EAGE
EUROPEAN ASSOCIATION OF GEOSCIENTISTS & ENGINEERS

A29

Microseismic Monitoring with a Surface Array

P. Duncan* (MicroSeismic, Inc.) & J. Lakings (MicroSeismic, Inc.)

SUMMARY

We propose an alternative to down hole microseismic monitoring that uses large arrays of surface geophones. The method presents several logistical and technical advantages over more common down hole techniques, but has its drawbacks as well. We have employed the technique in more than 16 projects to date and present here some of the results and observations on that work.

Surface Array Methodology

The commonly employed method of microseismic monitoring uses one or more down hole arrays of geophones and an event location algorithm that involves picking the arrival times of the P and S phases of the seismic events at these array locations. The picks can then be used to locate the event hypocenters in much the same way as large earthquakes are located with data from the global seismic network.

An alternative approach to down hole microseismic monitoring is to use surface based phones (see Figure 1). Array design is based on the same principles as designing an array for a 3-D survey. Spatial sampling must be adequate to properly sample the lowest apparent velocity that needs to be captured, usually the noise. Groups of phones can be used to suppress very slow noise although in this case the source of such noise is no longer the shot or the boat, but more likely pumps and compressors. Array size considerations, that is maximum offset, are based upon familiar NMO stretch and migration aperture criteria, although the normal rules of thumb have to be adjusted for the fact that travel is one way.

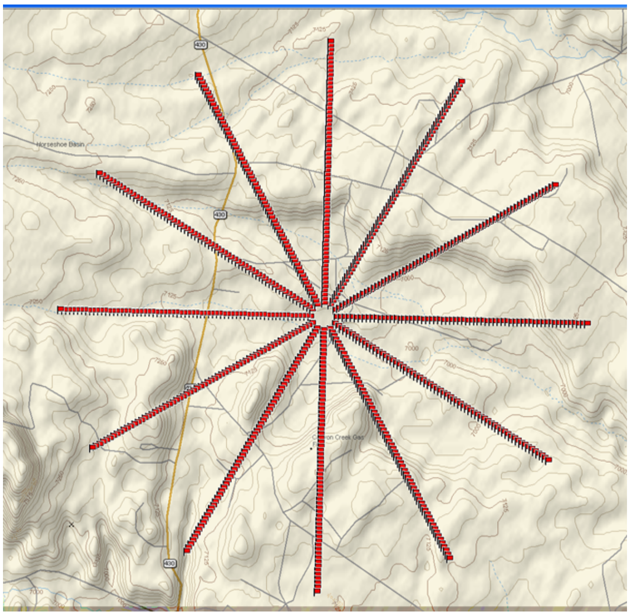

Figure 1: Typical layout for surface array monitor of a vertical well frac. Arms are 3300 m. Station spacing is 35 m.

Event location must be approached differently because the events, as detected at the surface, usually are too small relative to the surface noise to allow a reliable first break pick. The solution is to beam steer the surface array in order to identify the points of highest energy emission in the subsurface. The process involves calculating travel time corrections for all subsurface locations of interest, time shifting the surface station trace data as appropriate and stacking the data for each target point. Searching the resulting energy distributions of the subsurface gives the location of all likely microseismic events.

Such a surface methodology offers some advantages over a down hole approach. The most obvious is that no observation well is required. The availability of a well close enough to the monitor target that can be appropriated, at least for a time, as an observation well is often very problematic. Finding 2 or more wells is even more so. Rarely will the project carry the cost of drilling an observation well. The other issue with down hole is the area of investigation. While this is dependent upon local conditions, most would put the distance of investigation from a borehole at less than 1000 m.(Rutledge and Phillips 2003). A surface array can easily be deployed to cover a much larger area, perhaps even the entire field, with a single deployment. The surface array is also much less intrusive on the production and drilling operations in the field at least in terms of interfering with any in-well operations. On the other hand, surface access and permitting can hamper the deployment of a surface array and crew size requirements can make the cost of a temporary deployment exceed that of a single well operation, excluding the cost of the well, of course.

Hydraulic Fracture Monitoring

The monitoring of hydraulic fracture operations is the fastest growing application of microseismic monitoring. Much of this growth has been driven by the emergence of the gas shale and tight gas plays in North America. We estimate that less than 2% of the wells actually frac'ed in North America were monitored last year. However, with the recognition of the value of monitoring, we believe that number will double every year for the next few years.

Figure 1 is a typical layout that we employ to monitor the frac'ing of a vertical well. Figure 2 shows the results of the monitor operations, where each dot represents a microseismic event. The size of the dots represent the relative magnitude of the energy released.
This stage of the stimulation appears to have excited an existing fault that was seen on the seismic data. The events detected here are at depths in excess of 3800 m, allaying any doubts of the ability of a surface array to detect microseismic events at reservoir depths.

