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# Full waveform inversion methods for source and media characterization before and after SPE5

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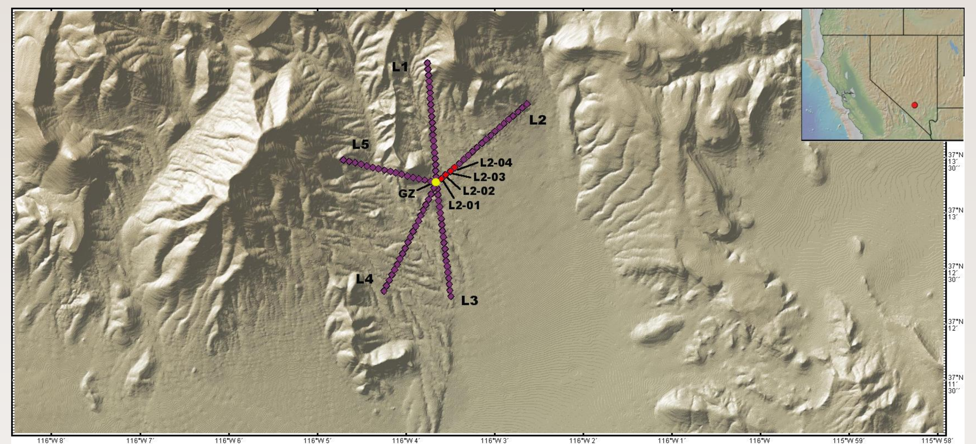
**Abstract**: The Source Physics Experiment (SPE) was designed to advance our understanding of explosion-source phenomenology and subsequent wave propagation through the development of innovative physics-based models. Ultimately, these models will be used for characterizing explosions, which can occur with a variety of yields, depths of burial, and in complex media. To accomplish this, controlled chemical explosions were conducted in a granite outcrop at the Nevada Nuclear Security Test Site. These explosions were monitored with extensive seismic and infrasound instrumentation both in the near and far-field. Utilizing this data, we calculate predictions before the explosions occur and iteratively improve our models after each explosion. Specifically, we use an adjoint-based full waveform inversion code that employs discontinuous Galerkin techniques to predict waveforms at station locations prior to the fifth explosion in the series (SPE5). The full-waveform inversions are performed using a realistic geophysical model based on local 3D tomography and inversions for for media properties using previous shot data. The code has capabilities such as unstructured meshes that align with material interfaces, local polynomial refinement, and support for various physics and methods for implicit and explicit time-integration. The inversion results we show here evaluate these different techniques, which allows for model fidelity assessment (acoustic versus elastic versus anelastic, etc.). In addition, the accuracy and efficiency of several time integration methods can be determined.

