

Improving Our Understanding of Explosion Seismic Waves from the Nevada Source Physics Experiments



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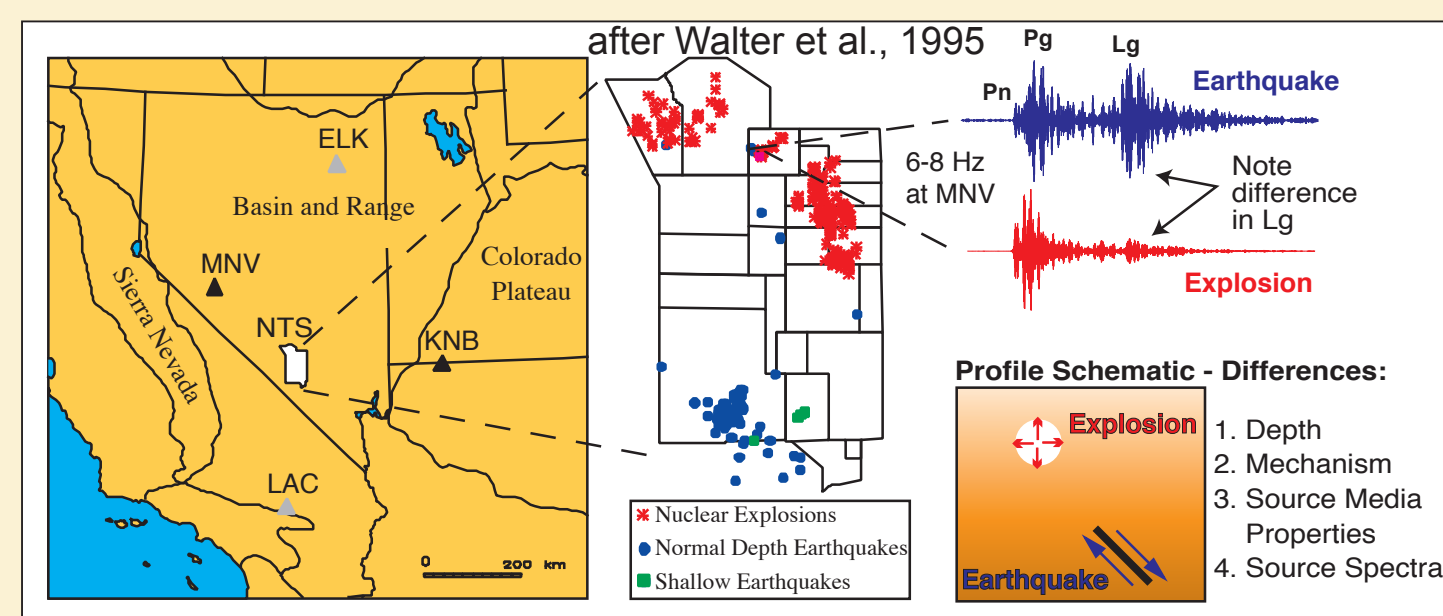
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ABSTRACT

