

GC Passive Seismic: Something Old, Something New*

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General Statement

Seismic imaging has changed radically over the last 80 years and has become a billion dollar business. Recording systems with thousands of channels and fleets of vibrators operating in tandem and helicopter-supported field operations are commonplace.

But there are environments where such modern systems are too expensive to operate, or where environmental or community concerns prevent the use of heavy machinery. There also are problems in today's oilfield that reflection seismic cannot address.

Enter passive seismic, which is seismic imaging without sources! Wait a moment. Surely, one has to have some sort of energy source. Right? Let us say that it is seismic imaging using sources of opportunity rather than the standard airguns, vibrators, or dynamite. A passive seismic crew merely lays out an array of receivers and ... listens. They are listening for earthquakes and microseisms -- some naturally produced and some the result of production activity, but all useful to create an image of what's going on in the subsurface.

Distinct Branches of Passive Seismic

Passive Seismic Transmission Tomography

Passive seismic transmission tomography creates 3-D images using the observed travel time of seismic signals originating from micro-earthquakes occurring below the target. The field setup is illustrated in Figure 1. A sparse array of independent seismographs is established above the target. The array usually consists of 20 to 100 stations, each recording the output of a three-component geophone. Typical imaging areas for such an array are 300 to 1500 square kilometers.

The three-component phones are placed 10 to 30 meters below the surface to get away from the noisy surface environment. The stations may store their data locally, but often are linked to the processing center by some form of telemetry. With the array in place, the survey proceeds by simply listening.

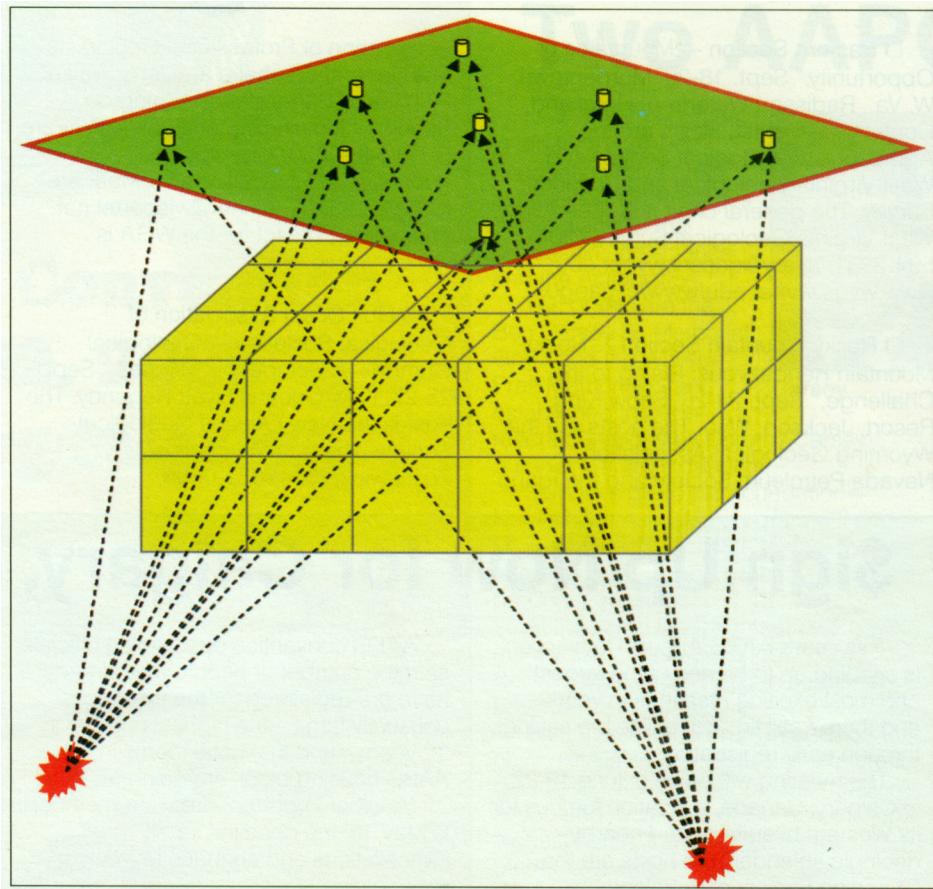


Figure 1. In passive seismic transmission tomography, micro-earthquakes occurring below the target, illustrated here as the yellow cube, serve as the seismic source. Three-component geophones on the surface record the arrival time of P and S waves from these tremors.

Assuming an initial velocity model, the observed micro-earthquakes are located in time and space using long-standing location algorithms based upon picks of the P and S arrival times at each observation station. Once a number of events have been located, one flips the process--assumes the origin time and hypo-centers of the events are known and uses some form of travel time inversion to estimate a new velocity model.

The three-component nature of the observations allows for estimation of the V_p and the V_s velocity structures. As more events are added to the dataset, finer estimates of the velocity structure can be achieved.

Most of us are surprised to find that there are enough micro-earthquakes occurring to make this a viable tool. We are conditioned to think of earthquakes in terms of life-threatening, concrete-crushing events that happen only rarely. Such events have a local magnitude of 3 or greater. Earthquakes are observed to be log-normally distributed to their magnitude. This means that there will be, on a statistical basis, 10 times as many magnitude-2 earthquakes as magnitude-3, and 10 times as many magnitude-1 as 2, and so on. The micro-earthquakes used for passive seismic transmission tomography are typically all those down to magnitude 0, or even smaller.