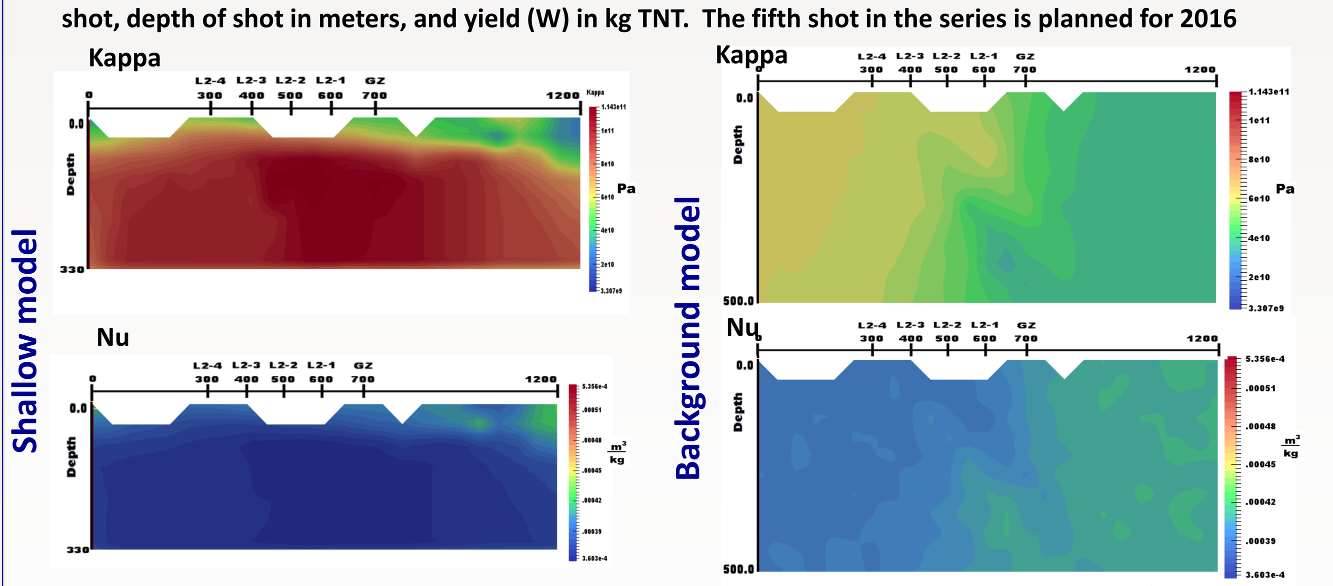
## Source Physics Experiment



Map showing stations nearest to the SPE shot epicenter considered for this investigation. Note that Lines 3, 4, and 5 extend further with more widely spaced broadband stations not shown here.

| SPE 1 | SPE2 | SPE3 | SPE4prime | SPE5 |
|---|---|---|---|---|
| 3/3/2011 | 10/25/2011 | 7/24/2012 | 5/21/2015 | Spring 2016 |
| 54.9m | 45.7m | 45.8m | 87.2m | |
| W 87.9 kg | W 997 kg | W 905 kg | W 89.1 kg | |

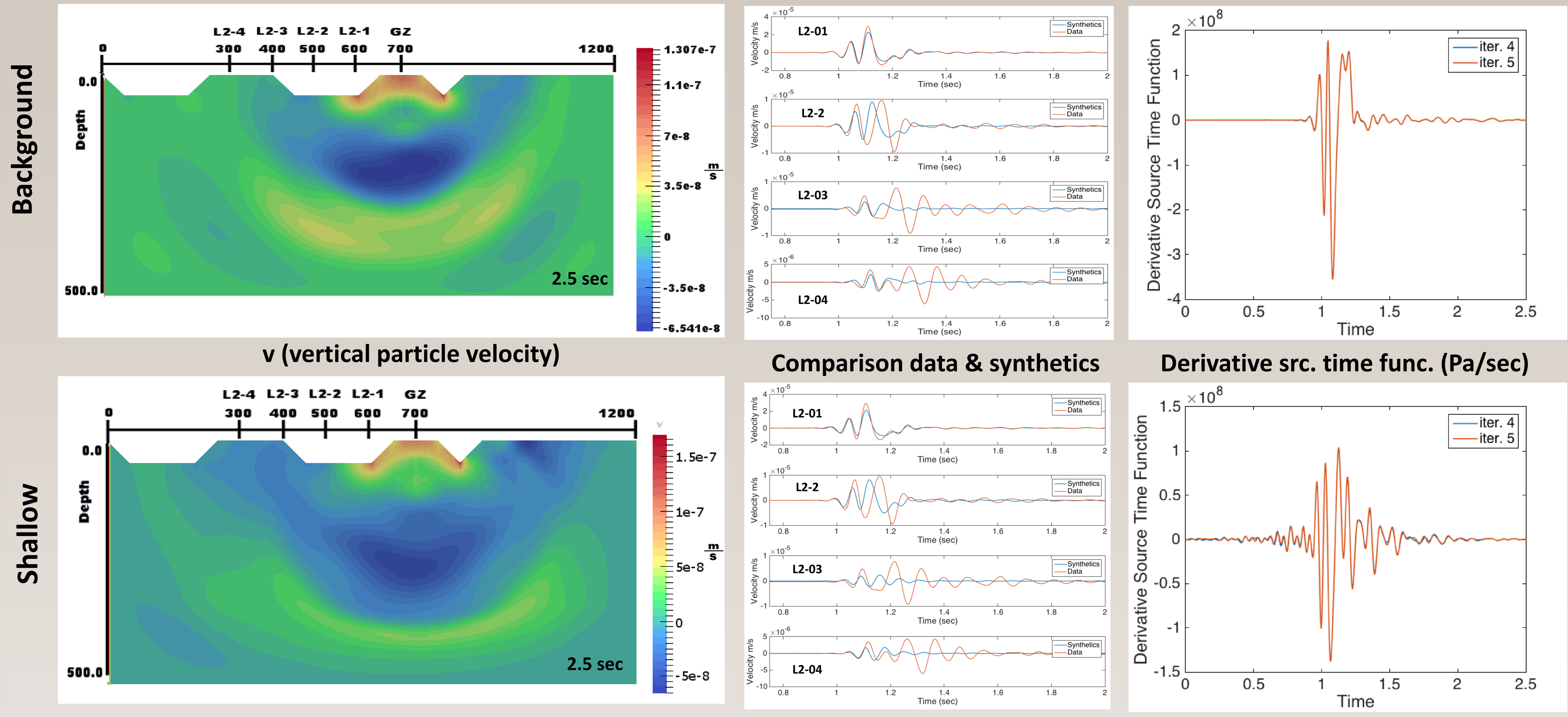
Chemical explosions conducted as part of the Source Physics Experiment. Shot name, date of shot, depth of shot in meters, and yield (W) in kg TNT. The fifth shot in the series is planned for 2016




