UNDERSTANDING NATURALLY FRACTURED RESERVOIRS

by

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ABSTRACT

Naturally fractured reservoir differs from clastic reservoirs in the sense that the concepts of porous media which were usually applied for clastic reservoir analysis must be modified. This means that handling naturally fractured reservoir is also different compared to handling clastic reservoir. The porosity may be changed a bit bigger but the permeability is drastically changed. Also at a depth where rock layers are usually tight, naturally fractured reservoirs converts it to become a good reservoirs. Naturally fractured reservoirs can be found in some part of the Indonesian basin which may contribute a considerable additional reserves in the near future.

Key words: reservoir, naturally fracture, porosity, permeability, fracture intensity, fracture density.

I. INTRODUCTION

Fractures consist of cracks, ruptures, joints or faults in a rock due to mechanical failure by stress (Geller, 2003). Fractures can convert tight rock like basement to become good reservoir.

In the seventies, it looks fool to look for oil and gas reservoirs in the basement. This is due to the fact that oil and gas were generated in the source rock within the sedimentary layers and then migrated upward to fill the reservoir rocks which are trapped there when this reservoir rock is covered by impermeable layer. But nowadays, people realizes that the basement high may act as a good reservoir when natural fractures occurs. Actually, fractures are present not only in the basement but also in all rock formations, either subsurface or outcrop. (see Figure 1).

The trend of finding natural fractures reservoir has gained attention in recent years, following the introduction of fracture- finding well logs. Once it is found, the next problem is how to evaluate the petrophysical parameters : how to determine fracture permeabilty, fracture porosity, fluid saturation within the fractures and the recovery factor expected from the fracture system? Other problem which is not less important is how to determine the extension of the fractures in the subsurface?

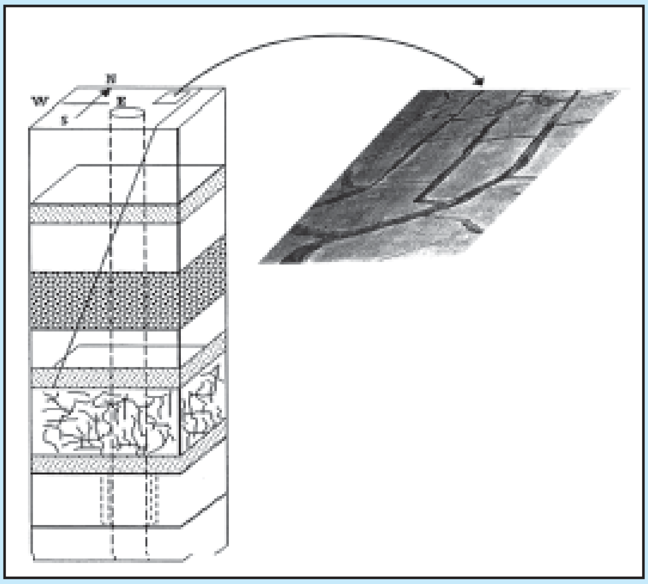

Figure 1
Fractures are present in all rock formation, either subsurface or surface (modified from Tiab and Donaldson, 2004)

The physical character of these fractures is dictated by their mode of origin, the mechanical properties of the host rock, and the subsurface diagenesis (Nelson, 2001). These factors combine to develop a feature that can either increase or decrease reservoir porosity or permeability. It is only when fractures occur in sufficient spacing or length that their effect on fluid flow bocomes important.

An important factor that dictates fracture porosity and permeability are the morphology of the fracture planes.There are four basic types of natural fracture plane morphology, i.e., open fractures, deformed fractures, mineral-filed fractures and vuggy fractures (Nelson, 2001). Open fractures are usually represented as open conduits to fluid flow, deformed fractures are formed as a relative ductile shear zone were physically altered by tectonic shear motions, mineral-filled fractures (occur frequently in sandstone, shale and limestone) are those which have been filled by secondary or diagenetic mineralization such as quartz and carbonate, vuggy fractures are the matrix alteration surrounding the fracture; vugs develop along and adjacent to the fractures and restricted to a narrow zone surrounding the fracture channel which produces vuggy porosity intimately associated with fractures.

