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Evaluating Fracture Parameters by Conventional Wireline logs.- A Case Study of Son Valley in Vindhyan Basin

Abstract

In Petroleum exploration and exploitation, fractures are an important geological feature. Fractures have large impact on production of tight reservoirs. The presence of open and partially open fractures can increase the hydrocarbon flow and connectivity within the reservoir. Core and image well logs are used for identification and evaluation of fractures. However, while core data provide direct information, they are costly to acquire and recovery is often less than 100% as they seldom encompass the entire stratigraphic interval of interest. New imaging technologies such as Formation Micro Scanner, Extended Range of Micro Imager and Formation Micro Imager provide the fracture images and its properties (fracture porosity, fracture aperture, fracture density and dip of fractures). However, due to economic and other reasons, image logs are not recorded in all the wells. Another limitation of these logs is, owing to their low depth of penetration, these logs see the immediate vicinity of the borehole as compared to the deep penetrating resistivity logs such as DLL. This should make the constructed fracture model using DLL, supposedly, more reliable. Taking cue from this hypothesis, an attempt has been made to estimate fracture parameters such as fracture aperture, fracture porosity and fracture density using DLL log. This technique is based on electrical resistivity anomalies due to the presence of separation in shallow and deep laterolog curves. The applicability of this technique was tested in tight carbonate reservoir of Rohtas Formation of Son Valley of Vindhyan Basin and validated with image logs.

Introduction

Fractures have large impact in production of tight carbonate reservoirs. The presence of open and partially open fractures can increase the hydrocarbon flow and connectivity within the reservoir. Fractures can be either open or mineralized, with the later one acting as a barrier or seal and by this preventing fluid flow. Usually more important are the open and hydraulic fractures that enhance the fluid flow (Laongsakul .P.et al; 2011).

In low porosity, tight formations, natural fractures are the primary source of permeability. The open fractures do not contribute much to porosity but they provide an increased drainage network to any porosity. This may also connect the wellbore to zones of better reservoir characteristics. Core and image well logs are used for identification and evaluation of fractures. New imaging technologies such as Formation Micro Scanner, Formation Micro Imager etc. provide the fracture images and its properties (fracture porosity, fracture aperture, fracture density and dip of fractures). However, they seldom encompass the entire stratigraphic interval of interest. Owing to their low depth of penetration, these logs see the immediate vicinity of the borehole as compared to the deep penetrating resistivity logs such as DLL. This should make the constructed fracture model using DLL, supposedly, more reliable. The present study makes an attempt to estimate fracture parameters such as fracture aperture, fracture density and fracture porosity using DLL log. The technique is based on electrical resistivity anomalies due to the presence of separation in shallow and deep laterolog curves (Saboorian-Jooybari, et al., 2015). The applicability of this technique has been tested in tight carbonate reservoir of Rohtas Formation of Son Valley of Vindhyan Basin and validated with image logs.

Methodology

For the estimation of fracture porosity, fracture aperture and fracture density established equations have been studied. For the present study in tight carbonate reservoirs of Son Valley in Vindhyan Basin, equations utilizing the dual laterolog have been found to be most suitable.

The Dual Laterolog (DLL) provides two resistivity measurements with different depth of investigation, one is deep resistivity curve (LLD) and another is shallow resistivity curve (LLS). Against fractures large separation between the shallow and deep laterolog measurements are observed. The difference in resistivity measurements, is because of the difference between conductivity of the invaded drilling mud and the displaced fractured fluid, is a function of the volume of mud losses during drilling (Saboorian-Jooybari, et al., 2015).

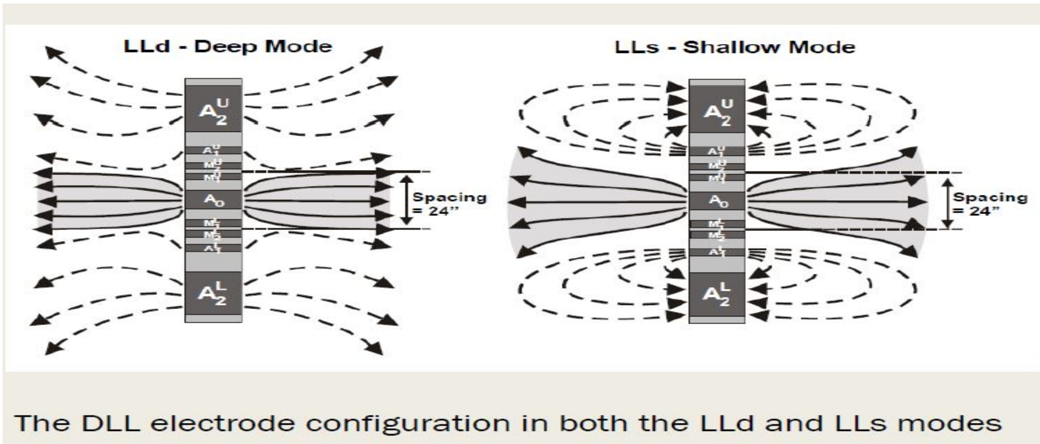

Figure 1: Dual Laterlog (DLL) tool (after Schlumberger, 1991).