Starting velocity models for source inversions. Kappa = ρ $V_p^2$, Nu = 1/ρ. Left: Model that includes shallow velocities from AWD (accelerated weight drop) survey. Right: Based on 3D tomographic model from Leiph Preston (SNL)

## SPE4prime, Source inversion, Acoustic physics

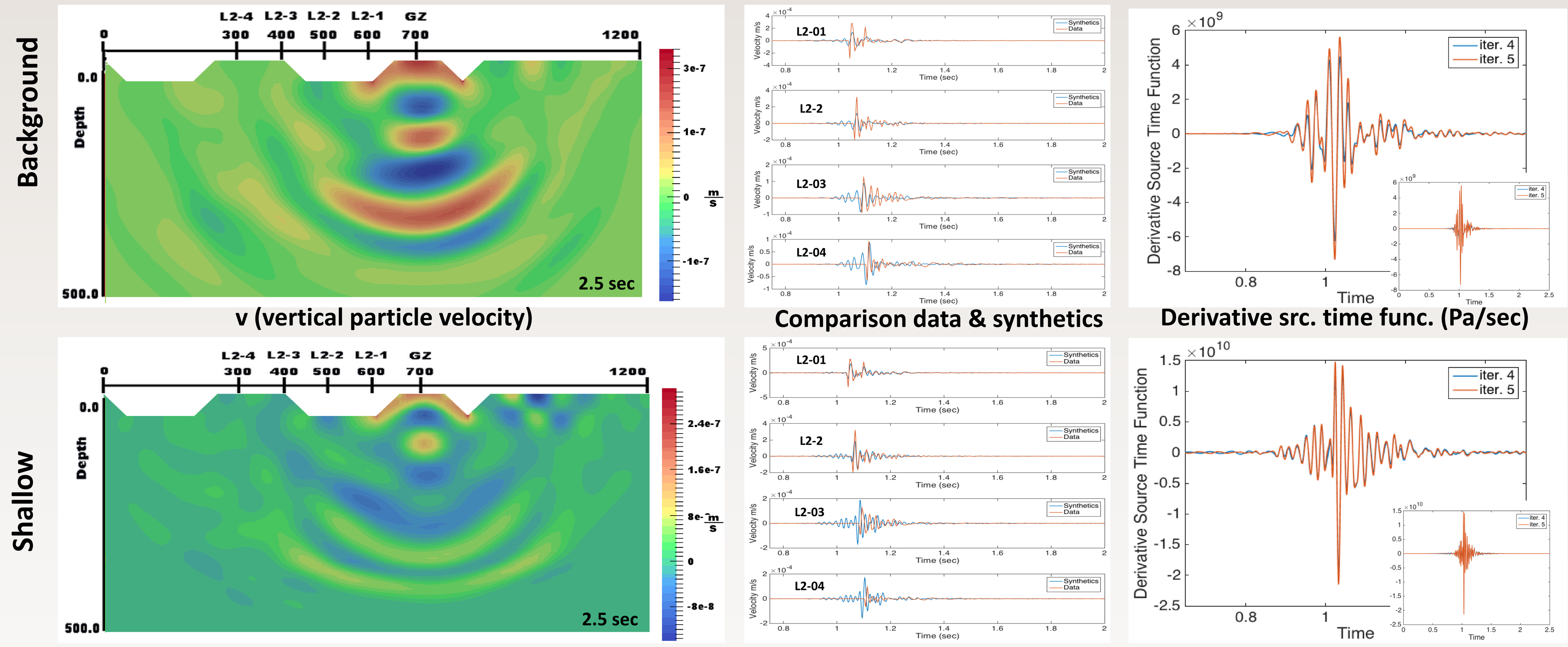
10 Hz peak freq.