Perhaps most of the explorationists and reservoir engineers in this country so far dealing with matrix reservoirs, either sand body or limestones. This paper tries to reveal the specific things of the natural fractures reservoir so that the different with the common matrix reservoirs can be easily understood, as a result our practicionists can start handling the exploration and exploitation of our naturally fracture reservoir. This is the intangible reserves of our oil and gas in the near future.

II. ORIGIN OF NATURAL FRACTURES

The earth pulsates an average of 10 to 15 inches, four times a day under the moon and sun gravitational attraction, triggering numerous small and large earthquakes daily that shatter rocks by brittle failure. The shattered earth is wrinkled by tectonic deformations and by myriad fractures, joints, and faults which find morphologic expression at the surface and at depth (Pirson, 1983). In a zone within competent and brittle rocks, the tension stress causes rock failure along major fault, giving rise to porosity development as openings between separate fracture faces, but away from the major faults the opening separation decreases.

Gomez (1967) has shown with the structural deformation models that the greatest probability of fracture occurence in a brittle bed is at or near the structure surface's maximum curvature (see Figure 5). In other word, obtaining a structure surface's second vertical derivative should point out the areas of maximum probability for fracture occurences which are referred to as Fracture Density Index (FDI).

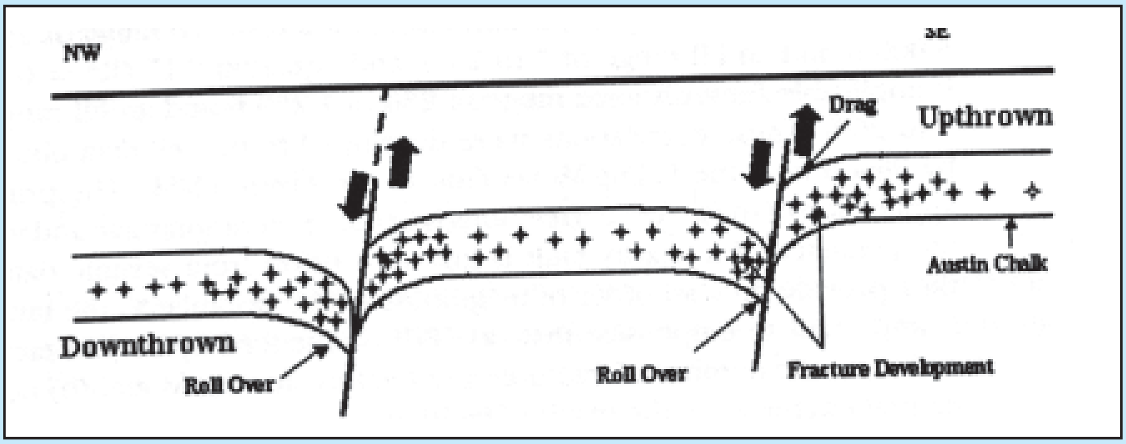

Figure 2
Away from the fault plane the fractures decrease their width, length and frequency of occurence (Tiab and Donaldson, 2004)

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III. FRACTURES POROSITY

Tension stress causes rock failure along major faults, giving rise to fracture porosity (Tiab and Donaldson, 2004). Away from the fault plane the fractures decrease their width, length and frequency of occurence (see Figure 2).

Rock containing fractures are considered to be a two porosity system, one is the matrix porosity and the other one is the fracture porosities. The basic concept of both porosity is the same, i.e., the percentage of a particular void volume in a rock mass compared to a total volume. But fracture porosity accounts for only voids occuring between the walls of fracture, while matrix porosity accounts for all voids within a rock other than those within farctures. Matrix porosity includes voids of various origin such as vuggy porosity, intergranular porosity, dissolution porosity, etc.

IV. FRACTURE PERMEABILITY

How fracture affects permeabilty? Are reservoir fractures always act as high-permeabilty channel? The answer is that the permeability depends on the character and morphology of the fracture plane.

Fracture porosity and matrix porosity are different in their effect on permeability. Relatively small increases in fracture porosity may cause immense change in permeability parallel to the fracture.

