

PINNACLE | PINNACLE FRACNET MICRODEFORMATION MONITORING

FracNet surface microdeformation fracture mapping

Provides accurate information about fracture development and fluid placement

FRACNET HDI

- Hydraulic Deformation Index
- Identification of rock volumes having higher or lower volumetric activity
- Stimulated reservoir area and approximate fracture dimensions

FRACNET SRC

- Stimulated Reservoir Characterization
- Spatial distribution of primary fracture components

FRACNET DIRECT

- Hydraulic orientation (fracture azimuth and dip)
- Horizontal fracture detection and characterization
- Fracture complexity (multi-planar growth) and relative volumetric composition

Over the past two decades Pinnacle has performed Microdeformation based fracture mapping on more than 12,000 treatments. Pinnacle is the world leader in this technology, performing more than 95% of this type of fracture mapping.

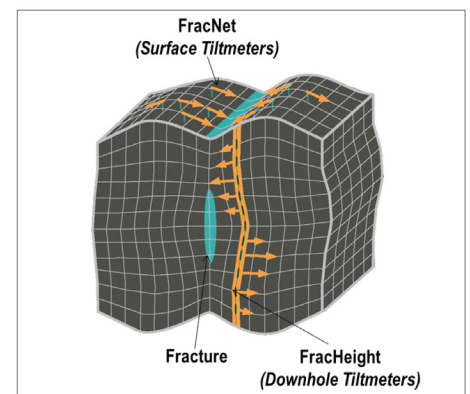
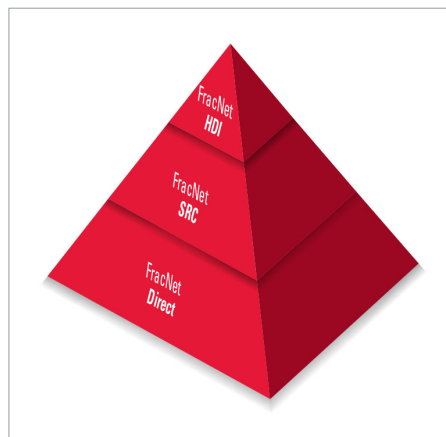


Fig. 1—Illustration of Microdeformation

Microdeformation fracture mapping is a unique diagnostic technology in the oil and gas industry that provides a direct measurement of critical fracture parameters—specifically identifying where and how injected fluids have been placed within the reservoir. FracNet includes three primary deliverable tiers:

How it works

Using surface tiltmeters, Microdeformation mapping measures the fracture-induced tilt at many points above a hydraulic fracture, and then it solves the geophysical inverse problem to determine the fracture parameters that would produce the observed deformation field. While the concept is simple, the magnitudes of the induced surface deformations are quite small and require highly sensitive instruments. A typical hydraulic fracture treatment at a 7,000-ft depth results in induced surface tilts of only about 10 nanoradians (10 parts in a billion). These miniscule tilts are measured with highly sensitive tiltmeters that operate on the same principle as a carpenter's level.

Pinnacle's custom designed and manufactured tiltmeters (30 in. long and 2.5 in. in diameter) measure their own tilt on two orthogonal axes. As the instrument tilts, a gas bubble contained within a conductive liquid filled glass cavity moves to maintain its alignment with the local gravity vector. Precision electronics detect changes in resistivity between electrodes mounted on the sensor that are caused by repositioning of the gas bubble. Our current generation of high-resolution tiltmeters can detect tilts of less than one nanoradian and were recognized with a prestigious R & D 100 Award.

Each tiltmeter site has an instrument surrounded by sand within PVC pipe (3- to 9-in. diameter) that is cemented in a relatively shallow (40 ft) borehole. Fig. 2 shows a sample record of tilt data versus time on three different time scales. The first view illustrates the daily swings of the tilt data in response to the solid earth tides caused by the earth's rotation with respect to the sun and moon, and a long-term drift due to minute production-induced surface subsidence.

The next zoom-in shows a 16-hour time period when three hydraulic fracture treatment stages (seen in the data) were pumped in the well being monitored. The final close-up is a 3-hour time period that clearly shows fracture-induced tilt from one of the propped fracture treatments. Fig. 2 shows fracture-induced tilt is recorded at each instrument site to yield an array of observed surface tilt vectors.