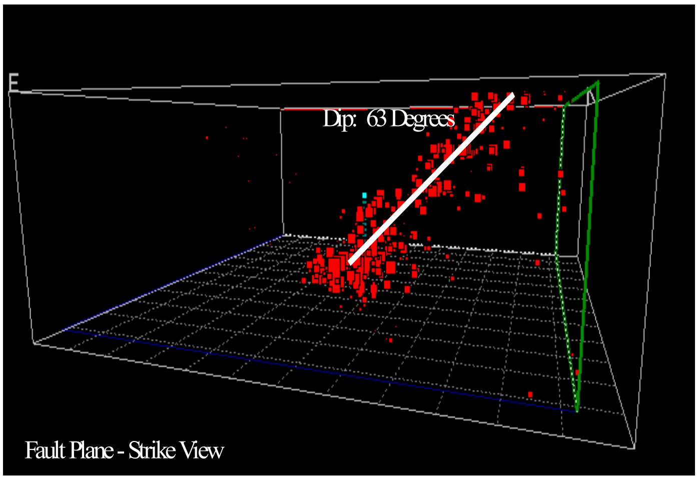

Figure 2: Perspective view of frac pattern captured from one stage of a multi stage frac. Top of cube is at 3800 m. Cube is 800 m on each side and 650 m in height. Pattern shows a fault that was excited by the frac operation.

CO_2 Injection

Fluid or gas injection in a reservoir, whether to support production or dispose of some unwanted material, offers another fertile opportunity for monitoring. One may want to confirm where the injected material goes in the reservoir in order predict and perhaps avoid premature breakthrough. One may be concerned about compromising the reservoir seal by pumping too hard. There may be a concern that faults are being activated as a result of the change in pore pressure. Figure 3 shows a seismic energy pattern which we believe was associated with the breakout of CO_2 being injected in a reservoir at about 800 m. depth. The figure is a time lapse snapshot representing about 30 minutes. The "plume" began at the reservoir level, grew upward, was diverted by a pressure boundary and then collapsed over a 6 hour period.

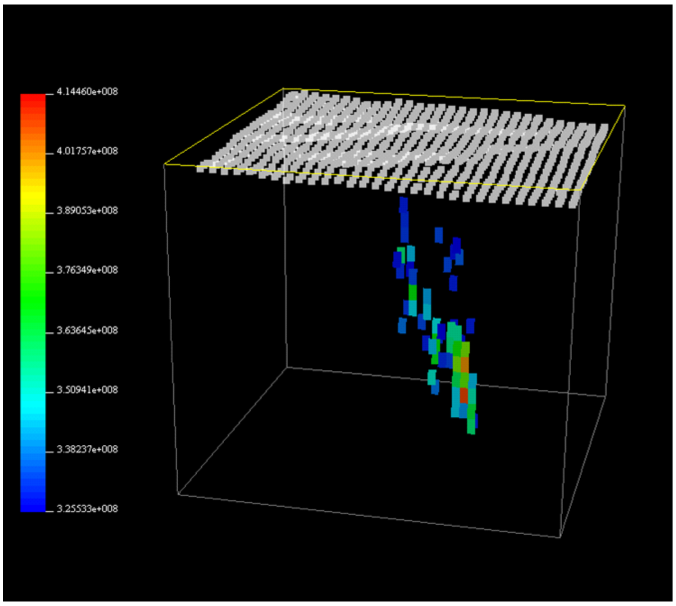

Figure 3: Seismic energy pattern captured over 30 minutes during CO_2 injection operations. Hotter colors represent higher energy emissions. White dots represent position of 900 station surface array. Cube is 1000 m in height and 2500 m. on a side.

Future Directions

Microseismic monitoring, whether from the surface or down hole, provides an exciting tool for the direct observation of reservoir performance, as opposed to the indirect observations of well bore pressure and temperature. It is also more immediate than time lapse 3-D seismic, sometimes called 4-D. Perhaps we should refer to microseismic monitoring as continuous 4-D. The technique is not without challenges. The volume of data and the continuous time nature of those data are huge logistical, data management and data presentation issues. The interpretation of the data in terms of the geomechanics and fluid dynamics of the reservoir are areas desperately in need of more research.

References

Rutledge, J. T. and Phillips, W. S. [2003] Hydraulic stimulation of natural fractures as revealed by induced microearthquakes, Carthage Cotton Valley gas field, east Texas. Geophysics 68(2) 441-452.