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Fractal Dimensions of a Fractured Formation in the Rondane Mountain Plateau, Norway

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1. Abstract

The objective of present study is to investigate the fractal dimension of naturally fractured reservoirs with secondary porosity only. Previous studies have shown that many fractured reservoirs may be of fractal type. We estimate the fractal dimension on two locations based on pictures from a fracture rock in an outcrop located in Rondane, Norway. The fractal dimension was obtained by the box counting method. In addition, we analyze two well tests from a geothermal field in Indonesia.

2. Introduction

A fracture network does not completely fill the Euclidean space dimensions 1, 2 or 3. Rather than that, the network falls somewhere in between the integer space dimensions. This property may be characterized by a fractal dimension. The fractal dimension is a key variable to characterize a fracture network of fractal type.

Close to Rondane National Park there is a fractured formation(Fig.1). The fracture network shows up on a variety of length scales. Visual inspection of the fracture system is of interest as an aid in mathematical modeling of fluid flow. Along the Ula Canyon, the fractured rock exists as a continuous outcrop of considerable extension. Exposed mountain sides elsewhere provide additional information about the fractured network away from the canyon. The geometry of the fracture system in the Ula Area is complex. It was decided to check if the fracture architecture could be described by a fractal model.

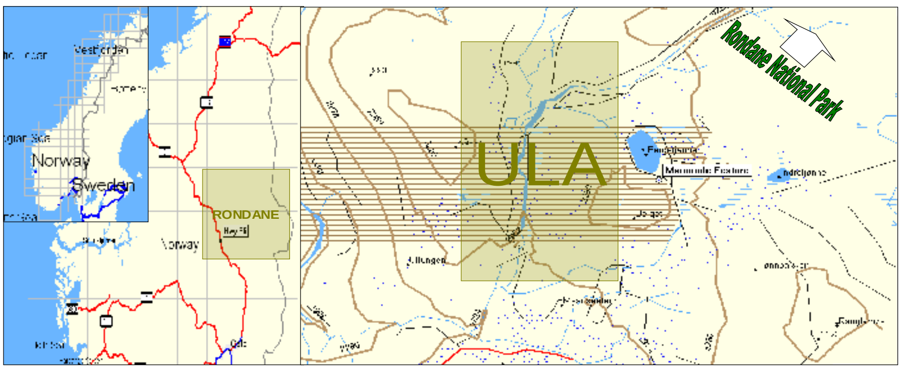


Fig.1. Map showing the location of the Ula Fractured Rock

3. The Fractal Dimension as obtained by the Box Counting Method

The proposition of fractal behavior can be verified by the testing for self similarity. Self similarity manifests itself in a power law relationship (Mandelbrot, 1977 and Hirata 1989). Consider a fracture system enclosed by a square region with a side length, Ro (see Fig.2). This domain is divided into $(Ro/r)^2$ square boxes of side length, r. Let N(r) be the number of boxes that the fracture line enters. If a fracture system has a self similar structure, we obtain the following relation:

$$N(r) \propto r^{-D} \tag{1}$$

where D is a fractal dimension. The above equation will show up as a straight line with slope –D when plotted in a log-log coordinate system. This property provides a practical test of fractal behavior. - Let N(r), as obtained by the box counting, be plotted against r on double logarithmic scale. If the graph is almost linear with slope –D, then eq. (1) is valid and the fractal dimension is available from the slope of the graph.

Many pictures were taken of a fractured rock around the Ula River. The altitude is roughly 1020-1140 m above sea level. Fortunately, the rock is exposed in many places and detailed pictures are easily available. Two pictures were selected for further analysis; one with a side view and the other one with a top view of the fracture system. Pictures of a fractured rock cannot be analyzed by the box counting method directly. The need for some preparation may be argued as follows.

i) The picture is a two-dimensional image of a three-dimensional reality. Hence what appears to be a wide fracture could be a shade. A shade, however, indicates the existence of fracture plane and that some part of the rock has disappeared.
ii) A fracture that has a wide opening in an outcrop probably has a very small width at reservoir depth. In fact it may be closed when the stress is sufficiently high or when the fracture has been filled with mineral coming out of solution from an aquifer.