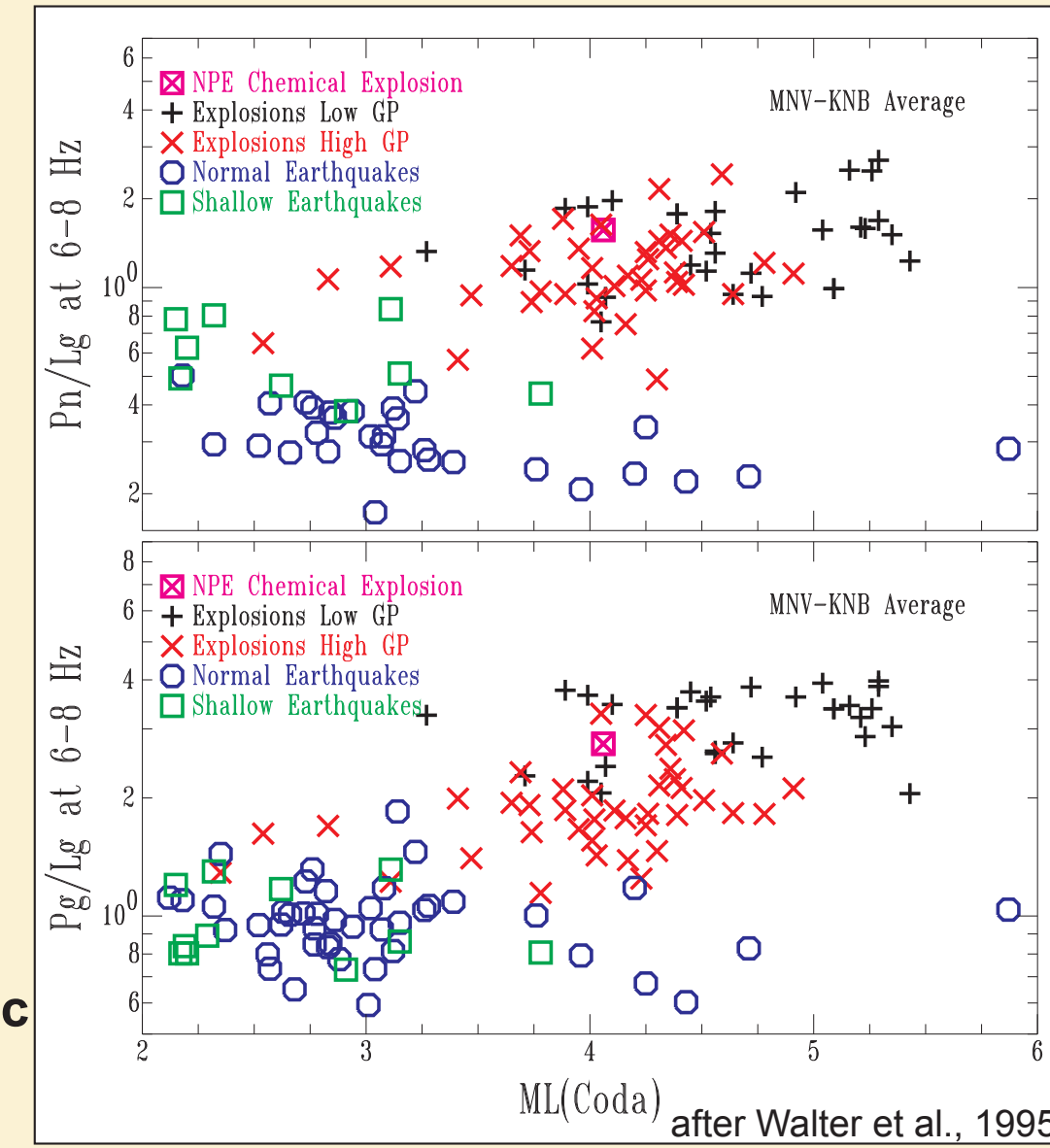
The Source Physics Experiments (SPE) are a series of well-instrumented chemical non-nuclear explosions at the Nevada National Security Site (NNSS) designed to improve the understanding of seismic wave generation and propagation from explosions. The 5-ton SPE-5 on April 26, 2016, and 2.2 ton SPE-6 on October 12, 2016, were the last of the Phase I series of six underground chemical non-nuclear explosions conducted in the same granite borehole. By varying the size and depth of the shots, while recording them on a common sensor network, ranging from near- to far-field, we are able to improve our understanding of the effects of yield, scale depth, scattering and emplacement properties on explosion seismic wave generation. This has resulted in refinements to previous models for explosion P-wave spectra, S-wave generation, P/S discrimination, correlation behavior and more.

As part of the SPE, a temporary deployment of 1000 geophones was installed from April 20 to May 20, 2016, to record the SPE-5 explosion and background signals and noise before and afterwards. A set of large weight drops at 53 locations both inside and outside the array were also recorded, as were several local, regional and teleseismic events.

