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NanoSeis

Velocity/Anisotropy Inversion for Microseismic Data

The need for accurate velocities is well understood in microseismic monitoring. The accuracy of the velocity model affects the positioning of microseismic events in surface and borehole monitoring, and also affects the sensitivity of surface microseismic monitoring because of the need to properly focus weak signals to detect them.

Velocity/anisotropy inversion for microseismic data is an under-constrained problem, because of the large number of variables (depths, thicknesses, velocities, anisotropy parameters) and the small number of observations - typically only a few perforation shots or string shots that are often in a narrow depth range and travel through a limited range of raypaths. The search for the best velocity/anisotropy solution is fraught with local maxima – solutions that are unacceptable poor but cannot be readily improved.

To combat these problems we use the simulated annealing approach in the family of Monte Carlo solutions, which is a well understood approach for searching for a global maximum in under-constrained problems. For velocity inversion the approach can be summarized as follows:

1) Randomly perturb the velocities or anisotropy parameters.
2) Determine if the perturbation improved the focusing of all perforation/string shots.
3) If an improvement was made, keep the perturbation and return to step 1.
4) If no improvement is made, reject the perturbation and return to step 1. Or if no improvements have occurred after a large number of attempts, assume that a local minimum has been reached.
5) If a local maximum has apparently been reached, introduce random perturbations of the velocities or anisotropy parameters and start over. This is the “heating” step in simulated annealing, which keeps the method from being stuck at a local maximum.
6) Continue steps 1-5 until the run time has been exhausted, and then output the best solution from all trials.

As with all Monte Carlo methods, this method is faster and produces better results when the perturbations are constrained to be geologically reasonable. The result is not necessarily the best velocity solution, but it tends to produce an acceptably good solution in a reasonable amount of time. An acceptable good solution is geologically reasonable one that focuses all perforation shots and strings shots for the surface data or borehole data, or one that focuses the surface data ***and*** the borehole data in the case of co-recorded data.

The effect of VTI anisotropy may be an under-appreciated problem in microseismic monitoring. We find that it is usually impossible to correctly focus string shots from significantly different depths (more than about 1,000 feet) without correcting for VTI anisotropy, which implies that it is also impossible to correctly locate events that are from significantly different depths. Fortunately it is a simple matter to incorporate VTI anisotropy parameters in the simulated annealing inversion, by including some perturbations of VTI anisotropy parameters in Step 1 above.

Figures 1-3 show some typical results from the use of the simulated annealing velocity inversion. In Figure 1 we see that the velocities that were used to independently process the surface data produce very poor corrections of the borehole data perforation shots. Conversely, the velocities that were used to independently process the borehole data produced poor focusing of the surface data (not shown). In Figure 2 we see that the original vertical p-wave velocities from the well log and the vertical p-wave velocities from the simulated annealing inversion are quite similar, and that the inversion solution primarily used VTI anisotropy to simultaneously focus the surface and borehole perforation shots. In Figure 3 we see that the velocities and VTI anisotropy parameters that were output from the inversion were successful in flattening the surface p-wave events, the borehole p-wave events, and the borehole s-wave events.