We feel that subsurface fractures are best represented by lines.

The technique used for preparing a picture the box counting method may be described as follows: The selected image is zoomed in to a particular size(Fig.2 A). Next; a schematic of the fracture system is superimposed on the picture(Fig.2.B). Then the schematic is removed from the picture(Fig.2.C).

A B. C.

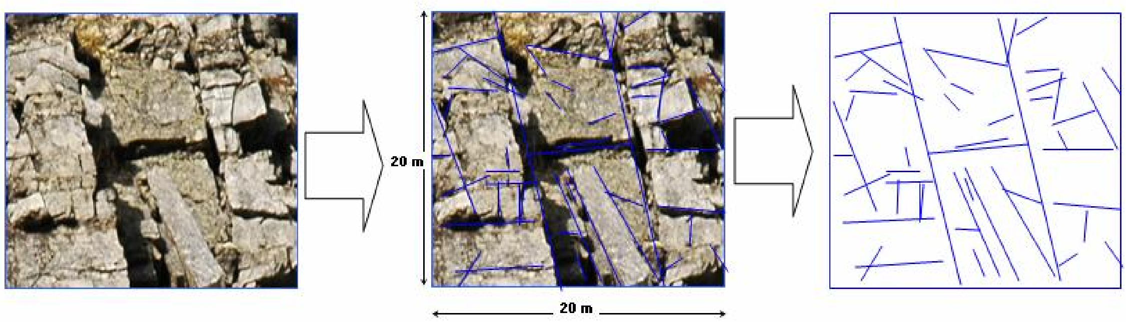


Fig. 2. The preparing a schematic of the fracture system for the box counting method

The schematic is now ready for box counting. A coarse grid is superimposed on the schematic fracture network. Next the number of boxes that the fractures enter, N(r) is counted. The method is repeated with a denser and denser grid to define the number boxes as a function of the grid spacing, r. The distance is reduced by a factor 2 for each update. The procedure is illustrated in Fig.3.A.We find that the fractal dimension of Upper side of Ula Canyon is 1.85 and the Lower side is 1.64.

A. B.

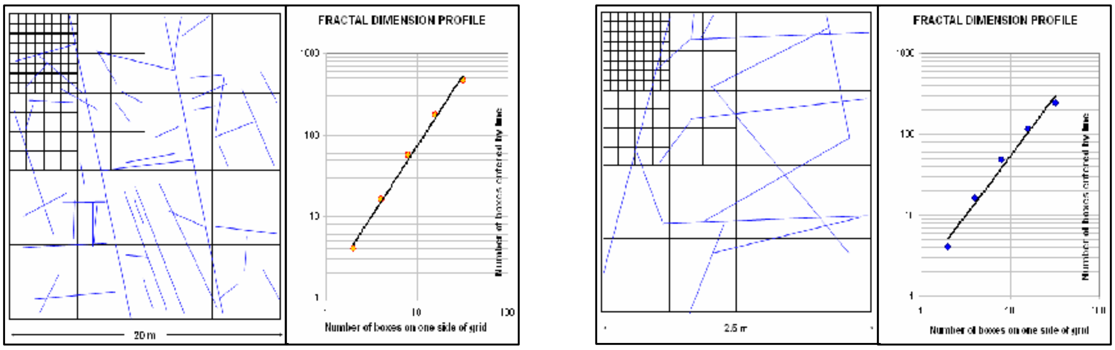


Fig. 3. A. Side view of fracture rock system from the upper side of the Ula Canyon. B. Top view of from the lower Side

