Geomechanical Approach for Cores Analysis of Jurassic Manusela Carbonate Fractured Reservoir from Oseil Field*

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Abstract

The geomechanical relationship between lithology and rock strength reveals a new method for fracture study and analysis. This practical geomechanical application is also valuable for drilling parameter design and could create a new way of development of field development. In order to simplify complications in the Jurassic Manusela carbonate fractured reservoir, we used the geomechanical as approach.

The method of geomechanical core interpretation and analysis of our carbonate fractured field is as follows:

- stress in the earth is simplified by using Smax and Smin system;
- all failure is simplified into shear and tensile fracture;
- tensile strength of rock is much smaller compared to compressive strength;
- evidence of multiple tectonic phases, such as extension, surface exposure and compression, are key for fracture development; diagenesis (e.g., cementation and compaction) creates higher rock strength;
- rock strength of Manusela carbonate is calculated from sonic log by using equation, drilling well data and triaxial test;
- direct relationship between helium porosity and rock strength is found in Oseil-1 well.

In the core workshop we are proposing new ways for fracture analysis by combining calculated rock strength and lithology. Higher rock strength has fewer fractures and less porosity, whereas less rock strength has more fractures and more porosity. In E Nief-1 well, compacted dolostone core has the highest rock strength (average 10500 PSI), less fracture, and is non-reservoir. Oolitic limestone core at this well has less rock strength (average 7200 PSI), more fractures and is good reservoir.

In Oseil-1 and 4, Oolitic limestone dissolution core zone has less rock strength (average 6800 PSI), and dolostone is slightly stronger (8800 PSI); both zones of limestone and dolostone are highly fractured and highly porous.
Selected References


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Stratigraphy of Oseil field

- Manusela fracture carbonate reservoir—Jurassic age.
- Tectonic extensional fracture was generated during Early Jurassic.
- Uplift of listric fault reactivation followed by karsting, dissolution and cementation caused by phreatic water.
- From Jurassic to Late Neogene's Manusela carbonate was compacted.
- Late Neogene's compression rectified the extensional fracture and compression fracturing was generated.
Mechanical Stratigraphy

Geomechanical approach for Oseil field

- Stress in the earth is simplified by using Smax and Smin system.
- All the failures are simplified into shear and tensile fracture
- Tensile strength of rock is much smaller than compressive strength
- Multi-phase of tectonics, such as extension, surface exposure and compression, are key for development of fractures; extension is good for fracture and compression good for structure.
- Diagenesis changed lithology and rock strength properties of the rock.
- Rock strength of Manusela carbonate facies is calculated from sonic log by using Militzer and Stoll equation (1973), drilling data and core triaxial test.
- Porosity is calculated using helium porosity measurement; direct relation of Helium porosity versus rock strength found in Oseil-1 well.

Geomechanics core measurement:
- a. Poisson ratio  b. Rock strength  c. Thomsen parameter

Lithology: Limestone

Low-rock-strength lithology has more fractures and is porous.
Higher-rock-strength lithology—fewer fractures and lower porosity.
Great Bahama Oolitic Limestone as an analog for Oseil field
Oolitic carbonate deposited in regressive cycle of shallow-marine environment, from low-energy restricted marine to high-energy marine sand shoals.
Dissolution and Breccias Alteration

Early Jurassic extension followed by uplift and surface exposure has generated dissolution, brecciation of Limestone and Dolostone.

Thin section and core of dissolution zone from OS-1 well occur in Oolitic limestone; dissolution of Mollusk has distorted some Ooids and created better porosity.

Heavily fractured (brecciated) Dolostone is clearly seen in core and thin section. Brecciation with high angle fracture could create very high vertical permeability that could connect reservoir to aquifer.
Compaction diagenetic alteration caused by burial will destroy dolostone porosity; Oseil-1 dolostone is less compacted, compared to E.Nief-1. Rock strength is also increased by compaction; rock strength of dolostone in E.Nief-1 area is much greater, compared to OS-1.
Fracturing History

Intergranular porosity is mostly filled with blocky calcite cement (G9). Later stage of fracturing caused millimeter-scale displacement.

Early fractures are cemented by calcite; later fractures are open and contain calcite and bitumen (E8).

