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Using Core *vs* Image-Log Diameter to Improve Fractured Reservoir Characterization

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Summary

It has long been known that a core will have many more natural fractures than an image log over the same interval. Carbonate rocks, in particular, can have very low permeability without the presence of fractures, so the determination of producibility is critical in evaluating reservoir quality. Image logs have revolutionized reserve calculation in the last 30 years, but they do not have anywhere near the resolution of cores (ground truth). When a well has been cored over the same interval as an image log, one can make a straightforward calibration, the "resolution" correction, but that calibration does not account for the difference in core size and borehole diameter.

Since core diameter is generally much smaller than the borehole diameter, fewer fractures should intersect a core than the borehole wall. Berg (2019) introduced an equation that relates sampling diameter to fracture abundance, orientation, and size. Using this relationship, a method is developed to find the expected fracture frequency and density of a core based on the image-log fractures. The resulting method will be called "diameter" correction.

This study was undertaken on a near-vertical well in Moose Field in the Alberta foothills. The well had a core in the Turner Valley formation within the producing zone. It will be shown here that together, the resolution and diameter corrections put calculated fracture density in that well on par with fracture density in a nearby horizontal well that was on strike with the study well.

Theory

The relationship introduced by Berg (2019) was derived by curve-fitting of points generated from a discrete fracture network (DFN) model. At the time it was arguably an empirical relationship, although some of the equations in that paper closely matched some published exact relationships on the same general subject. In Berg (2020), theory was derived directly from first principles, creating an exact theoretical basis for the very close fit between the equation and the DFN modeling.

Following is the rectangular fracture equation relating fracture frequency (F) to fracture density (P_{32}):

$$\frac{F}{P_{32}} = \sin\beta + \frac{\frac{D}{2}P_{pr} + \pi\left(\frac{D}{2}\right)^2}{L_f H}$$

Where β is the minimum angle between the fracture plane and the borehole axis, D is the borehole diameter, L_f is the fracture length, H is the fracture height, and P_{pr} is the perimeter of the fracture projected onto a plane perpendicular to the borehole. P_{pr} is calculated from borehole and fracture orientations and the lengths of the projected sides of the fracture. The derivation of the diameter correction is calculated based on this equation. See the Method section for more explanation.

Observations

The near-vertical well in this study was the "CaledonianMid MOOSE 2-27-23-7" in the Moose Rundle C oil pool. The hole was cored from 2491m to 2541m, although the core study was carried out on a subinterval from 2516m to 2524m (These depths are corrected image-log depths.) The perforations in this well ranged from 2485 to 2585m. The nearby horizontal well was the "CaledonianMid MOOSE 12-23-23-7", also in the C pool.

The image-log fracture density in the vertical 2-27 calculated much lower density than in the horizontal 12-23 well in the same pool, in spite of the fact that the density calculations, in theory, should match for on-strike wells with producing zones about 1150m of each other. (The reach on the 12-23 was about 1300m, with most of that within its open-hole producing zone.)

Method

Using the rectangular fracture density equation from Berg (2019), a relationship was derived for core versus borehole diameter for an individual fracture. The following description involves only those fractures in the image log that are within the core interval. Following is a description of the resolution and diameter corrections:

1. Resolution: This correction factor is simply the ratio of core fracture frequency to image-log fracture frequency.
2. Diameter: Predicted frequency weighting is calculated for each image-log fracture within the core interval. The diameter correction is calculated as inverse of the average of the predicted frequency weightings.

The last step is to multiply the calculated density and frequency over the full interval being studied by both the resolution and the diameter corrections. Note: step is based on the assumption that the image-log fracture orientations are in ratio similar to those in the core. In other words, the ratio of borehole-parallel to borehole-perpendicular fractures are similar in log and core. Figure 1 shows a segment of core next to the original image-log interpretation where fractures close to parallel to the borehole were missed.

Conclusions

Using the resolution and diameter corrections, the porosities and permeabilities in the original image-log interpretation were much lower than those in the horizontal 12-23 well. When the image-log was reinterpreted, the corrected porosities and permeabilities were more in line with the 12-23 well. This is because, in the original interpretation, the borehole-parallel fractures were severely underrepresented.

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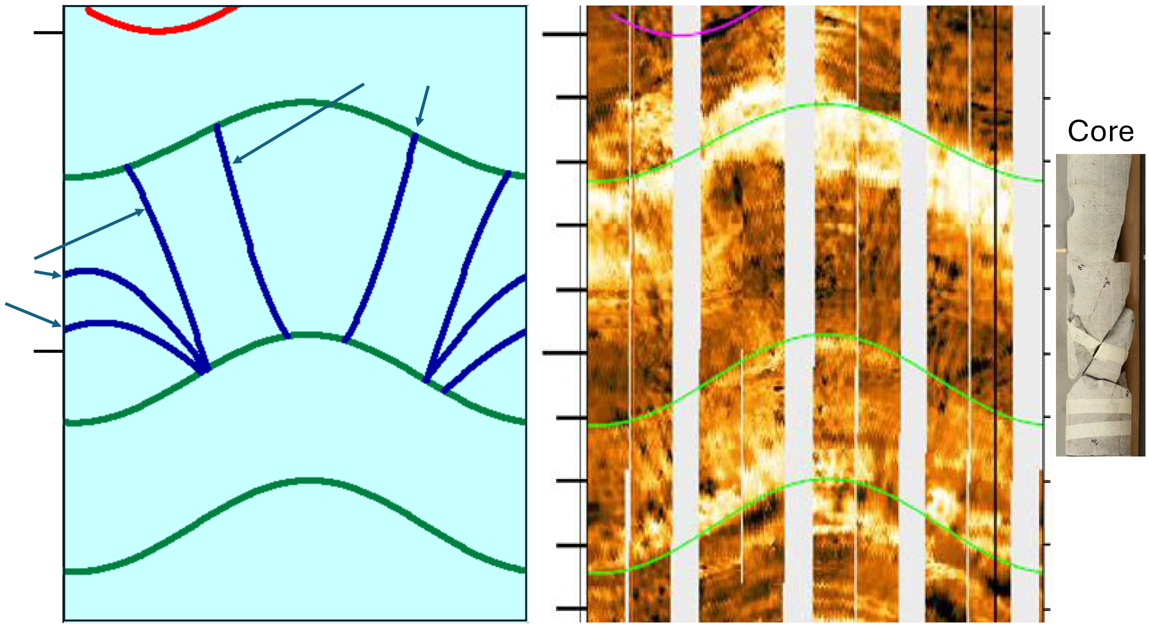

Figure 1. This is an example of fractures on the original interpretation that are clearly visible on core but were not picked by the interpreter. The blue traces are bed-bound fractures, the green traces are beds, and the red trace at the top is a low-dip fracture. On the left is a fracture-trace log showing the core fractures along with an additional proposed fracture that may or may not be visible on the core, depending on the relative dip of the fracture and the depth. The small break near the bottom right of the core could be along bedding.