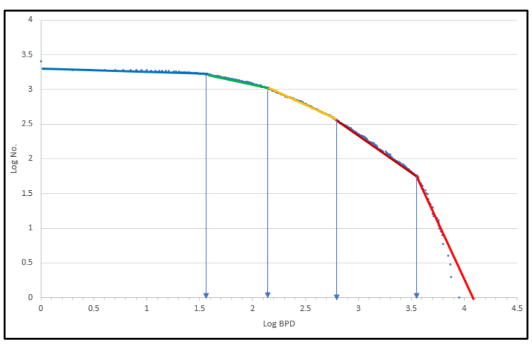

Figure 9. The N–S log-log of permeability.

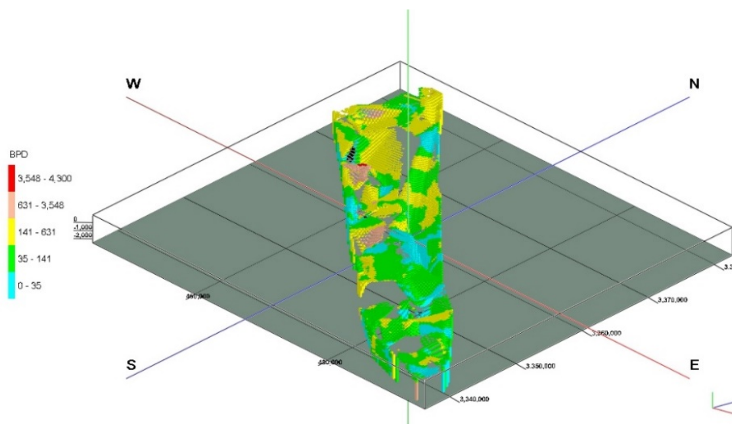

Figure 10. Permeability zones' distribution map of the permeability obtained by the N-S method in the study.

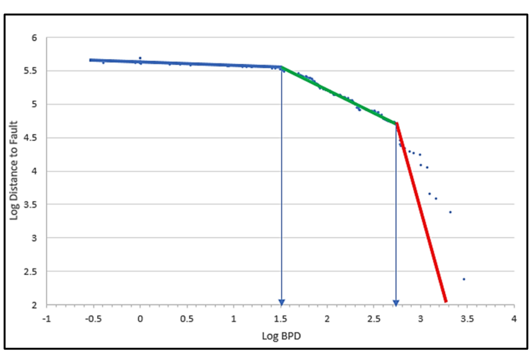

Figure 11. The C-DF log-log plot of permeability and related threshold values.

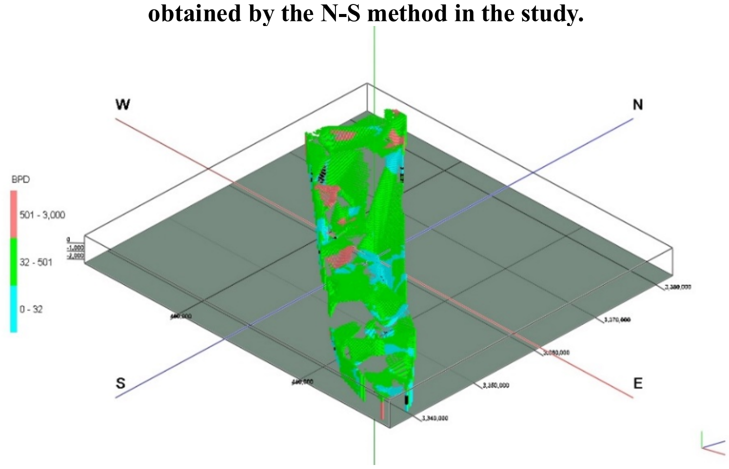

Figure 12. Permeability zones' distribution map of the permeability via the C-DF model in the Gachsaran oilfield.