Compression began in late Neogene and rectified early fractured rock that had been cemented by calcite and caused millimeter-scale displacement; younger fractures are open and could contain oil.
Exponential relationship of laboratory measurements of Helium porosity (taken from cores) versus rock strength (derived from sonic log).
Dissolution zone

Petrographic Data 6827' MD

Lithology: Limestone
Os-1 Petrography Data 6827' MD

Lithology: Limestone
Lithology: Dolostone

Petrographic Data Sheet

Lithology Classification: Dolostone

<table>
<thead>
<tr>
<th></th>
<th>0%</th>
<th>21%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grains</td>
<td></td>
<td></td>
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<tr>
<td>Cements</td>
<td>21%</td>
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<td>0%</td>
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<tr>
<td>Full Diameter Porosity: 5.6%</td>
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</tr>
<tr>
<td>Full Diameter Permeability: 0.55 md</td>
<td></td>
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</tbody>
</table>

Summary:
A dolostone is heavily fractured (recrystallized) and composed of intergranular dolomite crystals that form a mosaic fabric. The diameter of dolomite crystals ranges from 30 to 500 microns, with an average of 180 microns. No grains were evident.

Dolomite replaces the former lithology. Fractures were succeeded by calcite (P.E: E2) cementation that also inhibits intercrystalline porosity.

Excellent porosity is visible and consists mainly of fractures with lesser intercrystalline cores (P.E: E2).

Plate A: 1cm = 0.29mm, Plane polarized
Plate B: 1cm = 0.29mm, Plane polarized

Os-3 Rock Strength Calculated Using Militz and Stoll Equation (1973)
Core no.3 depth 7510 to 7513 feet

<table>
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<th>Depth (ft)</th>
<th>Rock Strength (ksi)</th>
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<tr>
<td>7510.00</td>
<td>61.44 149.38 9062</td>
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<tr>
<td>7510.50</td>
<td>61.37 149.58 9084</td>
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<td>7512.50</td>
<td>62.65 145.94 8666</td>
</tr>
<tr>
<td>751.00</td>
<td>62.92 146.31 8725</td>
</tr>
</tbody>
</table>

Average Rock Strength: 8882 PSI
Fracture zone from FMS or UBI

Core and seismic anisotropy of Oseil-1 upper zone showing high intensity of Manusela carbonate fractured reservoir.

**High fracture intensity = High seismic anisotropy**

E Nief-1 core and seismic anisotropy showing Manusela carbonate fractured reservoir not developed.

**Low fracture intensity = Low seismic anisotropy**
Future research on Geomechanical and AVAZ

Static geomechanical cores measurement for the following physical properties:
1. Poisson ratio
2. Rocks strength, unconfined compressive strength (UCS)
3. Thomsen parameter using ultrasonic stiffness at 0, 45 & 90 degrees to fracture planes.
In the case of anisotropy, Vs shear wave is polarized into Vs fast and Vs slow, shear wave traveling parallel to fractured zone will have faster velocity, while shear wave traveling perpendicular to fractured zone will have slower velocity, γ Thomsen parameter will be:

\[ \gamma = \frac{V_{s \ fast} - V_{s \ slow}}{V_{s \ slow}} \]  

created significant positive value 0.15

If in the case of dissolution or brecciation and P wave velocity changes dependent on fracture strike and direction, ε and δ of Thomsen parameter may change:

\[ \varepsilon = \frac{V_{p \ 90 \ deg} - V_{p \ 0 \ deg}}{V_{p \ 0 \ deg}} = -0.05 \]

\[ \delta = \frac{V_{p \ 45 \ deg} - V_{p \ 0 \ deg}}{V_{p \ 0 \ deg}} = -\varepsilon = -0.05 \]

and coefficient AVO Fracture anisotropy

\[ B_{an} = -0.05 + 1.2\left(\frac{V_s}{V_p}\right)^2 \]

\[ C_{an} = \frac{1}{2}[\varepsilon -0.05 \sin^2\phi + 0.05] \]
Thomsen parameter using ultrasonic stiffness at 0, 45 & 90 deg to fracture planes.

\[ \gamma = \frac{V_s \text{ fast} - V_s \text{ slow}}{V_s \text{ slow}} \]

\[ \gamma = 0.15 \]

\[ \varepsilon = \frac{V_p \text{ 90 deg} - V_p \text{ 0 deg}}{V_p \text{ 0 deg}} = -0.05 \]

\[ \delta = \frac{V_p \text{ 45 deg} - V_p \text{ 0 deg}}{V_p \text{ 0 deg}} = -0.05 \]

and coefficient AVO Fracture anisotropy

\[ B_{an} = -0.05 + 1.2 \left( \frac{V_s}{V_p} \right)^2 \]

\[ C_{an} = \frac{1}{2} \left( -0.05 \sin^2 \varnothing + 0.05 \right) \]

Oseil-1 Cores Anisotropy Measurement
Conclusion

• G&G Problems for carbonate fracture reservoir are lithology heterogeneity and fracture distribution.
• Combining cores, well data and seismic will be valuable to predict reservoir heterogeneity and fracturing.
• Rock strength is used because simple approach to heterogeneity of reservoir and AVAZ are used for fracture prediction.
• Low-rock-strength lithology will have more fractures, more porosity and more anisotropy. High-rock-strength lithology is less fractured, less porous and isotropic.