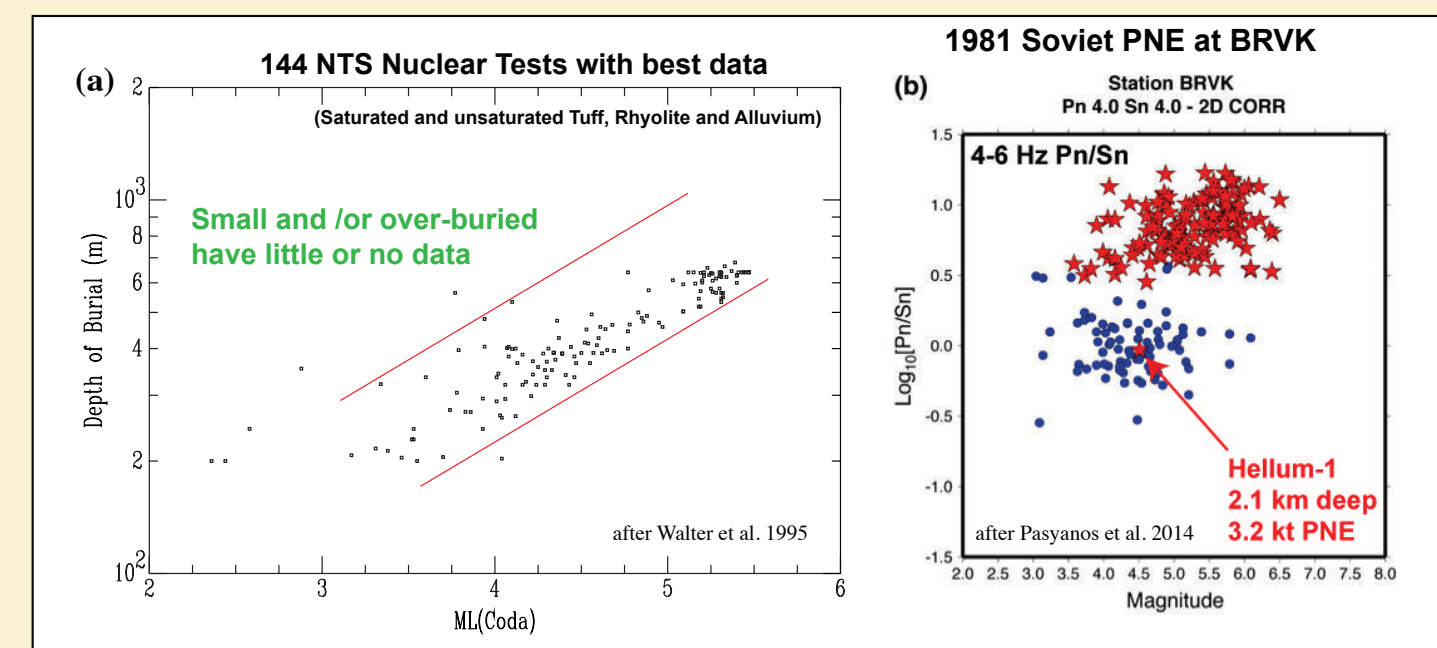
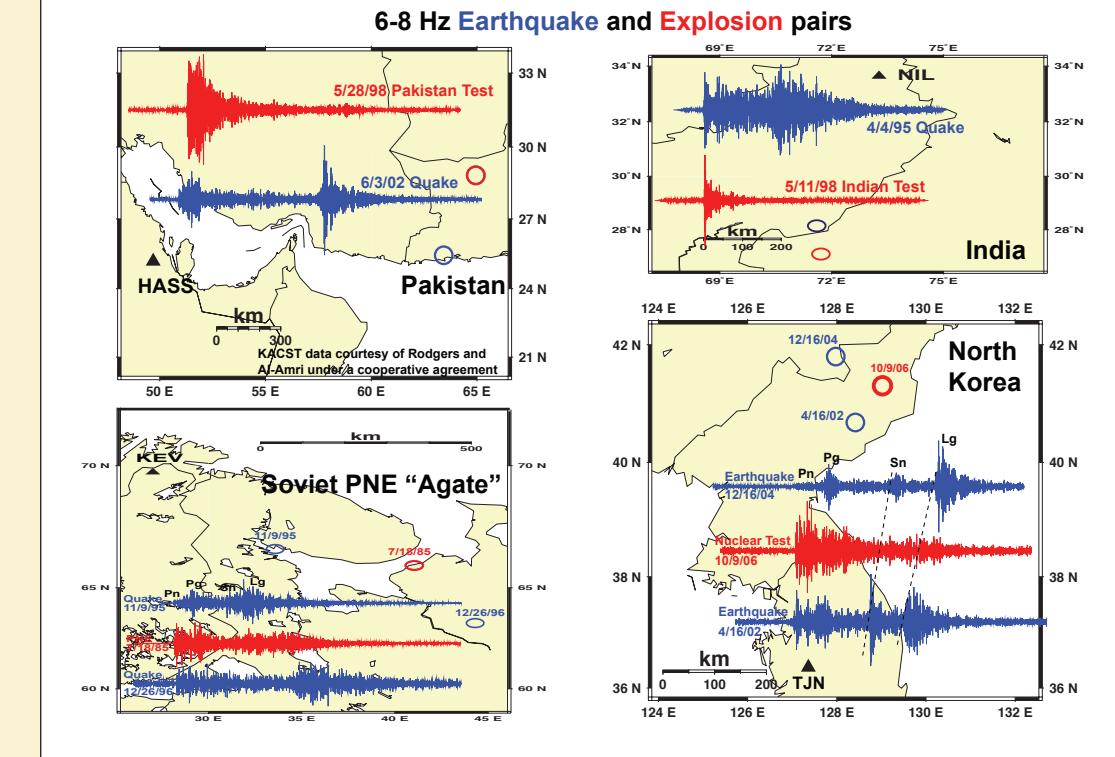
INSIGHTS INTO P/S DISCRIMINATION USING THE SPE