v (vertical particle velocity) | Comparison data & synthetics | Derivative src. time func. (Pa/sec)

## SPE4prime, Source inversion, Acoustic physics

60 Hz peak freq.

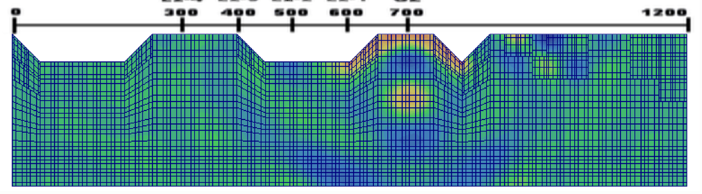


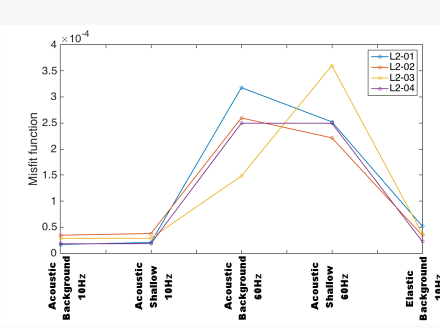

v (vertical particle velocity) | Comparison data & synthetics | Derivative src. time func. (Pa/sec)

Note: Pre-shot ringing in synthetics is a numerical artifact requiring further investigation. May be mitigated by better resolving source kernal or model improvements

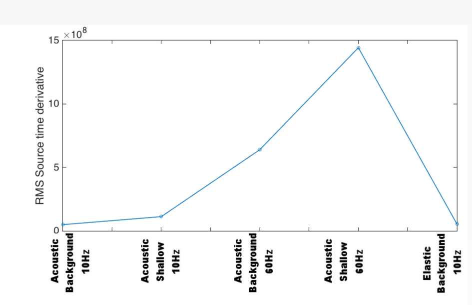
## Simulation Methodology:

Source inversions shown here are 2D inversions performed with 25m mesh spacing. Velocity model has 50m grid spacing. Mesh is altered at top of model to conform to topography resulting in more complex elements (see below). Uppermost boundary condition is an acoustic free surface. Riemann flux and Runge Kutta time integration are used for Acoustic physics. Lax Friedrichs flux is used for Elastic physics.
For simulations with a 10 Hz peak frequency, the data has been filtered to have a matching peak frequency while for the 60 Hz simulations the data is unfiltered.





