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Understanding the Interplay of Fractures, Stresses & Facies in Unconventional Reservoirs - Case Study from Chad Granites

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SUMMARY

This work presents a case study from Bongor basin, Chad which utilizes the geological evolution approach to effectively characterize unconventional granitic reservoir based on the interpretation performed with borehole images and open hole logs. Interplay of fractures and facies and the impact of the prevalent stress regime have been deciphered from the study wells with the help of borehole images and petrophysical logs. Three main distinct facies were interpreted; Unweathered, Leached and Fractured (Normal and Intensely Fractured sub-facies) granites respectively. Within the leached granite, there exist fault breccia and major faults with two dominant strike orientations; NE-SW and NW-SE. This resulted to the development of secondary porosity within these reservoir zones. The observed granite basement facies, particularly the fractured and leached granites developed good secondary porosity due to differential leaching and fracturing.

The placement of subsequent wells in the preferred leached and fractured reservoir facies bearing fractures that possess the same orientation as the maximum stress depends on several determinants, one of which is the location of the proposed well with respect to the prevalent stress regime attributed to tectonic forces from the Central African Shear Zone arising from the West and Central African Rift system.
Introduction

The unconventional granitic reservoirs of Bongor Basin, Chad exhibit complex inter-relation of different generations of fractures and the varying stress regime with the reservoir facies, often leaving the production behaviour little understood. Integration of sub-surface measurements of various well logs in the framework of geological evolution of the basin is imperative for optimal formation evaluation and reservoir characterization.

The producibility of granitic reservoirs is strongly related to few specific facies where secondary porosity develops. The basement granites encountered in the wells have unique facies assemblages with differing characteristics controlling the reservoir properties. Three major facies; Unweathered Granite, Fractured (Normal and Intensely fractured sub-facies) and Leached Granites were delineated based on their geological and petrophysical characteristics, the Leached Granites being the best reservoir facies accompanied by fault breccia.

This is an innovative work and offers a workflow for facies and fracture characterization whereby potentially productive facies and fractures are identified based on their characteristics and in-situ stresses in the absence of dynamic data.

Study Area and Background Geology

The study wells RS-10 and LE4 are drilled through the granitic basement, approximately 43km apart and located in the Bongor Basin, Chad. It has a fairly thick sedimentary cover overlying the granitic basement rocks (pink-shaded in Figure 1). This basin belongs to the West African Rift System (WARS) Precambrian or metamorphosed basement, the maximum sediment thickness is over 10km, including early Cretaceous strata and Paleocene strata (Genik, 1992; Dou et al., 2011; Pan et al. 2013).

Figure 1 Geologic cross section of eastern part of the Bongor Basin (Dou et al., 2011).

Possible source rock for the hydrocarbons encountered in the basement granites may be Lower Cretaceous organic rich mudstone, and several oil fields have been found in the Lower Cretaceous strata since 2007 (Dou et al., 2011). The Bongor Basin forms part of the concession currently being operated by China National Petroleum Corporation (CNPC) International (Chad) Limited. Thin section and mineral analyses of the cores and cuttings show that the basements drilled by wells are mainly granites. The U-Pb dating confirms that the basement was formed during pre-Cambrian time.

Methodology and Workflow

Data analyzed in this study includes electrical borehole images and open-hole logs (gamma ray, resistivity curves, density, neutron porosity etc.) along with core and cutting reports. The study analyses the fracture network of the basement granites encountered in the Bongor basin to enable quantification of possible fracture porosity and aperture which are necessary for the well to be productive. It also characterizes the different granitic facies encountered in the wells, and classifies them for further identification of most prospective facies. The association of fractures vs. facies is understood and established in the varying stress regime as a key to further development of the field.
Stress Analysis:

Breakouts in vertical wells generally indicate the direction of minimal horizontal stress. Borehole breakout analysis in both wells indicated a dominant minimum horizontal stress direction (Sh) trending NW-SE, although faulting and regional structural grain caused a slight rotation (less than 30 degrees) of the in-situ stresses (Figure 2). It is critical to understand the variation in stress for hydro-fracturing of the reservoirs, in designing the well-trajectory through the best productive facies.

