Evaluation of Fracture Parameters in Carbonate Fractured Formation with Laterolog Responses

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Tools Used to Evaluate Fracture Parameters in Carbonate Fractured Formations

Resistivity anisotropy

Wire line:
- TriAxial inductions tools
- Borehole resistivity image tools
- Laterolog tools

LWD:
- Geosteering tools

High base rock resistivity

Wire line:
- Borehole resistivity image tools
- Laterolog tools

LWD:
- AFR, GVR,...

Quantitative Interpretation

Wire line:
- Laterolog tools

LWD:
- AFR, GVR,...
Contents

1. Review of past work
2. Progress
3. Array Laterolog Tool responses in a fractured formation
4. Conclusions and future works
Fractured Formation Models

Three main fracture models considered in China:

- Plane model
- Matchstick model
- Cubic model
Resistivity Anisotropy of Fractured Formation

\[
\sigma_0 = \begin{bmatrix}
\sigma_{xxp0} & 0 & 0 \\
0 & \sigma_{yyyp0} & 0 \\
0 & 0 & \sigma_{zzp0}
\end{bmatrix}
\]

\[
\sigma_{xxp0} = \sigma_{yyyp0} = (1 - p_f)\sigma_b + p_f \sigma_f
\]

\[
\sigma_{zzp0} = \frac{\sigma_b}{1 + p_f (\frac{\sigma_b}{\sigma_f} - 1)}
\]

- \(\sigma_b\): Base rock conductivity
- \(\sigma_f\): Fracture conductivity
- \(p_f\): Fracture porosity
Resistivity Anisotropy of Fractured Formation (Cont.)

In dipping cases

$$
\bar{\sigma} = \begin{bmatrix}
\sigma_{xx} & 0 & \sigma_{xz} \\
0 & \sigma_{yy} & 0 \\
\sigma_{zx} & 0 & \sigma_{zz}
\end{bmatrix}
$$

$$
\sigma_{xx} = \sigma_{xxp0} + (\sigma_{zzp0} - \sigma_{xxp0}) \sin^2 \alpha
$$

$$
\sigma_{yy} = \sigma_{yyp0}
$$

$$
\sigma_{zz} = \sigma_{zzp0} - (\sigma_{zzp0} - \sigma_{xxp0}) \sin^2 \alpha
$$

$$
\sigma_{xz} = \sigma_{zx} = (\sigma_{xxp0} - \sigma_{zzp0}) \sin \alpha \cos \alpha
$$

$$
\alpha \quad \text{Dipping angle}
$$
Quantitative Interpretation Model

Simple Model:

\[ p_f = (A_1 \sigma_s + A_2 \sigma_d + A_3) R_f \]

| \( Y > 0.1 \) | 8.522532 | -8.24279 | 7.12E-04 |
| \( 0.1 > Y > 0 \) | -17.6332 | 20.36451 | 9.32E-04 |
| \( Y < 0 \) | -0.99242 | 1.97247 | 3.19E-04 |

\[ Y = \frac{(R_d - R_s)}{\sqrt{R_d R_s}} \]

Reliable results obtained for larger fracture porosity
Quantitative Interpretation Model

Complex Model

\[ \phi_f = F(\sigma_s, \sigma_d, \sigma_b, \sigma_f, \alpha) \]

Reliable results obtained always
Using Core Fracture Porosity to Calibrate Interpreted Fracture Porosity

\[ p_c = 2.2797 \ p_f^{1.4247} \]
Fracture Porosity Interpretation

Results

- Limestone
- Dolomite
- Clay

Non-calibrate

Calibrated
Limitations of the Interpretation Method

1. Water base mud, the lower the mud resistivity, the better the results

2. Based on one Dual Laterolog tool in fractured formation
   How about other Dual Laterolog tools and Array Laterolog tools?

3. Homogeneous fractured formation
   How about Layer’s medium?
   Inversion? Yes
Progress

New version **3D FEM** code developed to simulate laterolog responses in fractured formations

Interface support fracture porosity computation
1. 3D FEM code
2. Setup Laterolog Tool structure, *easily*,
3. Establish fracture porosity interpretation models, automatically (within 30 minutes),
4. Code to compute fracture porosity with the models,
5. Process field data.
Set Laterolog Tool Structure

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**Tool Name**: DualILL  
**Data Set**: 

[Image of the software interface showing the tool structure with columns for Name, Begin, Length, and Radius]
Set Laterolog Tool’s Focusing Boundary Condition
Setted Laterolog Tool’s Focusing Boundary **Condition**

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Characteristics of New 3D FEM Code

1. **Fast**, 5 logging point simulation per second in my laptop;

2. **Save memory**, total memory to be used is less than 200*200 matrix, which makes it possible for parallel computation;

3. **Stable**, reliable results always were obtained in any dip angle, any boundary position.

4. **Any kind of Laterolog tool**, laterolog tool, Dual laterolog tool, Array laterolog tool.
Array Laterolog Tool Used to Study Responses in Fractured Formation

Symmetrical structure
5 Modes of Array Laterolog Tool

Mode 1

Mode 2

Mode 3

Mode 4

Mode 5
Array Laterolog Tool Responses in Fractured Formation

![Graph showing apparent resistivity with dip](image)
Three Layer Formation Model

- $R_1 = 5 \text{ (ohm-m)}$
- $R_b = 10000 \text{ (ohm-m)}$
- Fracture Porosity = 0.1%
- Dip angle = 0/90 (deg)
- $R_2 = 5 \text{ (ohm-m)}$
- Depth = 20 ft
Responses in Layered Formation

Apprent Resistivity with Well Dip
Fracture dip=0(dgr), Thickness=20(ft)

Apprent Resistivity with Well Dip
Fracture dip=90(dgr), Thickness=20(ft)
Conclusion and Future Works

1. One methodology used to compute fracture porosity from laterolog measurements was developed.

2. One software used to establish quantitative interpretation model of fracture porosity from laterolog measurement was developed;

3. The software integrates four modules:
   - 3D FEM Code
   - Setup Laterolog Tool structure;
   - Setup focusing condition matrix (write focusing equation);
   - Establish fracture porosity interpretation models,

Adding following function to the software:
   - Code to compute fracture porosity with the model,
   - Process field data.
Thanks!