FracNet direct

On the data analysis side every fracture mapping project that employs Microdeformation begins with FracNet Direct to characterize:

- The number of main fracture components present in the fracture system
- The orientation of the identified main fracture components
- The volumetric ratios between the identified main fracture components

The observed tilt data is inverted to find the hydraulic fracture parameters that yield the best fit to the observed data, and a Monte Carlo technique is employed to estimate parameter uncertainty. The following figure on the next page compares the observed and theoretical fracture-induced tilt vectors from a best-fit fracture solution. Note how a careful visual inspection of the observed tilt vectors alone Fig. 3 (left) reveals a trough that runs northeast-southwest (fracture azimuth of 39°E) and that both ridges are of roughly equal magnitude implying a fracture dip that is nearly vertical (87°). In simple single-plane-fracturing cases like this, visual inspection alone reveals the essential results. Fig. 3 (right) shows another overlay of observed and theoretical tilt vectors for the case of a horizontal fracture, a case that is easily recognized within FracNet. When and where complexity exists, induced surface deformation presents itself as a superposition of all fracture components, which is readily decomposed during the FracNet Direct analysis.

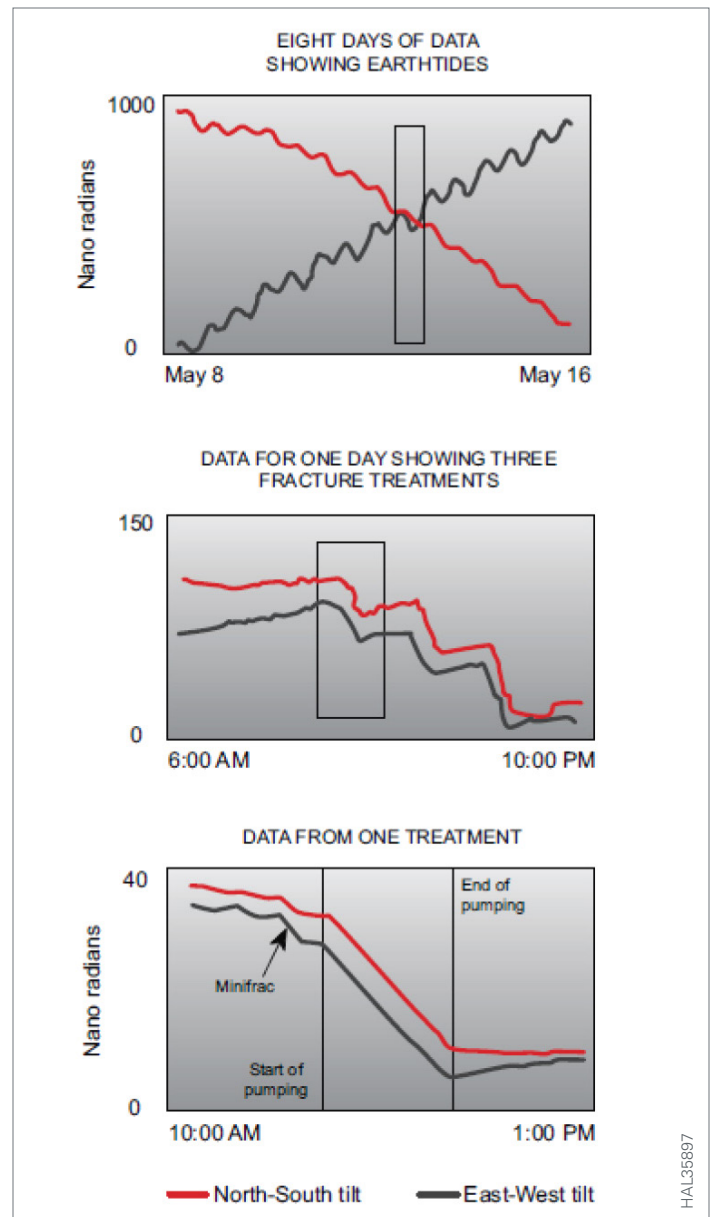


Fig. 2—FracNet Direct analysis - raw data shown for three different time windows

Since fracture-induced tilt is measured continuously, FracNet Direct can be performed throughout the course of the treatment (and, if desired, in real time). In some cases, fractures may initiate in one plane and then twist into another orientation, or initiate secondary fracture growth in another plane at some point in time during a treatment. Other parameters such as depth-to-fracture-center may also change significantly during a treatment if, for example, the fracture breaks through a barrier and begins rapid upward (or downward) height growth.

