Continuous 3D Seismic Reservoir Monitoring - a Modeling Study

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Summary

For monitoring the formation response to production we simulate a passive 3-D microseismic/acoustic emission survey. Acquisition of continuous three-component wavefield data provides the basis for event detection and mapping of variations of petrophysical parameters in space and time. Results from the modeling study will be used for array design and processing strategies of passive monitoring experiments.

Methodology and Objectives

In layered and heterogeneous media, the angular and frequency dependent seismic response point towards unique statistical distributions of physical properties in a reservoir zone. Investigations of the statistical nature of velocity and density perturbations provided useful insights into mechanisms governing wave propagation as there exists a strong correlation between the spatial properties of the velocity field of a reflective target and the lateral correlation length of the resulting seismic wave field. In our 3D modeling study, the reservoir is characterized by strong variations in elastic parameters. Figure 1 shows the acoustic impedance model for the study area. The reservoir is located at approximately 900m depth. Within the model, the Poisson's ratio varies from 0.15 to 0.48. Direct solutions of the elastic wave equation by finite differences (FD) must be obtained for complex fine-scale 3D subsurface models to better assess the scale and frequency dependent seismic wave propagation effects.

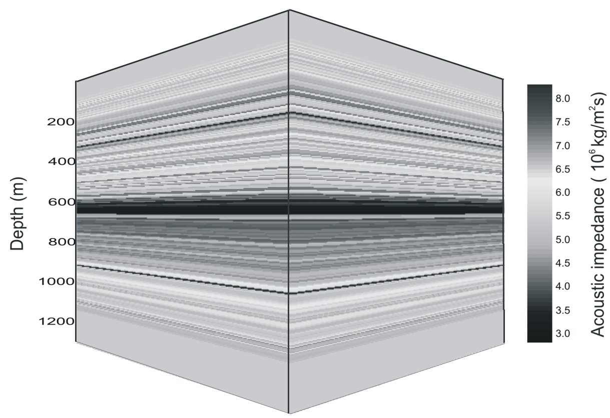


Figure 1: 3D seismic impedance model derived form borehole geophysical logs. The grid spacing is 4m.

Modeling Technique

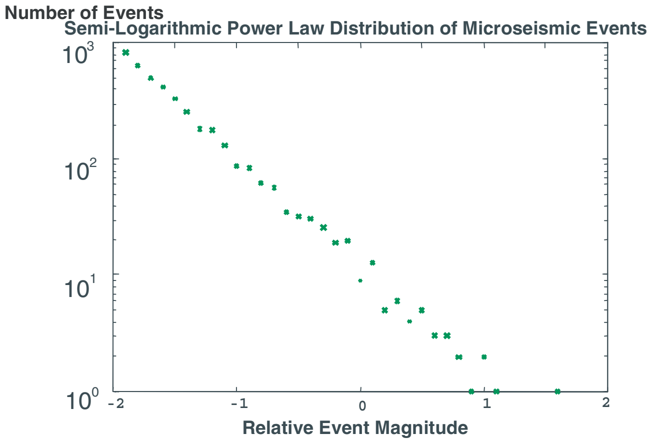
Here we present 3-D elastic modeling results for an acoustic emission experiment. Forward modeling is based on the implementation of 3D elastic FD codes on massive parallel and/or distributed computing resources using MPI (message passing interface). For parallelization the 3D model (Fig. 1) is decomposed into subvolumes. Each processing element (PE) or CPU is updating the wavefield within its portion of the grid. For wavefield update we apply staggered-grid, velocity-stress, finite difference equations which are of 4th order accuracy in space and of second order accuracy in time (Robertsson et al., 1994). The processors lying at top of the global grid apply a free surface boundary condition while the processors at the edges of the model apply an absorbing boundary condition. At the internal edges the processors exchange wavefield information. By clustering conventional PCs, wall clock time for 3D FD modeling can be significantly reduced and the possible grid sizes significantly increased (Bohlen and Milkereit, 2001).

Acoustic Emission Modeling Study

In reservoir geophysical studies microseismic/acoustic emission surveys are conducted to monitor seismic events caused by fluid flow in fractures, stress release due to gas build up, and hydraulic fracturing (Dobecki, 1992). Application of passive monitoring of microseismicity has been reported for heavy oil thermal recovery projects (Matthews, 1992) and detection of local stress build-up in hydrocarbon reservoirs (Caley et al., 2001). Here we model the 3D seismic response caused by distributed sources in space and time. A power law distribution of seismic sources (such as the Gutenberg-Richter law) is used for modeling elastic wave propagation through the model shown in Figure 1. The source strength distribution for the monitoring study is shown in Figure 2a and the spatial distribution of seismic events from the target zone is centered at 900 m depth (shown in Fig 2b).

The emitted continuous wavefield is recorded with a surface array on a 200 by 200 grid. A snapshot of the continuous waveform data is shown in Figure 3a. Data acquistion along an in-line (Fig. 3a) reveals prominent direct arrivals. However, weak seismic events of the source distribution shown in Fig. 2 become buried in the pronounced transmission coda. True amplitude three-component data is shown in Fig. 3c. The prominent transmission coda makes it difficult to identify direct compressional and shear wave arrivals. Consequently, conventional event detection and event file processing are difficult to implement. Nevertheless, surface array data help to identify source locations as revealed by the symmetric events in time slice shown in Fig. 3b. Future data processing of the continuous waveform data will be based on conventional event detection and on wavefield processing techniques such as reverse time migration.

a) b)



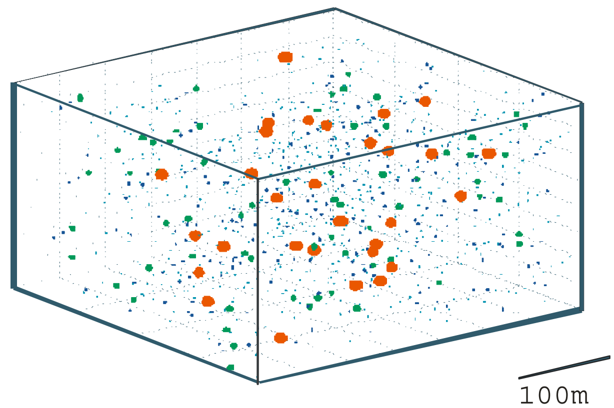


Figure 2: (a) Source strength distribution for continuous elastic waveform modeling based on a power law distribution. (b) Spatial distribution of seismic sources located at reservoir depth.