4. The Fractal Dimension as Obtained by Well Test Interpretation

Previous studies have shown that a fractal description of the fracture network may be used as an aid in well test interpretation, J.Chang and Y.C.Yortsos (1990), and Acuna et al. (1992). The fractal flow model was extended to interference testing by Aprillian et al. (1993) and the reservoir parameters were estimated by conventional type curve analysis. Their dimensionless pressure function (mathematical model) was found to be:

$$PDF(r_D, t_D) = \frac{(\theta+2)^{1-2\delta}}{\Gamma(\delta)(1-\delta)r_D^{(\delta+2)(1-\delta)}} t_D^{1-\delta} \exp\left(-\frac{1}{(\theta+2)^2 TDF}\right) + \frac{\Gamma(\delta-1)}{\Lambda(\delta)(\delta+2)} \tag{2}$$

where the dimensionless variables are proportional to the real ones.

$$TDF = \frac{t_D}{r_D^{(\theta+2)}} = \frac{k_f(r)t}{\varphi_f(r)\mu c_t r_b^2} \tag{3}$$

$$PDF = \frac{2\pi k_f(r)h}{q\mu}\Delta p, \qquad \Delta p = p_i - p(r_b, t) \tag{4}$$

A type curve is a plot of the dimensionless pd-function (PDF vs. TDF) in a log-log coordinate system. Equation (1) was programmed on a spreadsheet. A family of type curves was plotted. The result is shown in Fig 5. An interference test was conducted on well F1 and F2 in the Darajat geothermal field, Indonesia (see Fig.4) The observed pressure signatures were analyzed by type curve matching. This is a well known technique. From the pressure match one may obtain the transmissibility (kh/μ)

$$\frac{k_f(r)h}{\mu} = 1.1513 \cdot \frac{\text{R¥z¥T}}{M_s} \frac{(PDF)_{MP}}{(\Delta P)_{MP}} \tag{5}$$

and the storativity ($\phi\, c_t\, h$) from the time match.

$$\varphi_f(r)c_t h = 6.8180 \cdot 10^{-9} \cdot B \frac{1}{r_b^{\,2}} \frac{k_f(r)h}{\mu} \frac{t_{MP}}{(TDF)_{MP}} \quad (6)$$

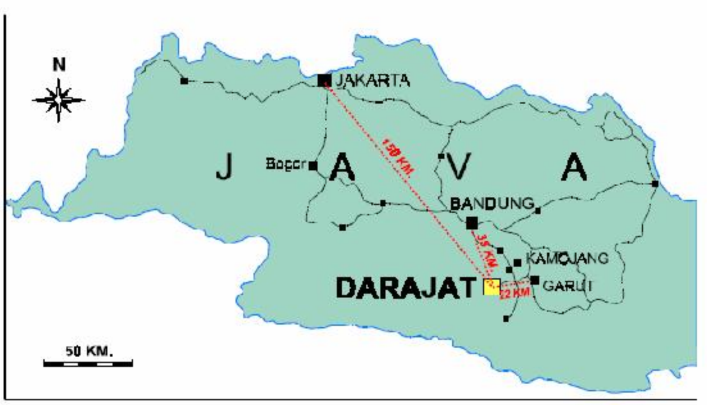
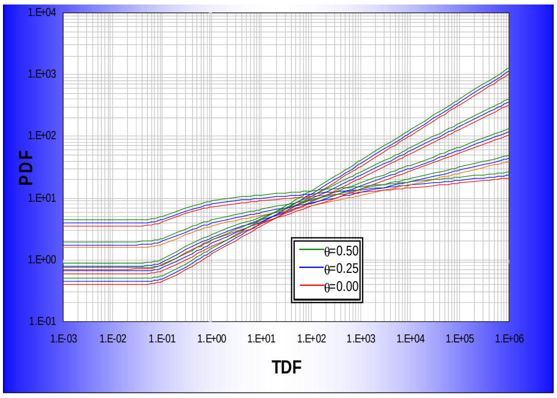


Fig. 4. Map showing the location of the Darajat Field.