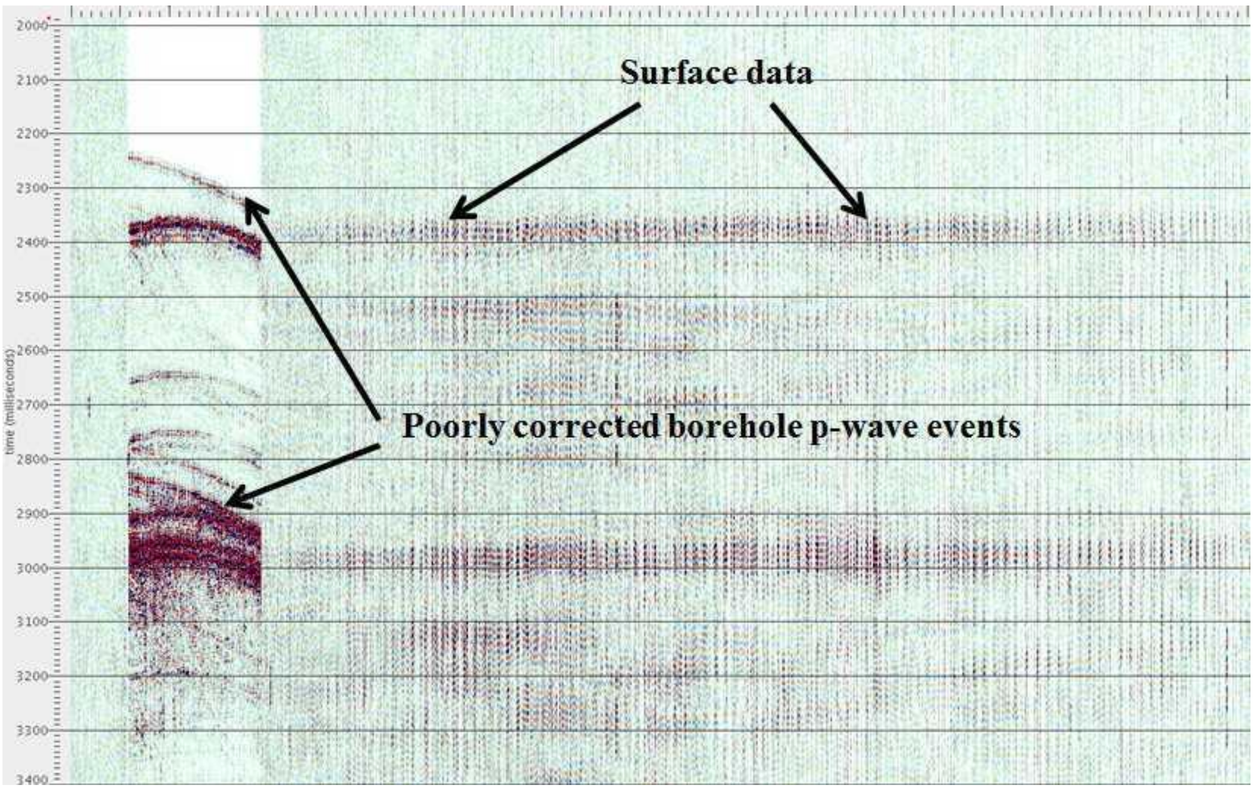

Figure 1. The velocities that were used to independently process the surface data in a co-recorded project result in poor corrections of the borehole data perforation shots.