Figure 3 taken from Nelson (2001) generalizes the non linear relationship between porosity and per

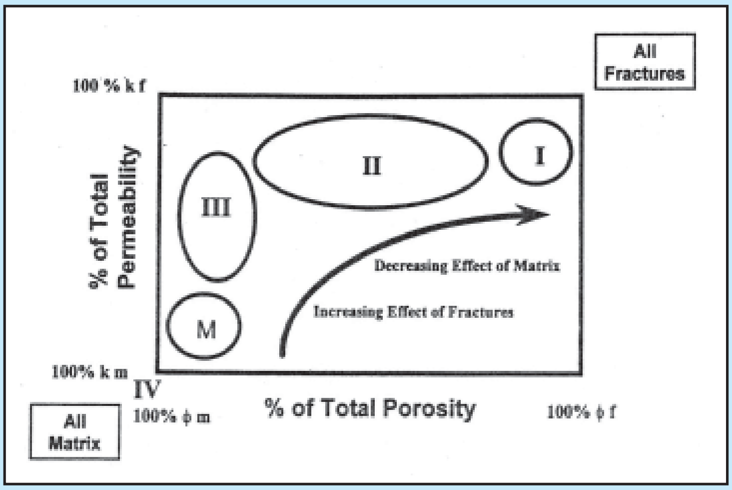
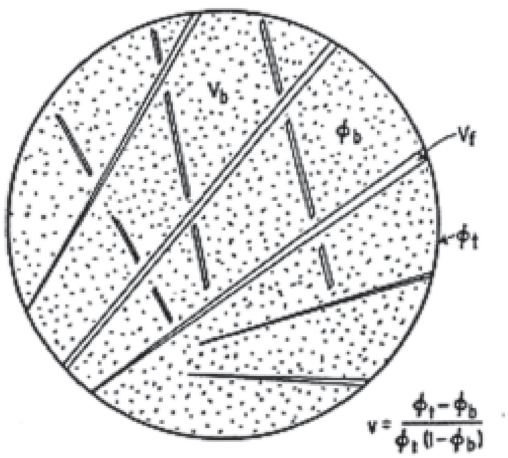


Figure 3
The generalized relationship between porosity and permeability in fractured rock



where V_b = total volume of block or matrix
V_f = total volume of fracture-fissure system
f_t = total porosity, including block and frac ture porosity
f_b = block or matrix porosity

Figure 4
Hypothetical cross section of a core in a fractured rock (Pirson, 1983)

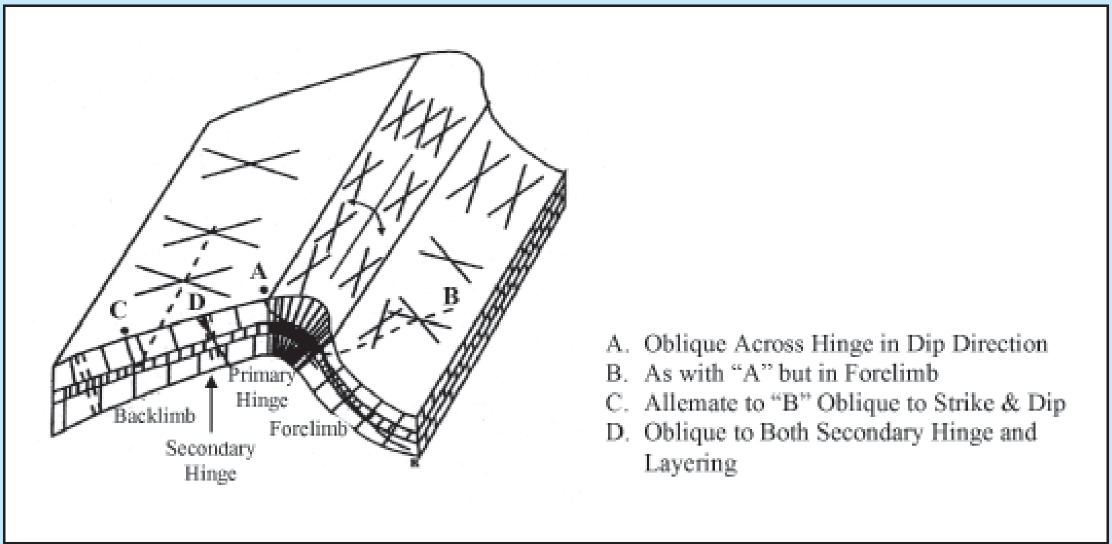


Figure 5
Diagram showing fracture intensity related to fault and curvature

meability in a fractured reservoir. This non linear relationship reflects the complicated dependancies between porosity and permeability in a fractured rock due to interaction between rock matrix and fractures. From Figure 3, Hubert and Willis (1955) classify four conditions in the relationship between porosity and permeability in fractured reservoir.

