Implications for S wave Generation from Subsurface Chemical Explosions using Large Arrays of Sensors

SnT 2019
CTBT: SCIENCE AND TECHNOLOGY CONFERENCE

T2.3-P17

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Abstract. The Source Physics Experiment (SPE) is a series of instrumented chemical explosions at the Nevada National Security Site (NNSS) designed to improve understanding of seismic wave generation and propagation from explosions. In April 2016 a temporary deployment of 996 geophones was installed at distances of 400 to 3000 m from a buried (76.5 m) 5000 kg TNT equivalent chemical explosion. The explosion was situated in a weathered granite body surrounded by volcanic tuffs, Paleozoic carbonates, and alluvium. The experiment included an active source campaign using a weight drop. In December 2018 a similar deployment (~500 sensors) was installed around a 50,000 kg TNT equivalent chemical explosion at a depth of 300 m. The geologic setting was alluvium over basement. Results show substantial differences in waveforms and associated particle motions over small spatial distances. Characterization of the velocity structure was conducted using first arrival P wave analysis, interferometry, and inter-station correlation. Statistical estimations of the spatial heterogeneity based on the recorded data led to improved modelling of the waveforms using 3D numerical models and demonstrated that path conversions account for a significant component of the observed S waves.

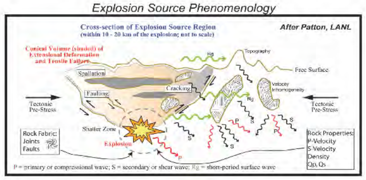


Figure 1a. Cartoon illustrating possible modes for generation of S waves from explosions.

Science goals

- Measure unaliased wavefield of P, S, and surface waves.
- Validate modelling and codes.
- Identify zones of scattering and conversion.
- Improve 3D velocity model
  - travel times
  - seismic interferometry
  - active source

Source *(chemical explosions)*
SPE5 (Source Physics Experiment #5)
5000 kg TNT equivalent ; depth: 76 m

DAG2 (Dry Alluvium Geology #2)
50,000 kg TNT equivalent; depth: 300 m

Sensors and deployment
SPE5: 500 Z (5 Hz DT-SOLO); 496 3C (5Hz Sercel SG-5)
DAG2: 496 5Hz 3C Sercel SG-5
Nodes: 14 GB disk space per node; ~ 20 days battery.

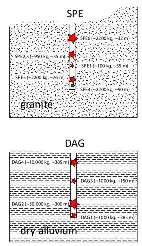


Figure 1b. SPE (top) and DAG (bottom) event series.

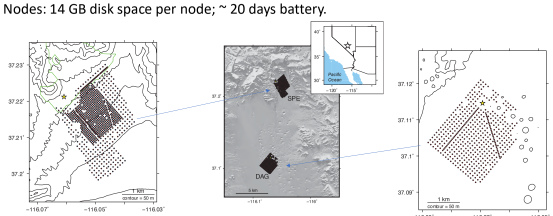


Figure 2. Maps of the SPE5 (left) and DAG2 (right) arrays. Orientation was designed to align with known geological features and avoid areas of rough or dangerous terrain.

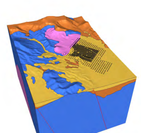
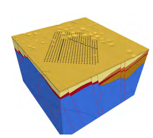


Figure 3. The geology of the two sites vary significantly. SPE5 (left) was emplaced in a largely fault-bounded granite batholith while DAG2 in layered alluvium above faulted basement rocks.



Question: How do explosions generate S waves?

- *Understand partitioning between source and path contributions to S wave energy.*
- *Measure unaliased wavefield of P, S, and surface waves.*
- *Validate and improve models and codes.*

Deployment and data

Figure 4. Images of the equipment and truck containing field computer (left), a view of the nodal unit (battery, digitizer/disk, and geophone)(middle), and the emplaced geophone.

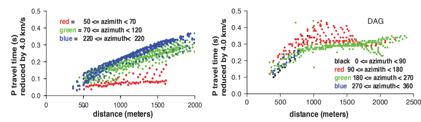


Figure 5. P wave arrival times distinguished by azimuth from event for SPE5 (left) and DAG2 (right). Paths through the granite at SPE (red) is much faster than the paths to the southeast, which transverse alluvium, and tuffs.