The depth of investigation of the laterolog depends on the resistivity of the rock and on the resistivity contrast between the fracture zone and the unfractured formation. Laterolog tools are generally recommended for salt muds, lower porosities and high-resistivity formations (Western Atlas, 1995; Fricke & Schon, 1999).

Estimation of Fracture Parameters

- **Fracture Porosity**

For estimating porosity from electrical properties the most widely used equation is the well-known Archie equation:

$$\phi_t^m = \frac{a \times R_w}{R_o}$$ ……………………………….. Eq-1

Where ϕ_t is the total porosity in fraction, R_w is the formation water resistivity in Ωm, R_o is the formation resistivity in Ωm, 'a' is the dimensionless constant known as tortousity factor, m is Archie's cementation exponent.

In order to estimate fracture porosity in tight formations especially carbonates, Boyeldieu and Winchester (1982) and Pezard and Anderson(1990) have proposed equations which have been developed from the Archie equation. However, the equation by Boyeldieu and Winchester (1982) has been found to be most suitable and therefore, has been used in this study. Fractured formations generally have a cementation exponent less than 2. In the present study cementation exponent (m) is taken as 1.4 for fractured tight carbonate reservoir (John 1999).

$$\phi_f^{m_f} = R_m\left(\frac{1}{R_{LLS}} - \frac{1}{R_{LLD}}\right)$$ …………………. Eq-2

ϕ_f is the fracture porosity in fraction, m_f is the cementation exponent of a facture, R_m is the drilling mud resistivity log with depth in Ωm, RLLD and RLLS are the resistivities measured by the deep and shallow laterologs in Ωm respectively.

- **Fracture Aperture**

For the estimation of fracture aperture, the following two equations (Sibbit-1985) have been found suitable for tight carbonate reservoirs, hence, have been used in the present study. Both horizontal and vertical fracture aperture are estimated based on equation below using Deep resistivity curve (LLD) and shallow resistivity curve (LLS) and mud resistivity curve with depth respectively.

APP_H=Rm1.2×10-41RLLD-1Rb ……………………………….. Eq-3

APP_V=Rm4×10-41RLLS-1RLLD ………………………………. Eq-4

Where,

APP_H is the fracture aperture of horizontal fractures (mm), APP_V is the fracture aperture of vertical fractures (mm), R_b is the resistivity of non-fractured host rock in ohm-m, R_m is mud resistivity log.

It is observed that the value of calculated fracture aperture of horizontal fractures is overestimated whereas the fracture apertures of vertical fractures are seeming in reasonable range. Therefore, only vertical fracture aperture is used in this study.

- **Fracture Density**

Fracture density has been estimated from empirical relationship between fracture porosity and fracture aperture of horizontal fractures. Since the DLL has a vertical resolution of 0.61m, so the fracture aperture calculated by equation (5) represents as averaged value of the measured section. Therefore this can be apparent fracture density. Using equation (2) and (3)

FRACDEN = 1000×ϕfAPP_H_MEAN =0.12 1RLLS-1RLLD1/m1RLLD-1RbRmm-1m ………………………….. Eq-5

This fracture density is not applicable, if RLLD<RLLS. However, this will happen only for single horizontal fractures with negative separation.

Applicability of the technique

Well data of three wells from Vindhyan Son Valley, was studied for analyses of fractures parameter through conventional resistivity logs. The studied sections are very tight carbonate reservoir containing both limestone and dolomite along with shale in some section apart from having lots of fractures as full sinusoids (fractures crossing the borehole) and partial sinusoids (fractures terminating within the borehole volume). Firstly, fractures were evaluated from image logs. The fracture parameter specially fracture aperture and fracture density have been estimated from image processing module software.

These same set of fractures were then identified and evaluated using conventional wire line logs especially the Dual latero log. One case study is discussed below:

Well A: The well has carbonate reservoirs with lots of presence of partially open and open fractures. The comparison of fracture aperture and fracture density calculated from Eqs. 4 and Eqs. 5 and same fracture parameters derived from XRMI logs are presented in Figure-2. A Fracture interpretation Plot is presented in this figure, which include comparison of fracture porosity and aperture calculated from DLL with FMI processing fracture analysis parameter. The first, second and third track shows the conventional logs, including CALI, BS, GR, NPHI, RHOB, LLD and LLS. The fourth track is depth and fifth track is processed XRMI images. The fracture dips are presented in sixth track. The fracture aperture and fracture density measured by XRMI and the same parameter estimated by DLL are presented in seventh and eighth track. The fracture porosity calculated using DLL log data is presented in ninth track. The unit of each curve is in the bracket.

