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Beyond "dots in a box" - Tomographic Fracture Imaging a new empirical view of reservoir permeability fields.

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Summary

Much of the research on reservoir permeability field has tended to focus on that of the rock matrix. While it has long been recognized that fractures are an important element of the total rock permeability due to imaging difficulties, the zones of high fracture density and permeability, sometimes referred to as fairways, have been less studied. Our technology, Tomographic Fracture Imaging (TFI) which uses Seismic Emission Tomography (SET) and surface based seismic networks now allows us to directly image and map the 4D behavior of fracture/fault systems which form the fairways that are the dominant paths for fluid flow. TFI shows that the reservoir permeability field consists of complex fracture networks formed from existing joint systems and typically have kilometer scale lateral and vertical dimensions.

Keywords*: Reservoir permeability, fracture/fault imaging*

Introduction

There currently exist two methods that are used to map some aspects of fracture/fault networks; seismic attributes (coherence) and downhole micro-seismic hypo-central techniques. Neither method is capable of directly mapping the networks themselves. Coherence can be caused by a number of rock attributes and is also limited by the coarseness of the image. Downhole methods provide "dots in a box" and do not directly image the fracture/fault networks but rather the events which may be occurring in the fracture/fault zones but often do not. Further because hypo-central techniques require resolvable events, attenuation limits both the size and the distance from the sensors that events may be seen.

TFI is a method that uses Seismic Emission Tomography (SET) in combination with empirical data on fracture geometry, to directly image and map both the natural fracture/fault networks and those induced by fracing. SET is a technique for imaging sources of seismic energy contained within the volume being imaged. The seismic energy is recorded by a beam forming surface array. The collected data is processed to provide a 3D grid of voxels (3D pixels) with node points at the body center of each voxel cube. Each node point is given the value of the seismic energy being emitted by the voxel volume. Currently we use semblance as a proxy for the seismic energy.

TFI are created during post-processing of the SET data. It uses a geo-mechnical model of fracture/fault propagation and empirical data on fracture/fault geometry to guide the post-processing to extract the TFI from the semblance data. Because the method uses stacking of the SET data over time it can resolve events that are too weak to be resolved by hypo-central methods. TFI has proved to be very robust and has achieved independently documented accuracy and precision of +/- 5 meters.

Geo-mechanical basis of TFI

We have demonstrated (Geiser et al, 2006) that because of the critical nature of the Earths brittle crust (Ziv and Rubin, 2000) and the weakness of pre-existing cracks to small stress differences that the crust is in a state of continuous failure at the second scale. The continuous small failure events illuminate what we define as the ambient fracture/fault network.

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Geiser et al (2006) show that an additional phenomena critical for illuminating the permeability field is a fluid pressure (Pf) wave that has soliton like properties. The pf wave which may be some form of the Biot (19..) "slow wave" is generated by the rapid changes in fluid volume that occur during both injection and production. The Pf wave produces responses that permit distinction between the "ambient" fracture/fault system and that which forms the fairway system. The distinction can be made because as shown by Barton et al (1995) the hydraulically conductive fractures of the natural fairway system largely consists of fractures critically oriented for Mohr-coulomb shear failure.

Because this fracture system is also fluid filled, they are the weakest fractures of a very weak system. A consequence is that a perturbation in fluid pressure is capable of causing these pre-existing fractures to fail, thereby illuminating the fairways and reorganizing the seismic energy field. Further orientation analysis of the TFI demonstrate that the fracture/fault fairways of the reservoir permeability field are formed from the existing joint systems.

TFI permeability field maps

The following figures are from a monitoring and TFI test program in the Devonian of southwestern West Virginia, USA. The TFI results were independently confirmed by a combination of image logs, tracer and pressure data.

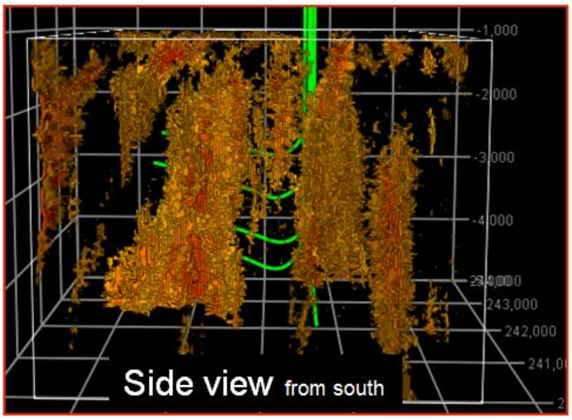

Figure 1: Three dimensional view of permeability field illuminated by 1 minute of injection during a frac stage. The green lines are the four stacked laterals included in the fracing program.