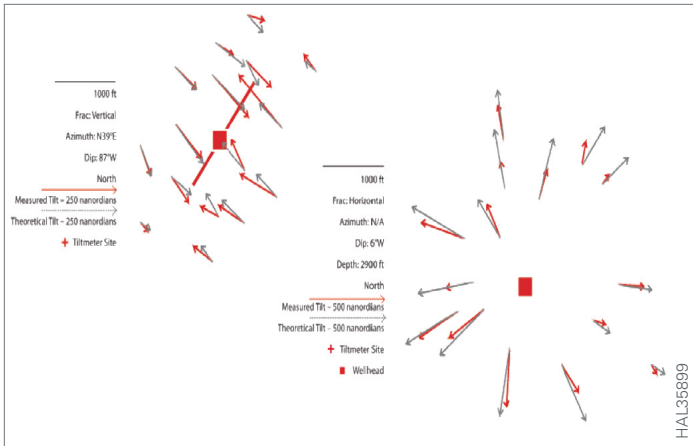


Fig. 3—Observed and theoretical fracture-induced tilt vectors for vertical (left) and horizontal (right) fracture. The vectors point inward to the “trough” following the azimuth of the vertical fracture. The vectors point outward to reflect “bulging” due to horizontal fracture.

FracNet SRC (stimulated reservoir characterization)

FracNet SRC seeks to identify the aerial distribution of the main fracture components identified in FracNet Direct. During this analysis a reservoir model will be developed, consisting of a mired of “resolution cells” extending across the mapped stage area. Resolution cells will be cubic in nature and have dimensions approximately 5 to 10% of the target depth for the stage. Placed within each resolution cell is the fracture information obtained during our FracNet Direct analysis. This includes fracture orientations for 1, 2, or 3 fracture sets, including any observed horizontal component.

At this point in the analysis all fractures within the resolution cell matrix have no volume—they are completely collapsed. A geomechanical inversion routine is then run which opens fractures across the matrix. A geomechanical inversion routine identifies the lowest misfit between the modeled tilt response and the observed tiltmeter responses. As shown in the lower left figure (Fig. 5), the final results provide not only a spatial distribution of fluid placement within the mapped reservoir area, but also the spatial characterization of which fracture set (or sets) was dilated.

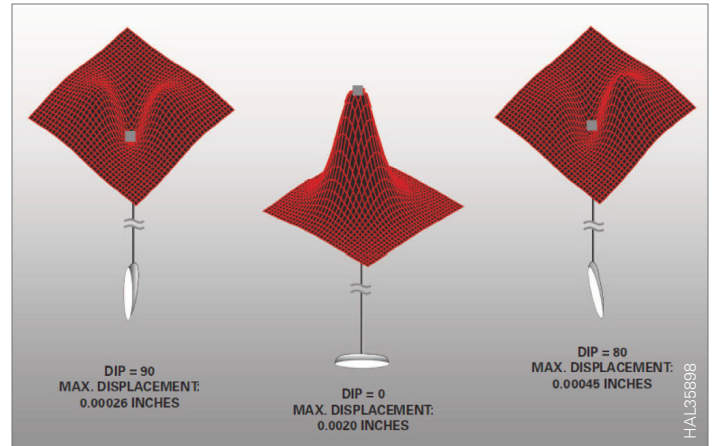


Fig. 4—Surface deformation for hydraulic fractures of different orientations at a 3,000-ft depth.

During project qualification, Pinnacle will determine whether the anticipated signal-to-noise ratios meet our performance criteria for the FracNet SRC and HDI analyses. Factors that affect this evaluation include ambient background noise levels, injection rates, injection volumes and treatment depth. In general the larger the injection rates and volumes and the shallower the treatment depth the more likely an SRC analysis can be performed. If SRC and HDI cannot be performed then in the majority of scenarios the FracNet Direct analysis will still be feasible.

FracNet HDI (hydraulic deformation index)

Once FracNet SRC is completed, the spatial distribution of main fracture components is then further characterized by delivering an HDI for the stimulation. As illustrated in Fig. 6, HDI aids in the identification of rock volumes having higher or lower volumetric fracture activity (scale from 1 to 0, respectively) and thus may provide additional insight into approximate lateral fracture dimensions and effective stimulated reservoir area.