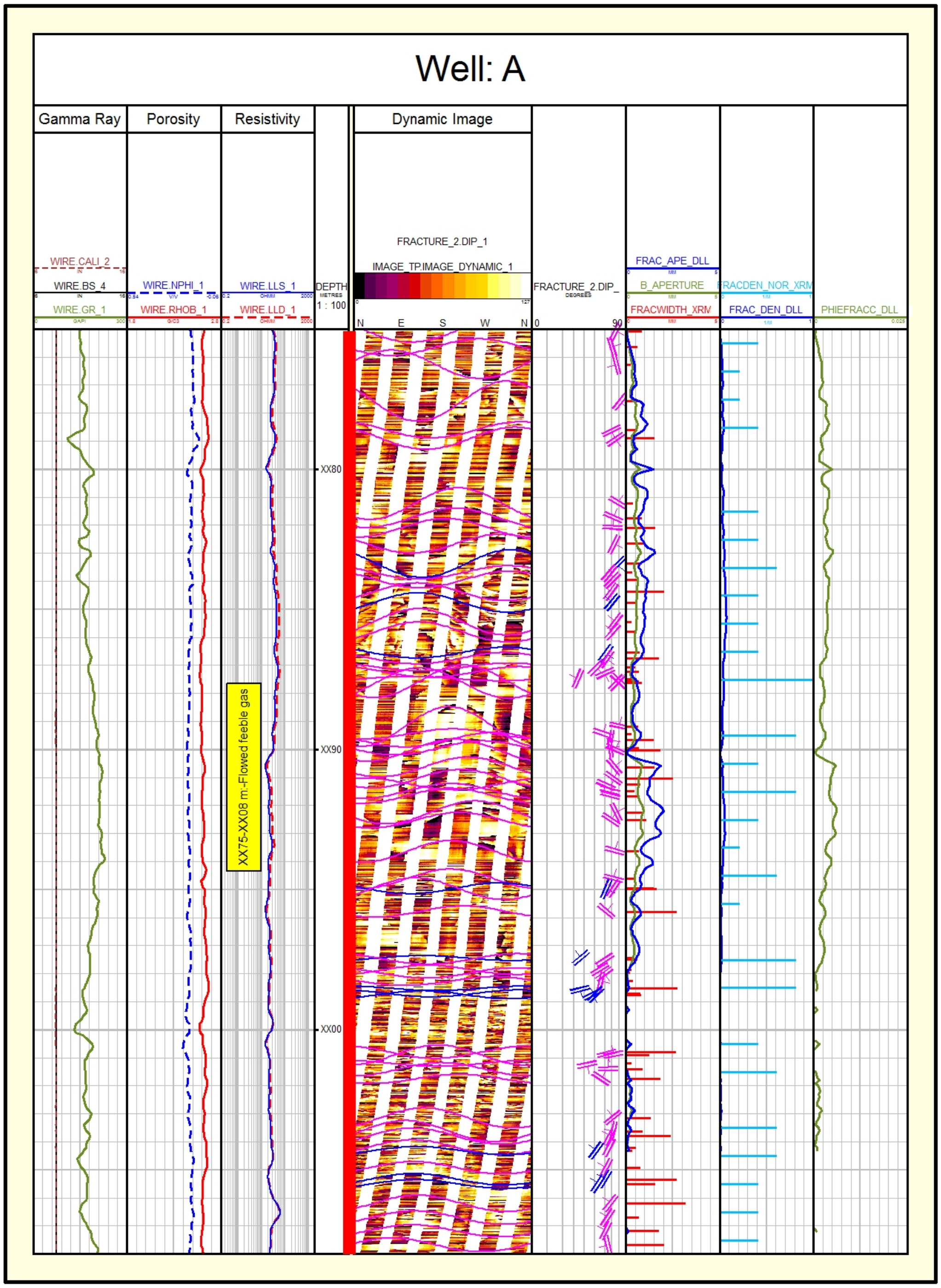

Figure-2- Well A: Estimation of fracture parameters based on conventional resistivity and its validation with image log data.