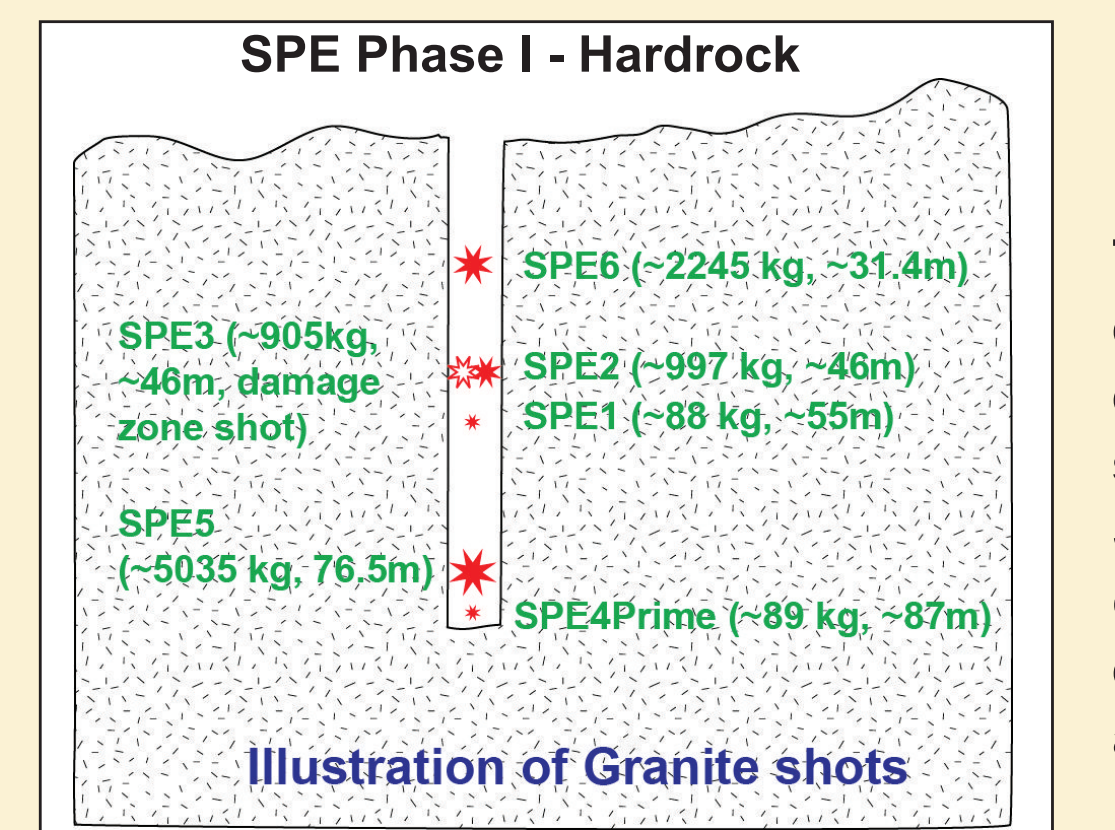
Prior work has shown that even very small ($M < 4$) nuclear tests discriminate from normal depth background earthquakes using P/S ratios from Nevada historic nuclear explosive tests. Shallow earthquakes are more problematic as shown at right. Empirically the technique works well at all historic test sites as shown below. However much historic testing emplacement was driven by cost and safety issues to follow a limited scaled depth of burial.