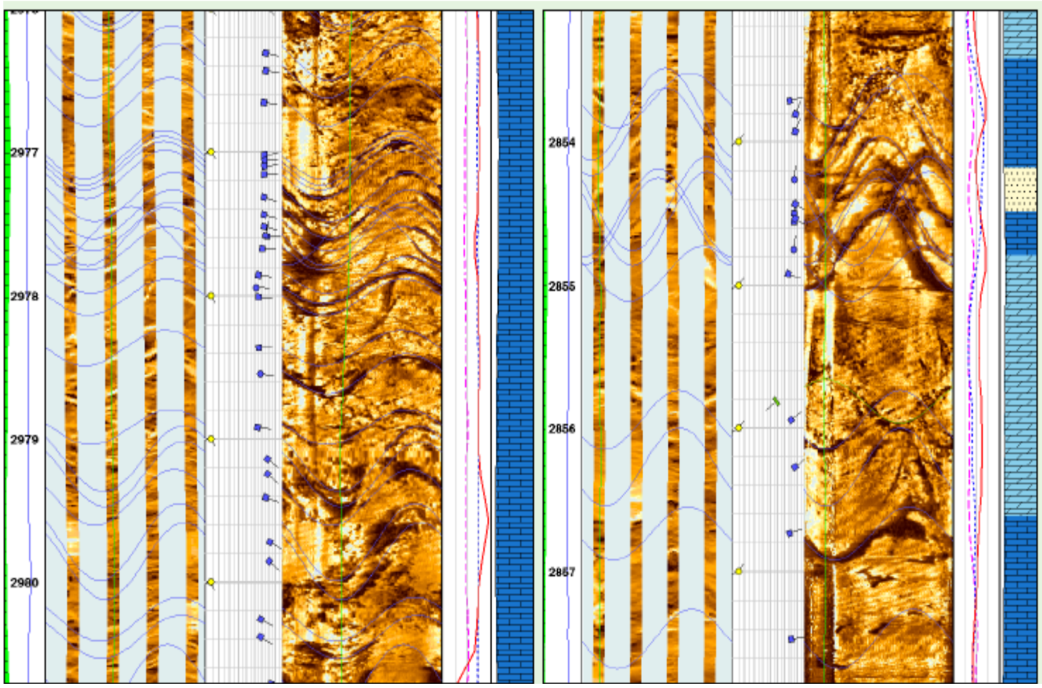

Figure 13. Open fractures in the Asmari reservoir of the Gachsaran oilfield in two image logs [6].

6. Conclusions

This research work presented that these three fractal models are appropriate technics for delineation of different permeable zones in a reservoir rock based on mud loss data. The conclusions are itemized as follow:

- The index multi-fractal behavior in this oilfield is an evidence for effect of faults for increasing permeability. Furthermore, the index multifractal in the C-V log-log plot can be shown two source for the permeability. Permeability lower than 501 BPD can be shown a diagenetic (dolomitized) source but the permeability more than the 501 BPD mud loss can be denote a source related to faults and fractures. This part of permeability is located in the SW, southern and central part of the reservoir with the SW-NE trending.
- The obtained zones recognized for the permeability with these techniques are approved by geological particulars, specifically the effect of fractures and faults in the Asmari reservoir. The major zones are correlated with faults, especially in the central and southern parts of this reservoir.
- Based on these model results, main permeable zones (≥ 501) occurred based on structural events and overlap with faults. Furthermore, trend of high value permeable zone is correlated with the faults' rose diagram in the Asmari reservoir of the Gachsaran oilfield.
- As a future challenge, interpretation of reservoir rock characteristics specifically structural features can be better by fractal modeling.

7. Disclosure Statement

The authors declare that they have no recognized competing financial interest or personal relationships that may have impacted the work presented in this paper.

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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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تعیین پهنه‌های نفوذپذیری در سنگ مخزن آسماری براساس داده‌های هرزروی گل با استفاده از روش‌های فراکتالی در میدان نفتی گچساران، جنوب باختری ایران

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کلمات کلیدی

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غلظت-فاصله از گسل
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چکیده

یک کار مهم برای مدل‌سازی مخازن دارای ساختارهای زمین‌شناسی و توسعه میادین نفتی، تعیین ویژگی‌های ژئومکانیکی مانند نفوذپذیری است. هدف اصلی این پژوهش، شناسایی پهنه های نفوذپذیری در مخزن آسماری میدان نفتی گچساران (جنوب غرب ایران) بر اساس داده های هرزروی گل می باشد. هرزروی گل به روش کریجینگ معمولی به صورت سه بعدی برآورد شد. سپس مدل‌های فراکتالی تعداد-اندازه، غلظت-حجم و غلظت-فاصله تا گسل برای طبقه‌بندی پهنه‌های نفوذپذیری استفاده شد. مدل فراکتال غلظت-فاصله تا گسل سه پهنه نفوذپذیری را نشان می‌دهد و مدل‌سازی فراکتال غلظت-حجم هشت پهنه را با رفتار چندفرکتالی شاخص نشان می‌دهد. علاوه بر این، تجزیه و تحلیل فراکتالی با روش تعداد-اندازه نشان داد که یک رفتار چندفراکتالی با پنج پهنه است. همبستگی بین نتایج به‌دست‌آمده از این روش‌های فراکتالی نشان می‌دهد که پهنه‌های به‌دست‌آمده دارای همپوشانی مناسبی با هم هستند. مناطق نفوذپذیری با ارزش بالا بر اساس مدل‌های فراکتال غلظت-فاصله تا گسل و غلظت-حجم از هرزروی گل ۵۰۱ بشکه در روز و ۶۳۰ بشکه در روز با مدل‌سازی تعداد-اندازه شروع می‌شوند. مدل‌سازی فراکتالی نشان می‌دهد که پهنه‌های با نفوذپذیری بالا در بخش‌های جنوب غربی، شمال غربی و جنوبی میدان نفتی گچساران وجود دارد که می‌تواند بخش شکسته سنگ مخزن آسماری باشد. گسل های اصلی از این میدان نفتی با مناطق نفوذپذیری به دست آمده از طریق مدل سازی فراکتال در ارتباط است.

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