It is observed that the fracture aperture calculated by equation 4 using resistivity curves seems to be overestimated. (Track 7 of figure 2). However, aperture calculated from fracture porosity using Kazemi's layered model gives better results. This is shown below:

$\phi f = ba$

Thus,

$b = a\phi_f$ ………………………………………….. Eq. 6

Where ϕ_f is the fracture porosity in fraction, b is the fracture aperture in mm and 'a' is the sampling interval of conventional log recorded in well bore i.e. 152.4 mm. However, hydraulic fractures often comes as a set of parallel fractures rather than single fractures (Aguilera,1995), so a sampling interval of 152.4 mm might be just sufficient for detecting the fractures; however not all fractures will be detected using this sampling interval. With shorter intervals the possibilities of detecting more fracture increase. Track 7 of Fig.2 clearly shows the measured apertures from FMI with the corresponding calculated values from DLL response of equation 4 is slightly overestimated but giving more accurate and satisfactory result by using Kazemi's layered model. Thus fracture aperture estimation from equation 6 gives better result. However, the comparison of fracture density from DLL and XRMI logs (Track 8 of figure 2) indicates that fracture density estimated from DLL is less than XRMI but still, it can be used effectively to determine fracture parameter.

The caliper tool measures the size of the borehole diameter. Any increase in borehole diameter by the tool from the drilled diameter (bit size) might indicate the fracture zone or soft rock. Since the reservoir is very tight carbonate formation in this study so any increase in the caliper log reading from the bit size, indicate the presence of fractures. A comparison between the fracture porosity estimated from resistivity log and the difference between the caliper reading and the bit size is plotted in Figure-3. This plot shows a very good match between calculated fracture porosity from DLL and the fracture indication from difference between caliper and bit size logs, thereby, validating the existence of fractures in the formation.

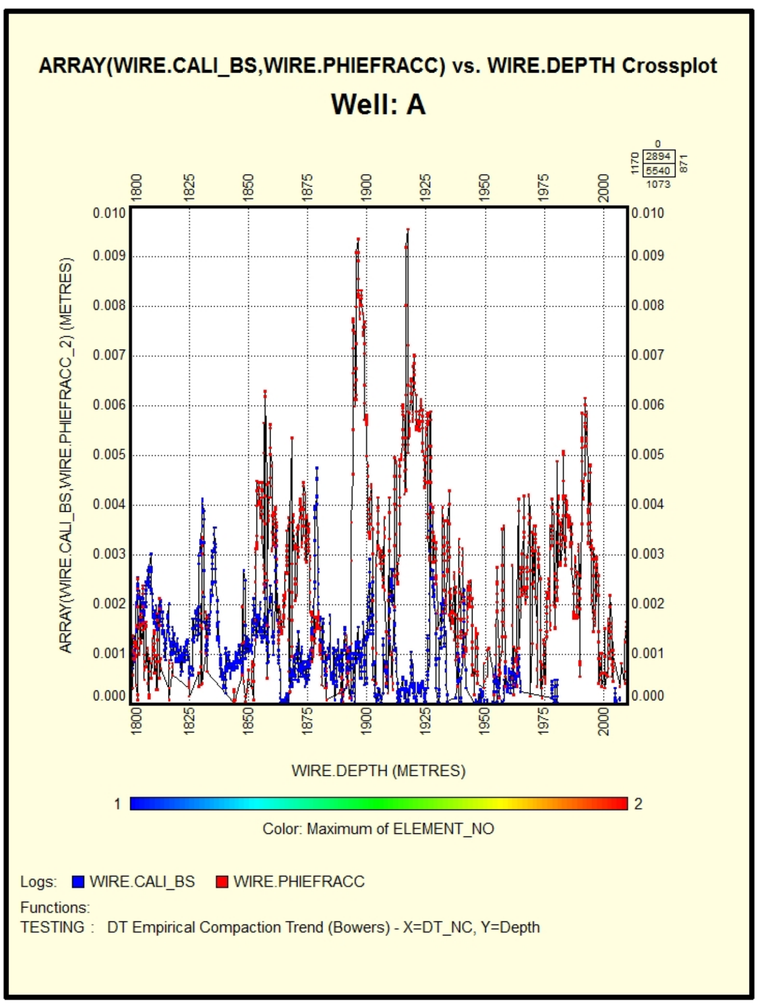

Figure-3: Comparison between the fracture porosity from DLL and the difference between the caliper and bit size.

Conclusions

This paper presents a technique for the detailed analysis of naturally fractured reservoirs by determining fracture parameters using conventional resistivity well logs. The study shows that fracture porosity, fracture aperture and fracture density can be calculated from conventional wireline resistivity logs with reasonable accuracy. The output results of fracture parameters have been validated by comparing them with image log data processing. The results are quite encouraging and show the effectiveness of conventional resistivity well log responses in the evaluation of fracture parameters and their visualization. The technique is straight forward and cost effective.

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