High-frequency P/S appears to work everywhere

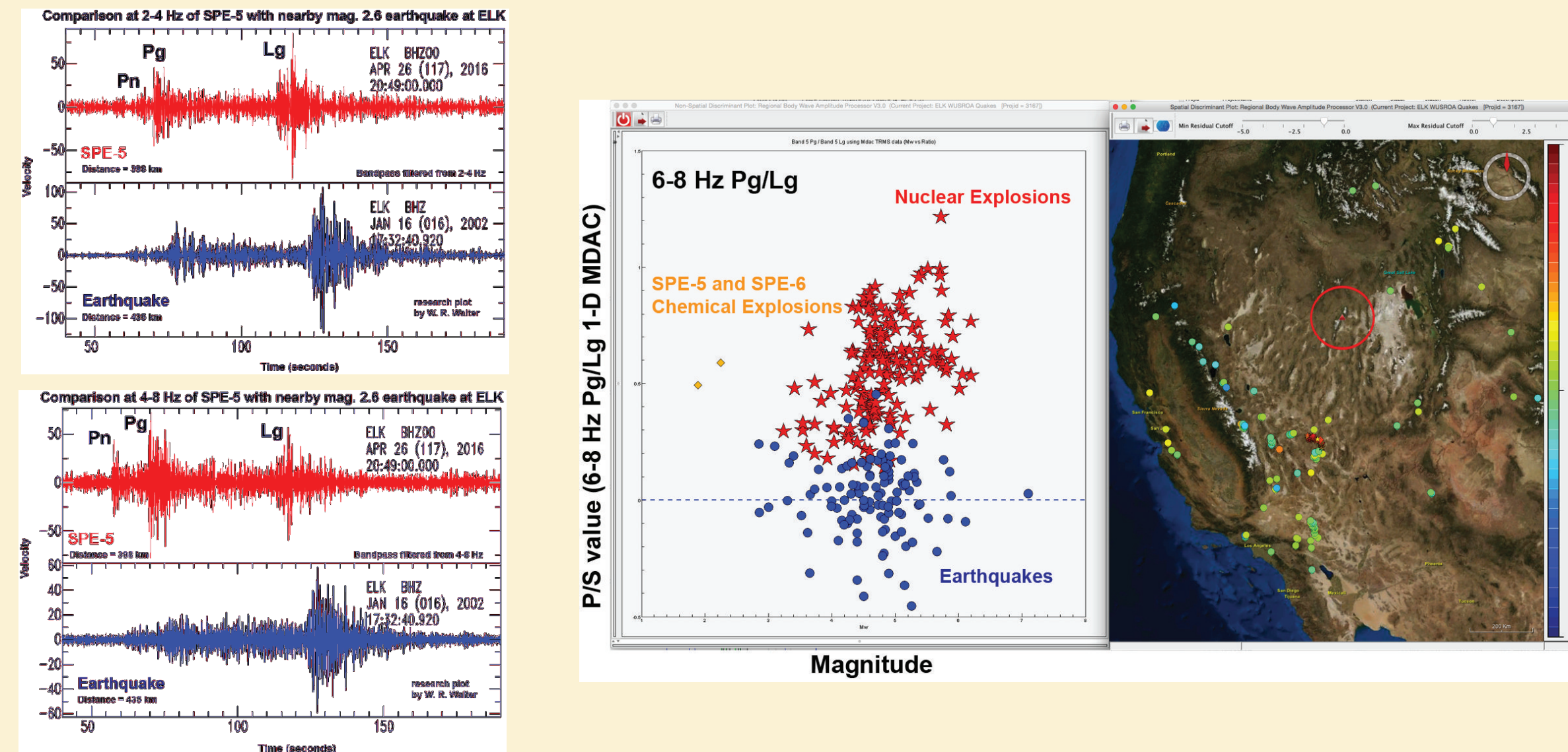


We have little data for small and/or over-buried explosions. In a recent analysis of the Borovoye data shown above, a very deep explosion does not discriminate well using P/S at frequencies up to 6 Hz (no SNR at > 6 Hz). The SPE goal is to develop physics-based modeling codes supported and validated by well-recorded chemical explosions to update our current semi-empirical historic test site based methodologies (e.g. Snelson et al., 2013).