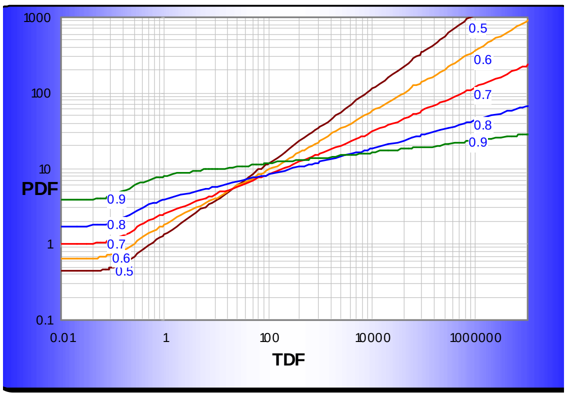


Fig. 5. A. Type Curves for $\theta = 0; 0.25; 0.5$ and various values of δ ;
B. Type Curves for $\theta = 0.25$ and various values of δ

The dimensionless pressure function, PDF, depends on two parameters, θ and δ. If one of these is known or assumed the other one may be obtained from the matched curves. Under this condition, fractal dimension, D, may be obtained from the equation:

$$D = \delta(\theta + 2) \quad (7)$$

We use a common assumption for reservoirs of this type, i.e.: $\theta = 0.25$. Then the variable δ becomes the only parameter. the result of the type curve matching is shown in Fig.6 and Fig.7. The important result of the interpretation is that the fractal dimension of Well F1 is D=1.8 and D=1.13 for well F2. It is interesting to note that the fractal dimension D=1.85 was obtained by the box counting method. See schematic of the fracture system, Fig.3. A One could argue that the fracture system on the picture is similar to the subsurface network of well F1 in a fractal sense.