![Figure 2](image1.png)

*Figure 2* The stress-regime as inferred in RS-10 and LE-4 respectively.

Fracture Analysis:

The fractures were picked on oriented borehole images and classified into two main sets;
- Set 1: Natural Conductive Fractures striking ENE-WSW
- Set 2: Natural Conductive Fractures striking WNW-ESE

Well LE-4 had significantly higher number of fractures compared to RS-10 (Figure-3), suggesting intense fracturing.

![Figure 3](image2.png)

*Figure 3* A schematic of the origin of reservoir interval in study wells, suggesting more intense fracturing in LE-4. First Schmidt plot with fracture populations corresponds to RS-10 whilst second Schmidt plot corresponds to LE-4.

Fracture Porosity and Aperture were computed on borehole image logs. Maximum fracture porosity in the study area is 0.3% and maximum aperture is 0.3cm. Increase in fracture aperture leads to a corresponding increase in fracture porosity (assuming the fractures are open).

Facies Analysis and Association:

Three major facies (Figure-4) were delineated based on their geological and petrophysical characteristics;
1. Facies A, Unweathered Granite (with mostly drill-induced and very few fractures)
2. Facies B, Fractured Unleached Granite,
   a. Facies B1: regularly fractured
   b. Facies B2: intensely fractured
3. Facies C, Leached Granites, with fault breccia and altered fractures

The Leached Granites are the best reservoir facies accompanied by fault breccia. Facies B and C constitute the main reservoir in the basement of the Bongor Basin.
Figure 4 Facies types in study wells.

Results and Discussions

Facies and fracture properties (Figure-5) suggest that Facies B and C have better reservoir properties.
Intensity of fracturing increases moving from RS-10 to LE-4. Leaching, which is more evident in RS-10 is notably absent from LE-4 (Figure 5). As shown in schematic of figure-2, RS-10 is much deeper than LE-4, thus, allowing the conditions suitable for leaching to take place in response to hydrothermal fluid flow through the granite under higher overburden pressure and temperature.

Absence of facies C (Leached/Weathered Granite) from LE-4 is possibly due to lack of conditions necessary for leaching to occur by geochemical alteration of rock minerals by hydrothermal fluid activity. The shallow depths at which the granites occur in this well imply relatively lower overburden pressure and temperature when compared to RS-10. The leaching pattern observed in RS-10 suggests obliteration of existing fractures by intense leaching. Hence, there are fewer fractured granite intervals in RS-10. In LE-4, facies A and B are dominant. Unweathered Granite (Facies A) is occurring in much more reduced amounts in LE-4 than in RS-10.

The placement of subsequent wells in the leached and fractured reservoir facies with preferred fracture orientation depends on several determinants, especially in light of the rotating stresses identified in the study; coming from an interplay of tectonic forces from the Central African Shear Zone arising from the West and Central African Rift system. This is particularly important for future production plans such as a stimulation treatment through hydraulic fracturing where specially engineered fluids are pumped at high pressure and rate into the reservoir interval to be treated, causing vertical fractures to open.

Conclusions

The granite basement facies, particularly the fractured and weathered granites appears to have developed good secondary porosity due to differential leaching (hydrothermal fluid) and fracturing in the Bongor basin in Chad. The leaching potential would depend on the mineral composition of the interval where relative geochemical mobility of elements would determine the extent of leaching. The maximum fracture porosity occurred in the fractured granite zones observed is 0.3% with a corresponding fracture aperture of 0.3cm. Present day in-situ stress as suggested by borehole breakout analysis showed that the stress orientations between the two wells show some rotation. Of the two sets of natural high angle conductive fractures, the potentially productive fractures are the fractures striking North West – South East. Knowledge of the stress directions, fracture aperture and dip magnitude can be used to identify the potentially productive fractures in the absence of more data. This study not only provides a methodology to characterize such complex reservoirs, but also suggests ways for optimal exploitation.

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