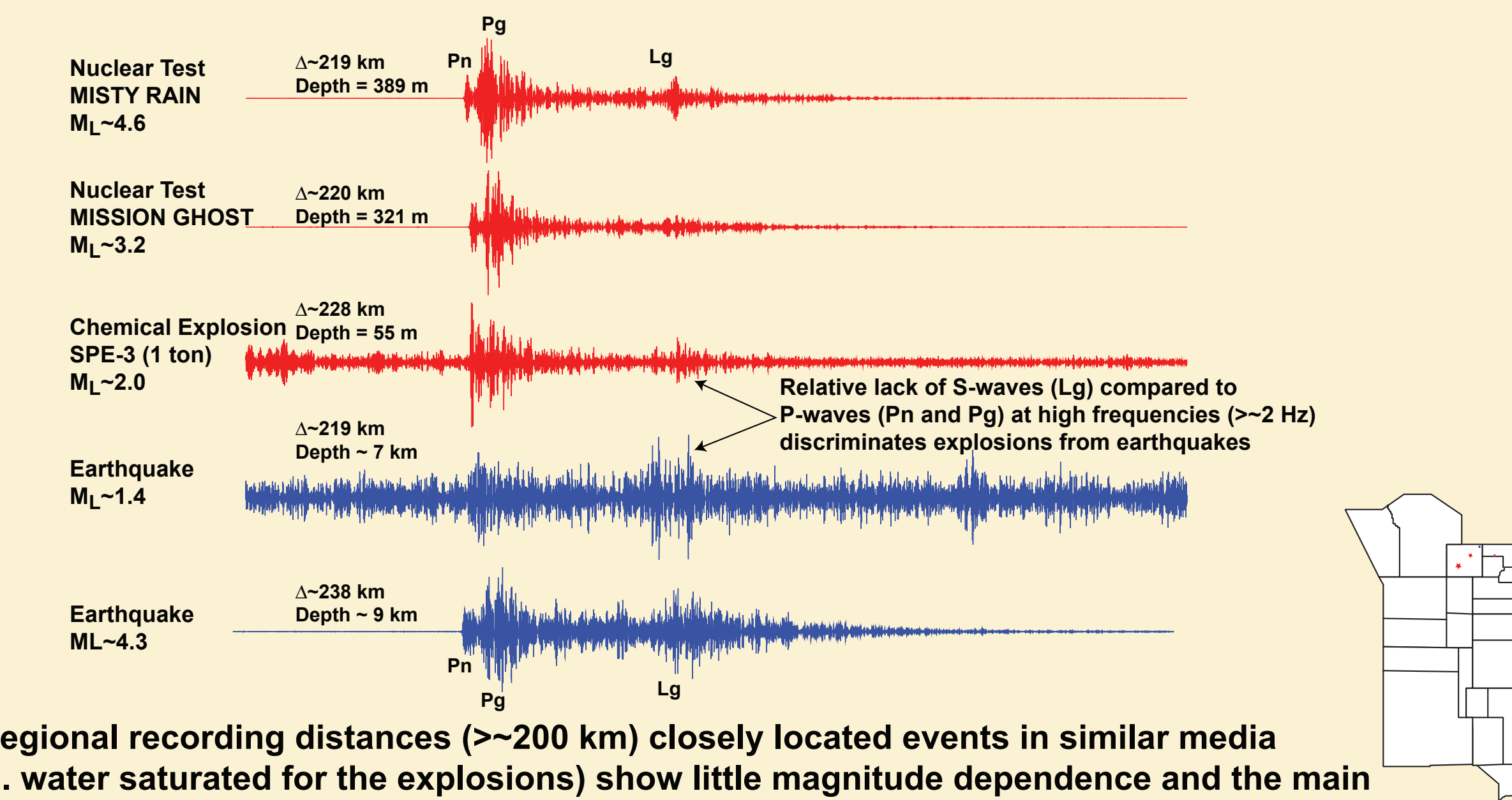
The SPE Phase I consisted of six chemical (non-nuclear) explosions in granite at various depth and sizes. SPE is exploring the effect of differences in depth, mechanism, source properties and source spectra. By recording the SPE explosions on common stations the signals can be compared to each other and the common path and site effects canceled out to focus on the source differences and their effects on the signals.