Area I : condition where fractures provide the essential reservoir porosity and permeability.

Area II : condition where fractures provide the essential reservoir permeability.

Area III : condition where fractures assist permeabilty in an already producible reservoir.

Area IV : condition where fractures provide no additional porosity or permeability but create significant reservoir barrier.

V. DETECTING AND PREDICTING FRACTURE OCCURENCE

The following section will discuss several techniques which have been used for detecting or predicting fractures. In exploration and development of fracture formation, the zones of highest fracture intensity must be localized first. Some of the indicators are as follows :

A. *Fracture Density Index (FDI).*

The FDI is an indicator which points out the area of maximum probability for fracture occurence, this parameter may be derived from any structural map of a brittle bed. Following Gomez (1967) which indicated that the greatest probabilty of fracture occurence in a brittle bed is at or near the structure surface of maximum curvature, accordingly, obtaining a structure surface's second vertical derivative should pointed the FDI.

$$\phi_t = -\frac{T}{2}\frac{\delta^2 H}{\delta z^2} \qquad (1)$$

where H is the structural height above the reference datum plane passing through the center of curvature.

This equation indicates that the total porosity developed by tectonic deformation and fracturing may be derived from the vertical second derivative of a structure map on top of a brittle formation of thickness T and the structural height H.

B. *Fracture Intensity Index (FII)*

By definition FII is the fraction of total porosity developed by fracturing. FII may be measured on the object bed if it is susceptible to became fractured reservoir (Pirson, 1983). Map of Fracture Intensity Index may guide exploration for fractured reservoirs

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or it may help plan field development after discovery. FII may be measured on the object bed if it is susceptible to become a fracture reservoir. FII computations based on well logs should permit remote sensing of such well's relative proximity to major faults. As an index it is best to determine the actual fracture porosity rather than the porosity partitioning coefficient (Pirson, 1983). The FII is related to porosity as follows :

$$FII = \frac{\phi_t - \phi_b}{1 - \phi_b} \qquad (2)$$

This index measures porosity development induced by fracturing.or the fraction of total porosity developed by fracturing (see Figure 5)which can also be formulated as :

$$FII = v\phi_t \qquad (3)$$

Electric logs may be used to determine FII. More elaborate discussion on this topic can be seen in Pirson (1983), p. 202-206.

C. *Fault Recognition*

Rock fracturing is usually associated with fault, so in predicting fracture occurence such fault must be recognized first. The probable subsurface fault position can usually be observed from logs with the following indicators (Moore, 1963, op. cit. Pirson, 1983):

1. Dip of a marker bed abruptly changes on a cross secton based on logs or on contour map of a marker bed.
2. Omission of marker beds generally spell a normal fault.
3. Repetition of marker beds characterizes thrust faulting
4. Thickening of marker beds on the fault's downthrown side characterizes growth faults.

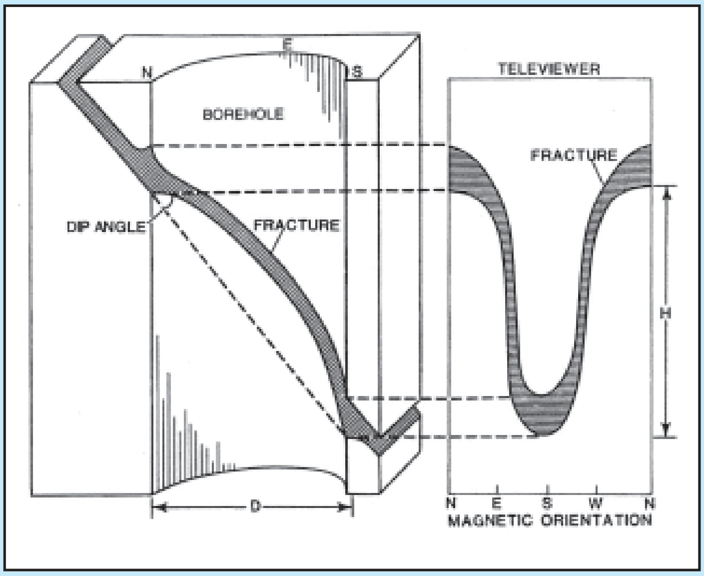

Figure 6
Open dipping fracture intersecting borehole and its corresponding FMI record, absis is the azimuth and ordinate is the depth or thickness. (Keys, 1997)