Conclusions

A 3D seismic elastic modeling study helps to fine tune the acquisition parameters for a passive monitoring study targeting a reservoir at 900 m depth. The study (based on the available log and velocity information) is used to determine the optimum array configuration for the continuous recording of seismic waveform data. For monitoring of the formation response during production we simulate a 3D passive microseismic (acoustic emission) survey. The synthetic surface array detects strong emitted events. However, the prominent transmission coda predicted by the 3D modeling study places additional burden on the processing and interpretation of continuous seismic waveform data as many weak seismic events are buried in the waveform coda.

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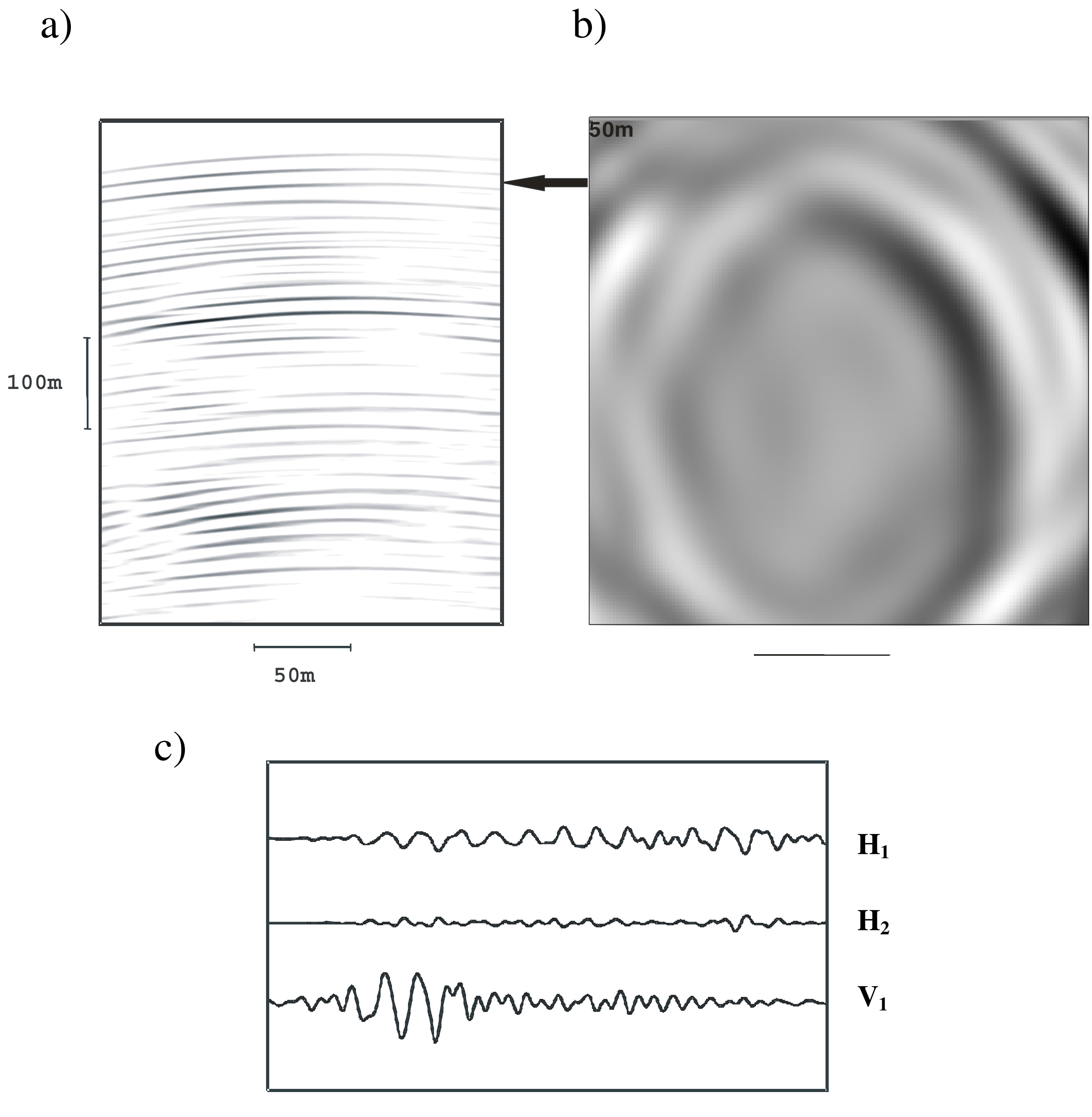

Figure 3: Continuous waveform data recorded with 3-component surface array (a) Snapshot of vertical component in-line section of seismic data excited by the source distribution shown in Fig. 2. Note the pronounced transmission code trailing the direct event. (b) Time slice through synthetic surface array data with seismic event identified by circular amplitude event centered above the source location. (c) Three-component seismic data example with transmission coda.