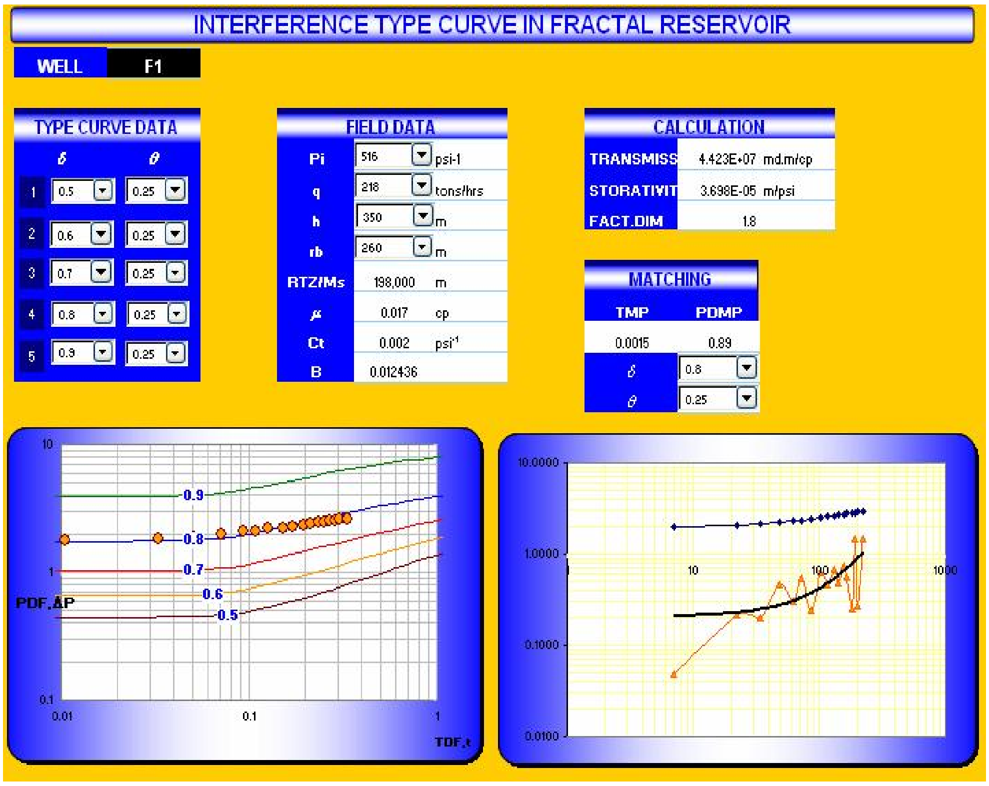


Fig. 6. Result of type curve matching, pressure and pressure derivative well F1

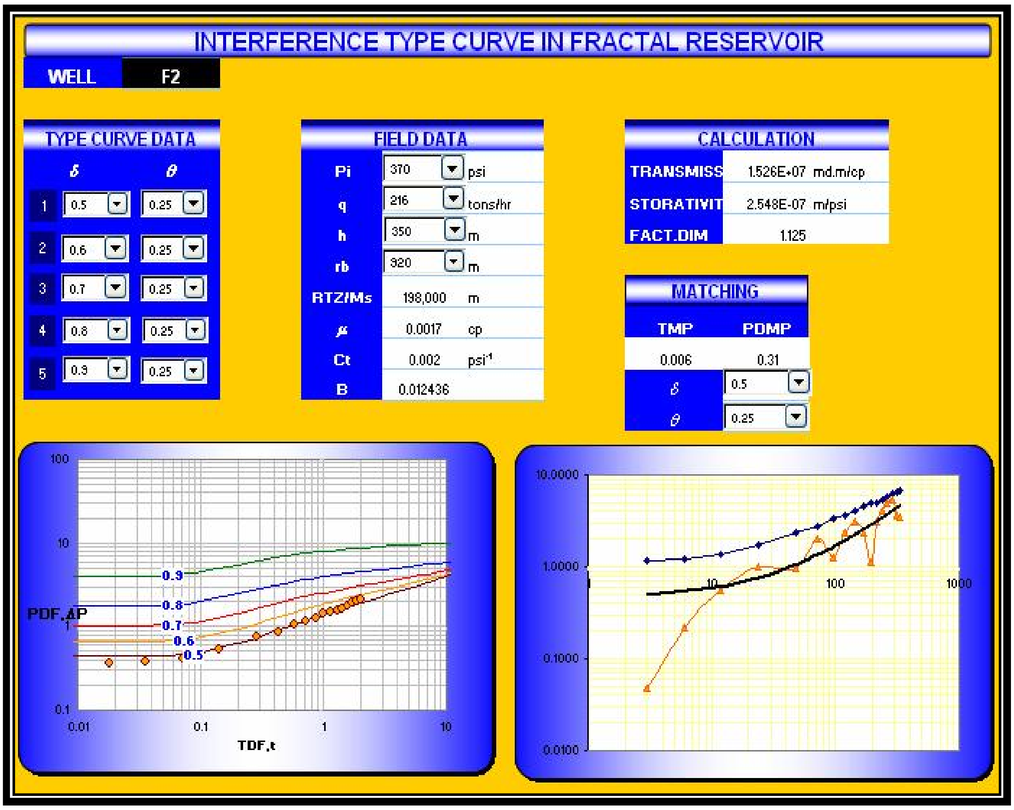


Fig. 7. Result of type curve matching, pressure and pressure derivative well F2

5. Discussion

Two methods to determine the fractal dimension has been discussed. These are the box counting method and type curve analysis. The box counting method was based on outcrop studies. The latter depends on analysis of pressure transients generated by subsurface flow. Obviously both techniques cannot be applied to the same location. Ideally both should be from the same structure. In our case this was not possible.

Direct comparison of the methods is problematic since the stress condition in an outcrop is very different from the sub-surface condition. Also the fractured networks are likely to be generated by different forces. Never the less, this study has been based on the assumption that information obtained by visual inspection of an outcrop may shed some light on the architecture of a sub-surface fracture network. The argument is that a fracture network is likely to develop from and along weak spots (micro-fractures) in the rock regardless of stress condition. According to this hypothesis, it is of interest to compare the fractal dimension obtained by well testing against the fractal dimension obtained by outcrop studies. This may be the only alternative to study a reasonable physical realization. As such, outcrop studies add an important element to well test interpretation.

6. Acknowledgment

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