Reservoir Monitoring

Pinnacle

GET RESULTS

- Injected fluid contained within zone
- Rate of subsidence
- Susceptibility to compaction
- Wellbore casing damage

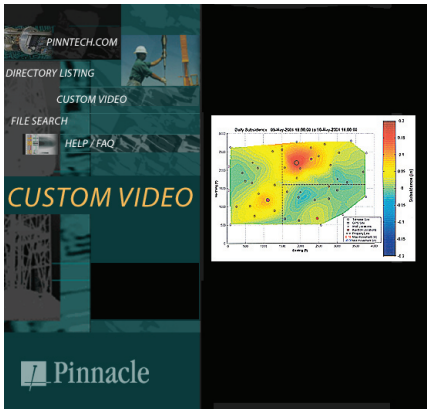

Figure 1. Clients can generate and view videos of field movement on a secure web site.

Pinnacle uses tiltmeters, InSAR and GPS to monitor reservoirs and surface map subsidence. Together, the technologies are uniquely able to provide extremely high spatial and temporal resolution of ground motion. The system is ideally suited to such diverse applications as:

- Providing early warning of impending casing failures in oil and gas fields
- Providing feedback for water, steam or waste injection
- Monitoring of landslide creep, volcano inflation, mining and excavation operations
- Production monitoring

Reservoir monitoring involves installing an array of tiltmeters and GPS receivers over the zone to be mapped. The array can consist of any combination of continuously recording surface and downhole tiltmeters and GPS units. The data can be sent in real-time via wire or radio to another location for immediate analysis (available on Pinnacle's secure web site, Figure 1), or the data can be collected and analyzed periodically.

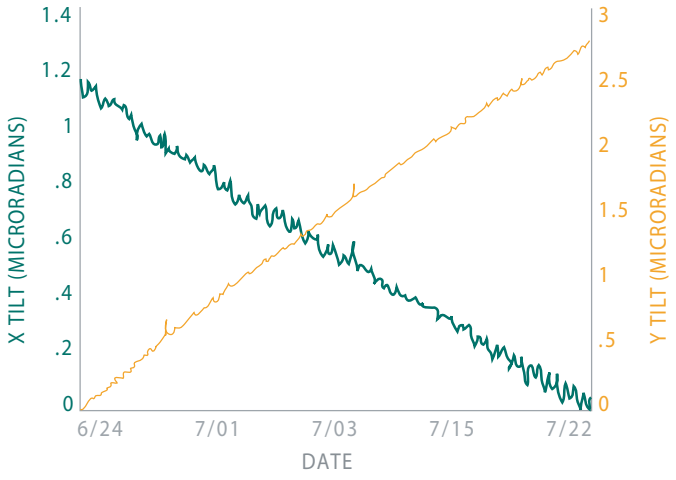

Figure 2. Signals from a surface tiltmeter over one month show subsidence-induced movement as well as twice daily earthtides.

SURFACE TILTMETER RESERVOIR MONITORING

Tiltmeters measure the rate of change in elevation, which is far easier to measure than the elevation itself. Figure 2 shows tilt measurements from one instrument over a one month period. Twice daily earthtide movements are evident in the data, but do not impact the measured tilt over a period of many days.

The high precision of the tilt measurement results in a high resolution of change in elevation after the data is integrated. Figure 3 shows a conceptual diagram of a one-dimensional subsidence array. The tilt measurements define the slope of the surface movement. Vertical displacement contours are determined by integrating the slope measurements from several tiltmeters. Since a constant of integration is required, one location in the array can be defined as the "zero" point—a steady reference against which all other elevation changes are measured. To obtain a true "zero" reference, the array can either be extended into a quiet area or the zero point can be calibrated with an accurate GPS or level survey reading. Pinnacle's unique software analyzes data from tilt and GPS simultaneously. A typical surface monitoring array consists of 15 to 50 or more surface tiltmeters, plus two or more GPS stations, depending on desired coverage and resolution requirements.