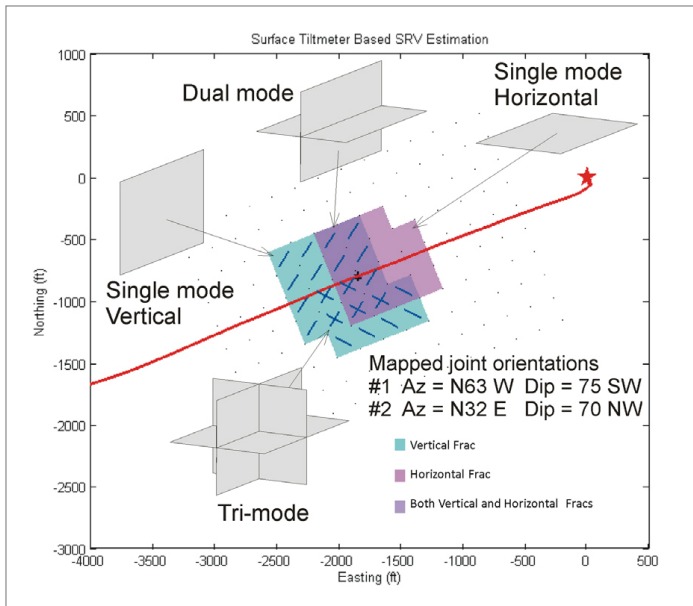


Fig. 5—Sample SRC result (plan view) indicating spatial characterization and distribution of fluid placement during stage treatment. Results are color-coded indicating which fracture set or sets were dilated.

Field operations

Depending on project conditions, an array of 15 to more than 40 tiltmeters are placed around the well to be fractured at radial distances from 15 to 75% of the fracture depth, as this is the region of maximum fracture-induced surface tilt. If project parameters permit SRC + HDI mapping then the array size is typically increased slightly. The exact layout of the monitoring sites is not critical. Fracture mapping resolution is primarily dependent on the number of tiltmeter stations employed and the signal-to-noise ratio of the measurements. Resolution of fracture orientation is typically better than 1° per 1,000 ft of depth.

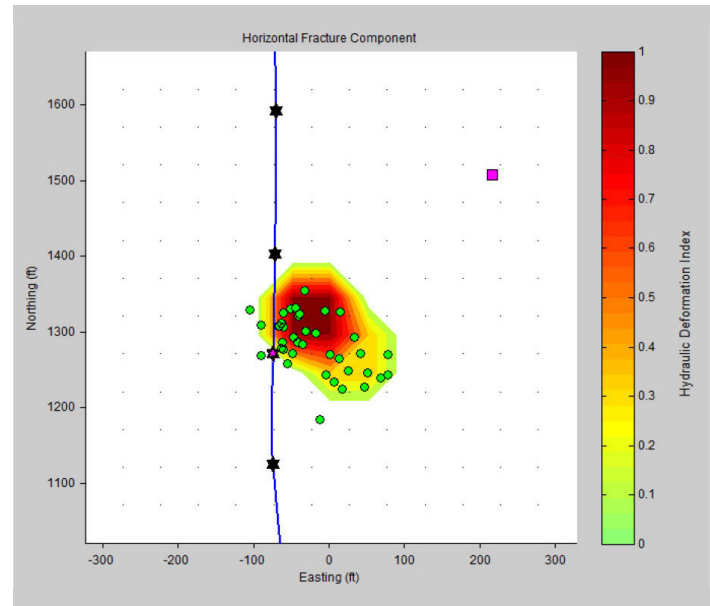


Fig. 6—Hydraulic deformation index (HDI) provides insight into likelihood of fracture activity and lateral fracture dimensions. In this example from the Viking Sandstone formation (2,000 ft deep) horizontal fracturing was identified and its spatial dimensions determined with SRC + HDI. Microseismic responses (green dots) were also collected and co-visualized with the HDI output from FracNet.

Economic impact

Knowing your fracture geometry can improve production economics by increasing reservoir productivity and/or reducing completion costs. Pinnacle's surface tiltmeter mapping is simply the most robust technique available for determining hydraulic fracture orientation and determining where your expensive fluid was placed within the reservoir. Pinnacle has a proven track record of technically enhancing fracture diagnostics AND reducing the cost of delivery every year. Contact us to learn how Pinnacle's award-winning diagnostics can help you.

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