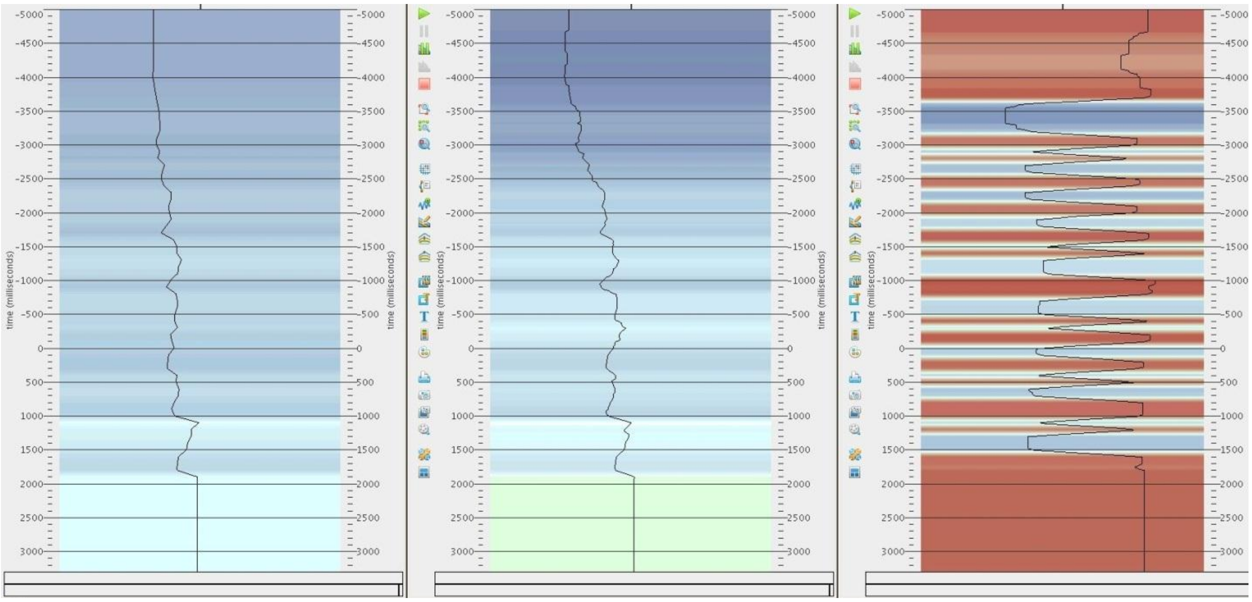

Figure 2. Results from a simultaneous simulated annealing velocity inversion of surface and borehole data. The left panel shows the original p-wave velocity function from the observation well, the center panel shows the p-wave velocity function that was output from the inversion, and the right panel shows the VTI epsilon function that was output from the inversion. The range of epsilon values is approximately 0 to 0.2.

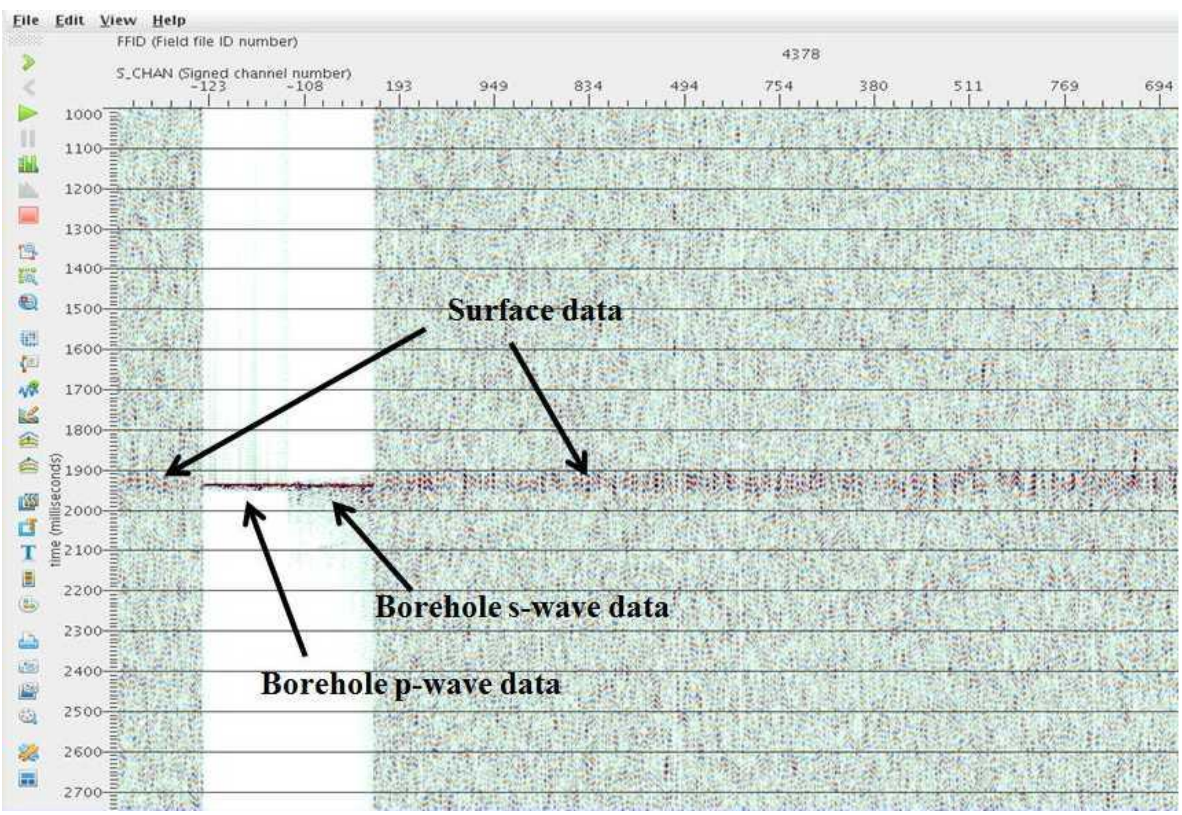

Figure 3. Dual moveout of borehole and surface data from a co-recorded microseismic project. A single set of velocity and VTI functions were used to correctly flatten borehole p-wave and s-wave data, and surface p-wave data.

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