The spatial resolution of surface tiltmeter subsidence mapping is a function of the density of the tiltmeter array. Although Pinnacle's 5000 series tiltmeters measure tilt to nanoradian resolution, there must be enough tiltmeters in a given area to ensure the tiltmeters will detect any significant changes in elevation. Optimum grid spacing is typically 1/3 (for monitoring deeper layers) to 1/10 (for monitoring very shallow layers) of the depth of the shallowest subsiding

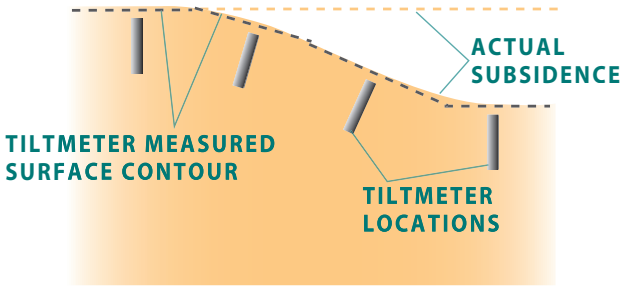

Figure 3. Example of tiltmeter layout designed to detect a subsidence slope.

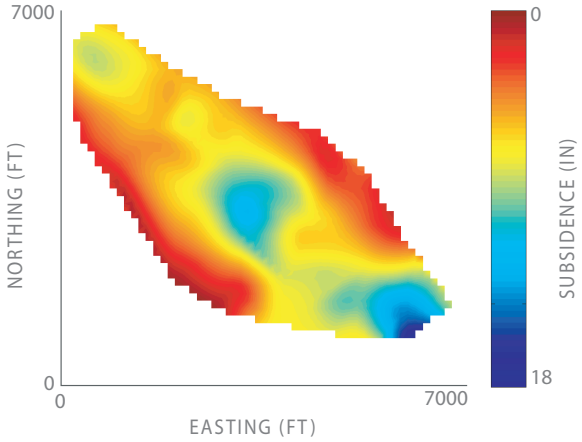

Figure 4. Two dimensional map of subsidence-induced earth movement over a one year period.

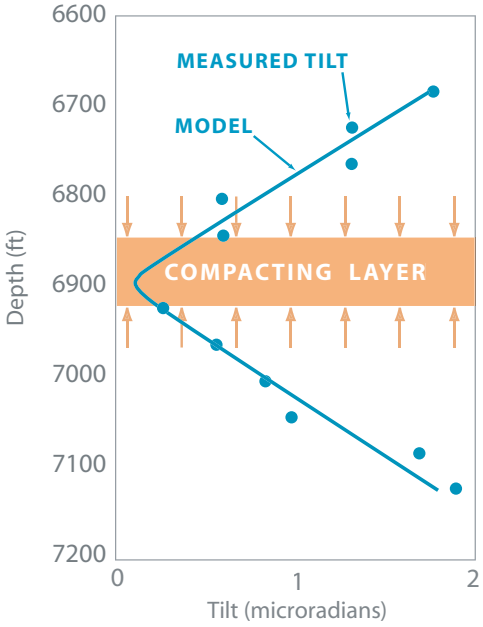

Figure 5. Downhole tiltmeters are used to pinpoint compacting layers.

layer. Surface deformations can be projected back to reservoir depths to provide approximate volume of displacement and locations.

DOWNHOLE TILTMETER RESERVOIR MONITORING

Downhole tiltmeters can also be used to monitor reservoir fluid flow and compaction. The different perspective of the downhole tiltmeters gives them sensitivity to which specific layer is compacting or expanding and can help answer questions such as:

- Is the injected (or produced) fluid contained within the zone of injection?
- From which zones are produced fluids coming?
- What is the rate of compaction?
- Is one type of rock more susceptible to compaction than another?
- Where and when is wellbore casing damage likely to occur?

One of the greatest advantages of Pinnacle Reservoir Monitoring is that the instruments are continuously recording information and will not miss discrete events or changes in subsidence caused by changes in operational strategy, unexpected events such as out-of zone breakouts of injected water or steam, earthquakes, etc. Data can be analyzed on large or small time scales as desired. Monitoring methods such as level surveys, conventional GPS, and InSAR take periodic snapshots of data that may be very difficult or impossible to correlate back to discrete events. Finally, having an array of tiltmeters in place allows simultaneous, inexpensive monitoring of other events on the property, such as the mapping of hydraulic fracture treatments. Please contact us to learn how Pinnacle's award-winning diagnostics can help you.

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