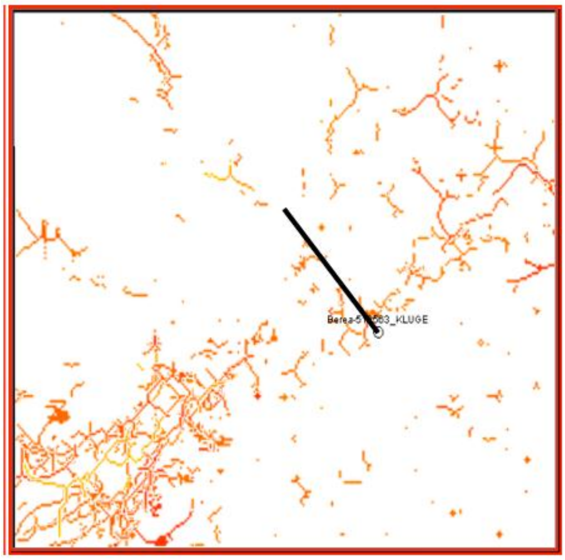

Figure 2: Map slice of the reservoir permeability field activated during one frac stage. The map is a slice at the level of the lateral. Length of lateral = 1 km. Of particular interest

In addition to the fore-mentioned tests the TFI results were directly compared to hypo-central results from down hole instruments placed in the 2nd lateral from the top. The results are shown in the following two figures.

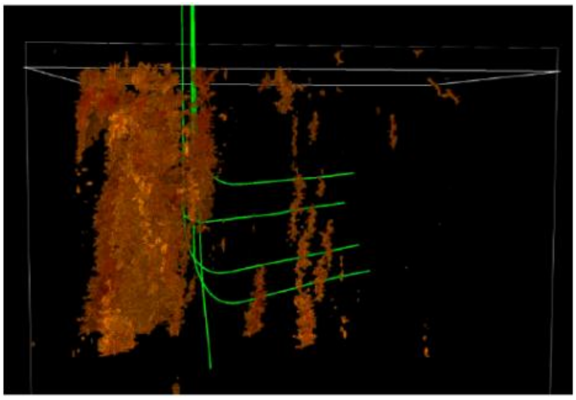

Figure 3: TFI maps of frac induced fractures show connectivity confirmed by tracer and pressure data.

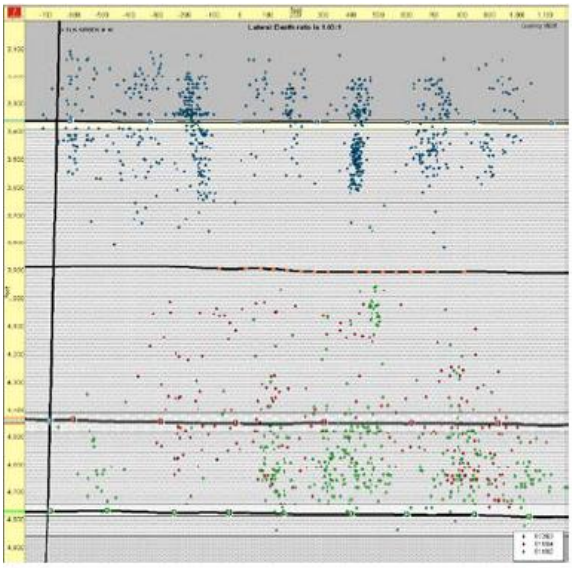

Figure 4: Hypo-central data from down hole instruments in 2nd lateral from top, fail to show connectivity shown by tracer, pressure and TFI data.

Perhaps one of the most significant results is that TFI successfully showed the location of the reservoir seal as well as establishing that fracing operations did not compromise it. The following figure shows that the fracing only activated permeability fairways that were restricted to the reservoir.

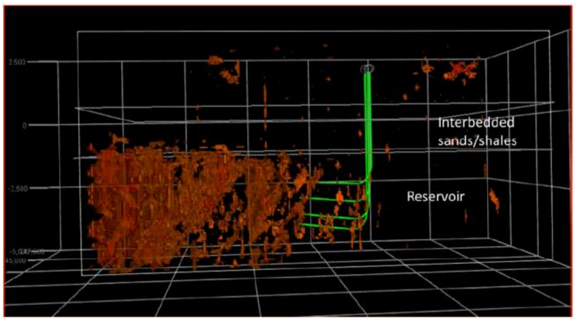

Figure 6: TFI show that reservoir seal was not compromised by fracing. The reservoir seal is the region labled "interbedded sand/shales" Note that the permeabilityf field fairways activated by the frac are stopped by the reservoir seal.

Conclusions

TFI is new technology for imaging fracture/fault fairways that cannot be done by other currently available imaging tools such as reflection and standard micro-seismic hypo-central methods. The technology has been subject to multiple blind tests and independent means of confirmation of results and has been shown to both robust and have a high degree of accuracy and precision at the meter scale. It reveals that the principal fluid pathways of the reservoir permeability field (fairways) are formed from the pre-existing joint fabric and typically have dimensions at the kilometer scale. TFI has been used to verify that the reservoir permeability field is bounded by the reservoir seal and that fracing activity did not compromise this important boundary.

References

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