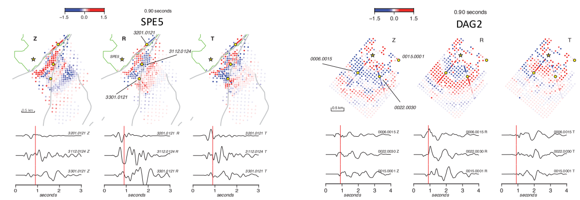


Figure 6. Images of seismic wave amplitude for vertical (Z), radial , and tangential (T) for SPE5, DAG2 and DAG3 at 0.9 seconds after the explosion. DAG3 appears to display a well-defined S wave that is clear on the tangential component at station 0022.0030.

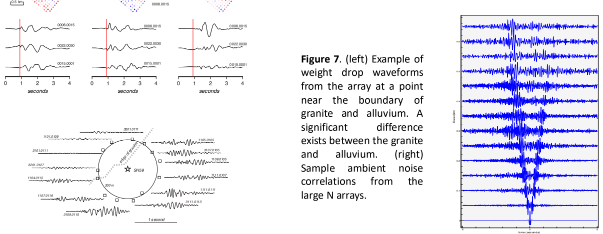


Figure 7. (left) Example of weight drop waveforms from the array at a point near the boundary of granite and alluvium. A significant difference exists between the granite and alluvium. (right) Sample ambient noise correlations from the large N arrays.

High-resolution velocity models and implications for S wave generation

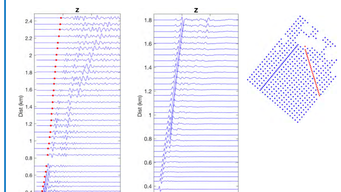


Figure 8 Example of observed data (far left) and modeled data (middle) for the line of dense sensors shown in red (above). Replicating the high frequency structure and amplitude of the observed S wave is challenging.

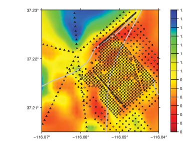
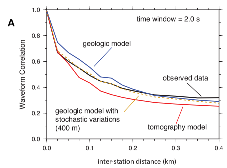


Figure 9. A 3D S wave velocity map generated from approximately 500,000 cross-correlations.

A



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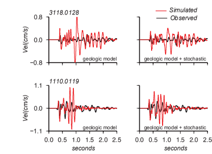


C

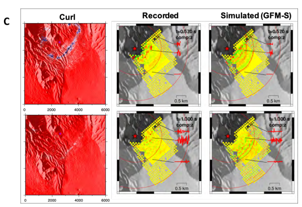
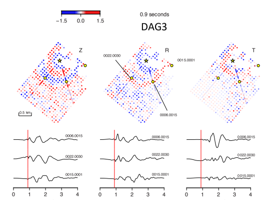


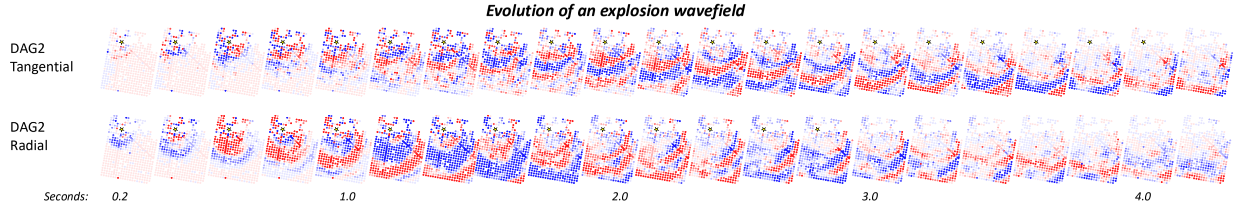
Figure 10. A) A comparison between the correlation between modeled and observed data as a function of inter-station distance. The modeled data includes a simple, geology-only model, a geology model with stochastic variations, and a model that includes tomography. B) Seismograms, observed and modeled, for the models shown in A. C) A comparison of observed and synthetic wavefields.

Summary:

- A high-quality dataset of both Z and 3C data was collected.
- The results are used to refine and validate the 3D models, both for overall general structure and stochastic variability.
- To adequately match the amplitude and frequency content of the observed S waves, velocity models need to include stochastic variations in the model.

Evolution of an explosion wavefield





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