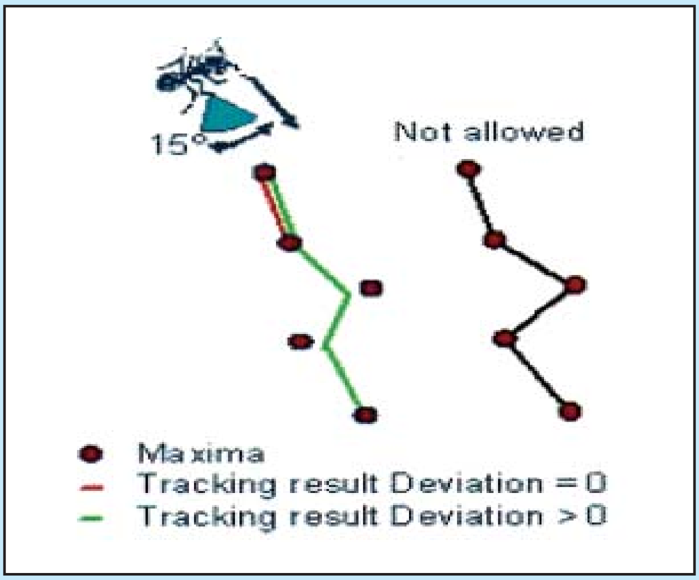

Figure 7
The track of ant does not go astray but it is also limited by a specific angle. For the implementation of ant colony optimization metaheuristic algoritm in the subsurface, this angle is taken from the rose diagram Figure 8) signifying the majority of stresses/ fractures direction in the field which is usually measured from the well

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D. *Tool and method for detecting fractures*

There are few tools and methods that can be used for detecting fracture such as FMI log or FMS log and seismic evidence.

F.M.I. Log or F.M.S. Log

F.M.I. stands for Formation Micro Imager, while F.M.S stands for Formation Micro Scanner. FMI is the successor of FMS. Both are the Schlumberger trademark log which can be used for investigation of borehole wall. The principle of both tools is based on micro resistivity behavior of a sedimentary structure. Fracture intersecting the borehole wall can be recognized as a curve like a sine wave. If this happens, it means the fracture plane intersects the borehole wall with a certain dip.(see Figure 6). This tool can be used to locate open fractures.

Seismic evidence.

It is hardly possible to see fractures from the original seismic section or from their time slice of

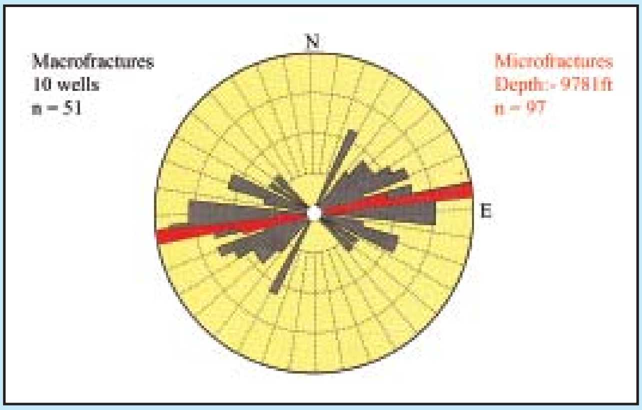

Figure 8
An example of rose diagram (Laubach, et al. 2000)