Since the processing of the data proceeds in near real time, it is possible to monitor the effectiveness of the survey and cease field operations when the particular needs and resolution of the survey have been met. Survey times of six to 12 months are to be expected.

Where and when does such an approach to imaging become cost effective? Certainly in flat, open country, a more conventional reflection survey is probably a better solution. But in mountainous terrain, passive can be as much as an order of magnitude less expensive. In environmentally sensitive areas the benign environmental impact of passive means that a survey that might otherwise never get permitted becomes possible. In highly cultured areas, the low impact of passive seismic again makes the likelihood of obtaining permits much higher.

Passive Seismic Emission Tomography

With passive seismic emission tomography the micro-seismic activity itself becomes the imaging target. The most straight-forward approach is to observe and record the direct arrivals of the seismic waves from these events and to map the distribution of hypocenter locations.

For the most part the events being considered here are small, with local magnitudes in the range -1 to -3, and rarely discernible as clean first breaks on surface recordings. Consequently, much of the work in this domain uses borehole receivers.

One of the more common applications of emission tomography is hydraulic fracture monitoring. Typically an array of 8 to 12 three-component geophones is clamped at or just above the reservoir level in a wellbore near the well where the fracturing will occur. First break picks are made of the observed events. A mapping of the event locations over time mirrors the development of fracturing. Often these results are presented as movies that nicely reflect the dynamic nature of the process. The availability of observation wells and the limitations on observation distance (usually 1000 meters or less) are serious impediments to the widespread usefulness of this downhole methodology.

A different approach to emission tomography is illustrated in Figure 2. Here an array of geophones is deployed on the surface, typically with 40 to 100 stations distributed over a few square kilometers. The array is sequentially beam-steered at all points in the subsurface and a 3-D map of emission energy is made; this reflects much of the same information as the hypocenter location map obtained with the downhole array.

Summary

The ability to monitor dynamic processes in real time presents many opportunities. These include fracture monitoring, mapping of fault creep and compaction, and tracking of injected fluids. In a very real way we are putting a stethoscope on the chest of the earth and listening. The challenge is that we don't have a lot of experience to draw upon with which to interpret these sounds.

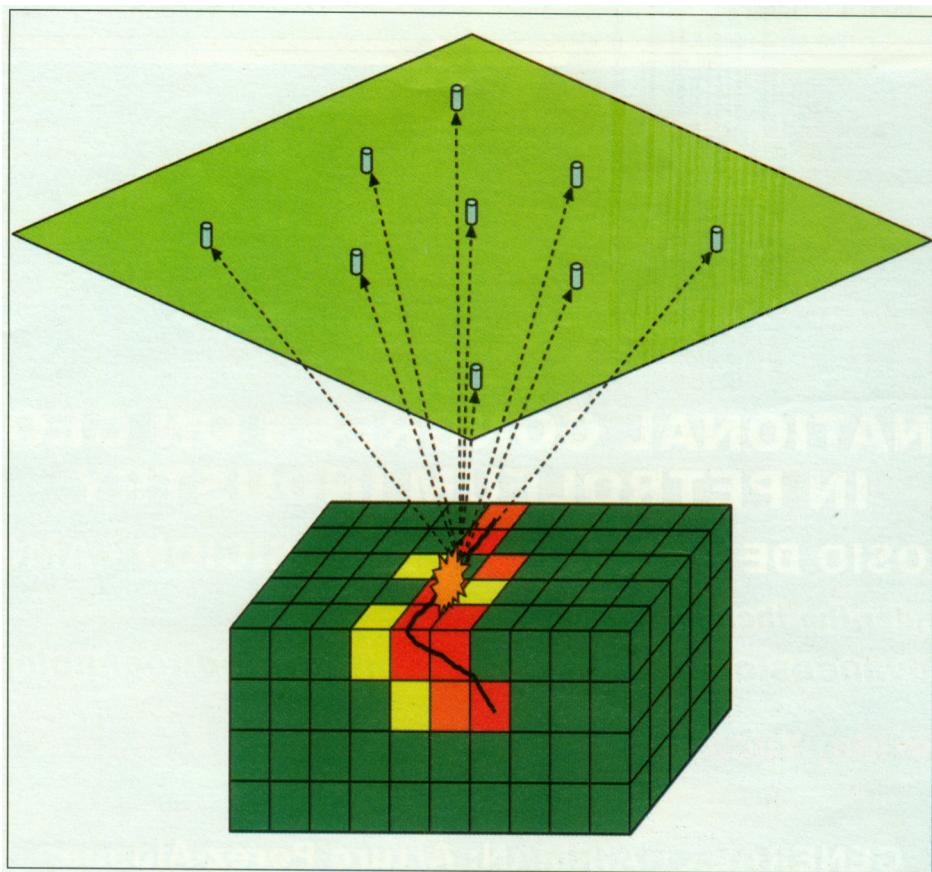


Figure 2. Illustration of the surface method of emission tomography. Movement on the fault causes a seismic signal that is recorded on the surface array. The array is beam-steered sequentially at each cell in the subsurface. The seismic energy recorded by the array over a period of observation time is displayed as colors in the cube, hotter colors representing higher energy levels. The areas of high energy will delineate where dynamic activity is taking place.