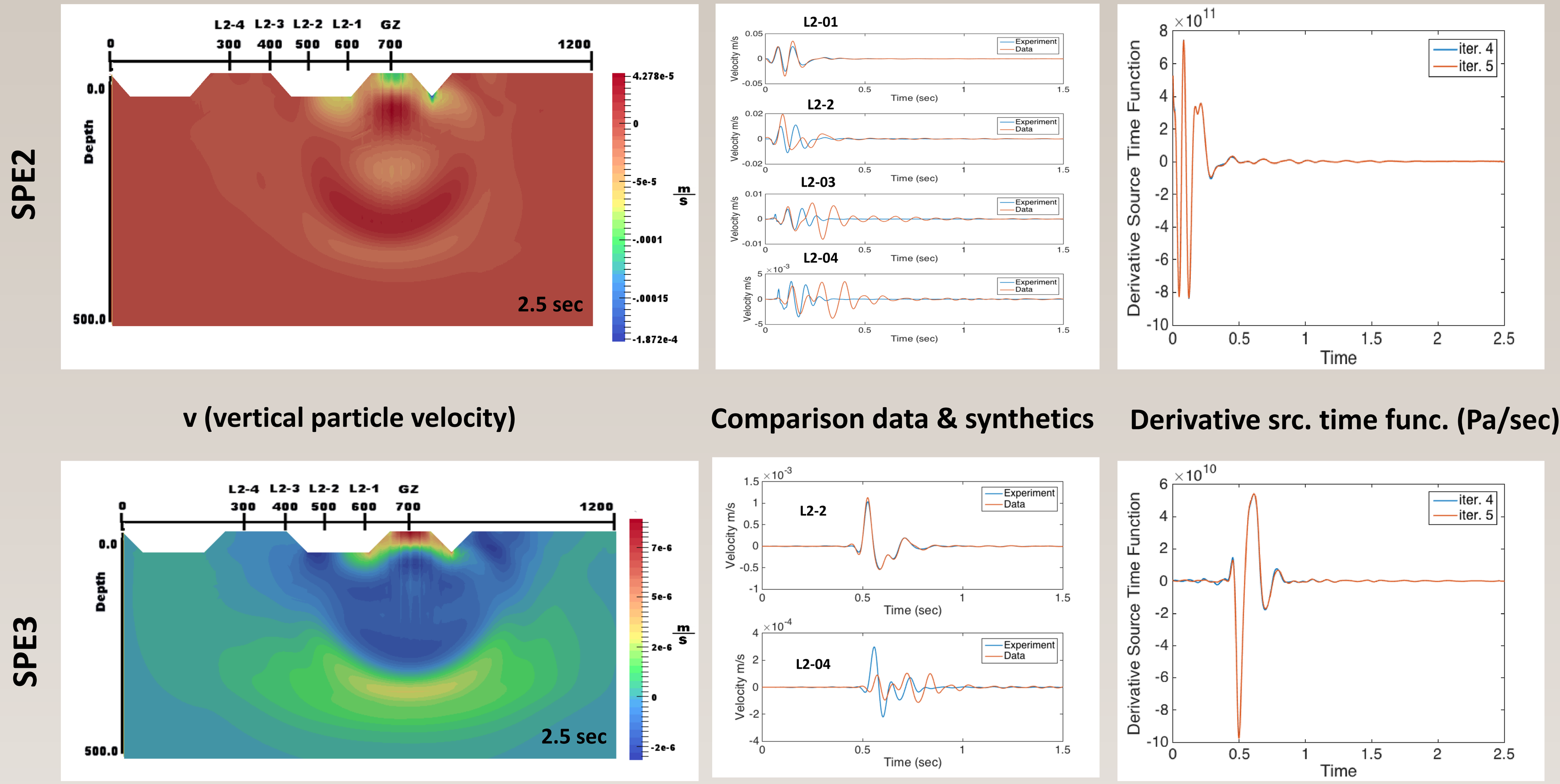

Misfit between data and synthetic traces calculated from L2 norm for each SPE4prime simulation



RMS (root mean squared) values for derivatives of the source time function for the fifth iteration of each SPE4prime simulation