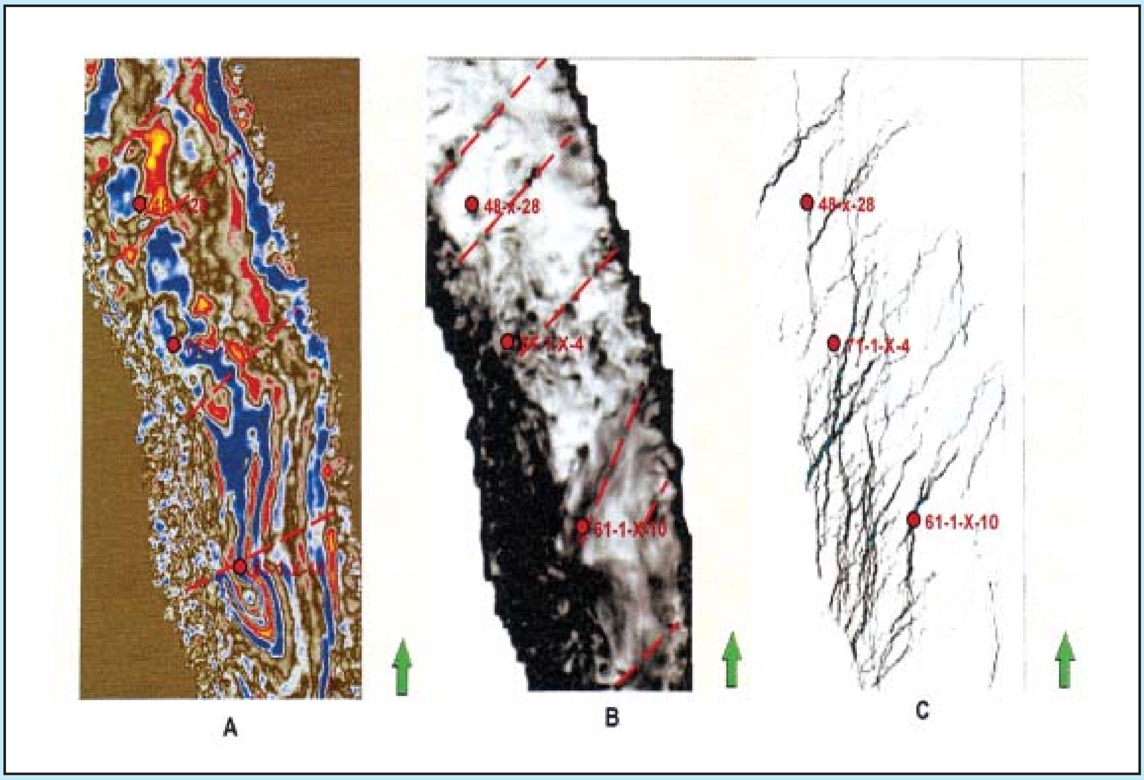

Figure 9
A : Seismic slice in depth domain, B : its corresponding variance slice and the result of Ant track applied to amplitude slice in figure A (Permada, 2008)

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the 3 D seismic cube, especially fractures whose width is in the order of a few millimeters. However, distinct fractures can probably be tracked using the enhanced seismic data. One of them is the use of variance applied to grid data values of a 3D seismic slice. Variance cube will reveal faults, distinct fractures and unconformities much more clearly than the original slice.

Basically variance is a non-negative number which gives an idea of how widely spread the values of the random variable are likely to be, the larger the variance, the more scattered the observation on average (Wahyu, 2007). The values of the random variables are taken from the grid points and the values of the variance are put in the center of the grid. Variance cube will improve the lateral resolution of the 3D data slice to some extend.There are still some edge detection techniques waiting to be exploited for this purpose.

The latest technique for fracture prediction is the ant track principle which greatly enhance the capabilty of seismic data for tracking fractures pattern in lateral direction. An track now is a menu incorporated in Petrel software. The principle of the Ant track algoritm is as follows :

When a colony of ant is looking for food, they move from the nest position to the food location. When an ant encounter a splitting track it must decide which track must be followed. An ant will leave a pheromone hormone in order to mark the chosen track. Track with a high concentration of the pheromon signifies the way that must be followed by other ants from the nest to the food location, but when they return home the ants will choose the shortest distance. More detail description on this method can be found in the theory of *Ant colony optimization metaheuristic algorithm*, see for example Pedersen et al.(2002).

VI. CONCLUSION

Brittle rock layers in a region where tectonic forces is extensive have high potential in generating naturally fracture reservoirs. This is the case of the condition in some part of the Indonesian region. The 3D volume of seismic slice plus the fractures pattern generated by ant track can be used to estimate the total volume of the fracture-fissure system which represent the porosity development induced by fracturing. The naturally fractures reservoirs will certainly constitute our considerable additional reserves in the near future. But handling naturally fractured reservoirs is different compared to handling clastic reservoirs. The naturally fractured reservoirs need to be studied more extensively and more attention is needed to explore them.

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