## Source inversion, Acoustic physics, Shallow model, 10 Hz peak freq.

SPE2 and SPE3

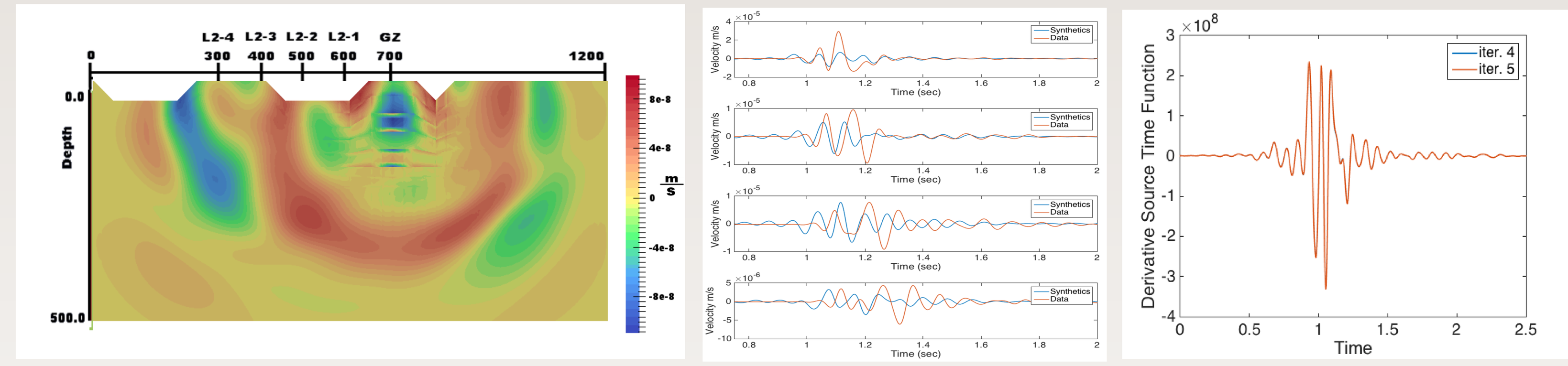



v (vertical particle velocity) | Comparison data & synthetics | Derivative src. time func. (Pa/sec)

Note that source origin time differs between the shots. For SPE3, L2-01 and L2-03 were removed due to lower data quality

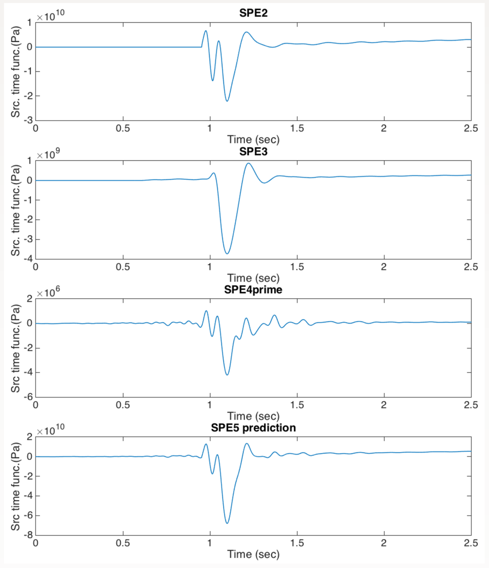
## SPE4prime, Source inversion, Background model, 10 Hz peak freq.

Elastic physics

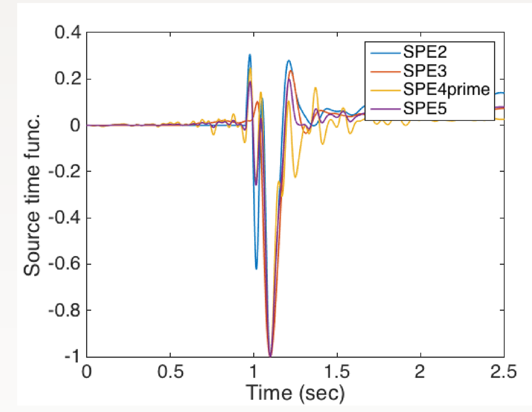



v (vertical particle velocity) | Comparison data & synthetics | Derivative src. time func. (Pa/sec)

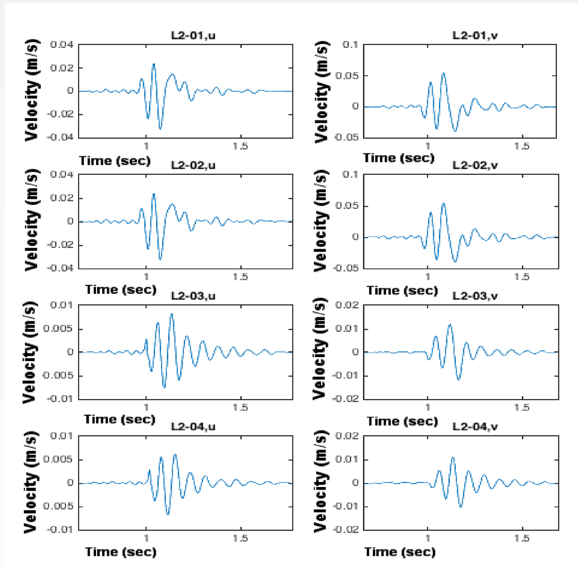
## Predicting SPE5




Acoustic source inversions using Shallow model and 10 Hz peak frequency for SPE2, SPE3, and SPE4prime and prediction for SPE5 with yield equivalent to 5000 kg TNT




Comparison of normalized source time functions showing similarities across shots



Predicted waveforms for first four stations of Line 2. Future work will yield improved predictions with updated 3D models, different physics, and medium inversions

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