REGIONAL DISTANCE P/S FOR SPE



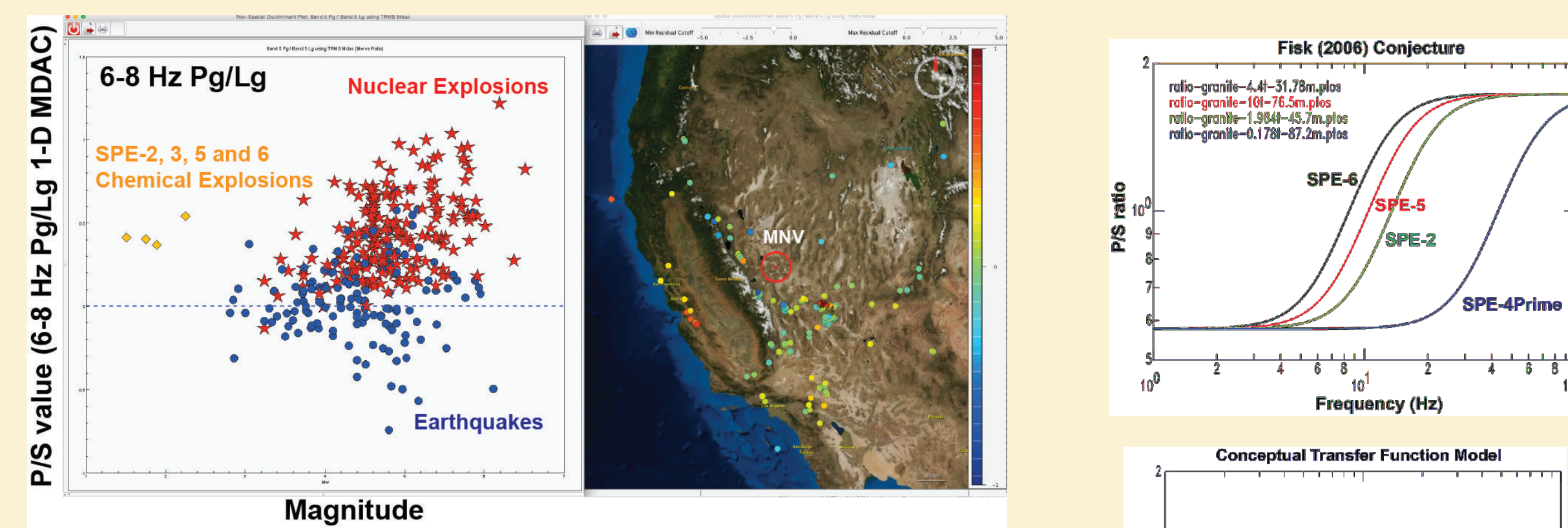
P/S APPEARS INDEPENDENT OF MAGNITUDE

Explosions and Earthquakes at Mina, NV bandpass filtered from 6-12 Hz



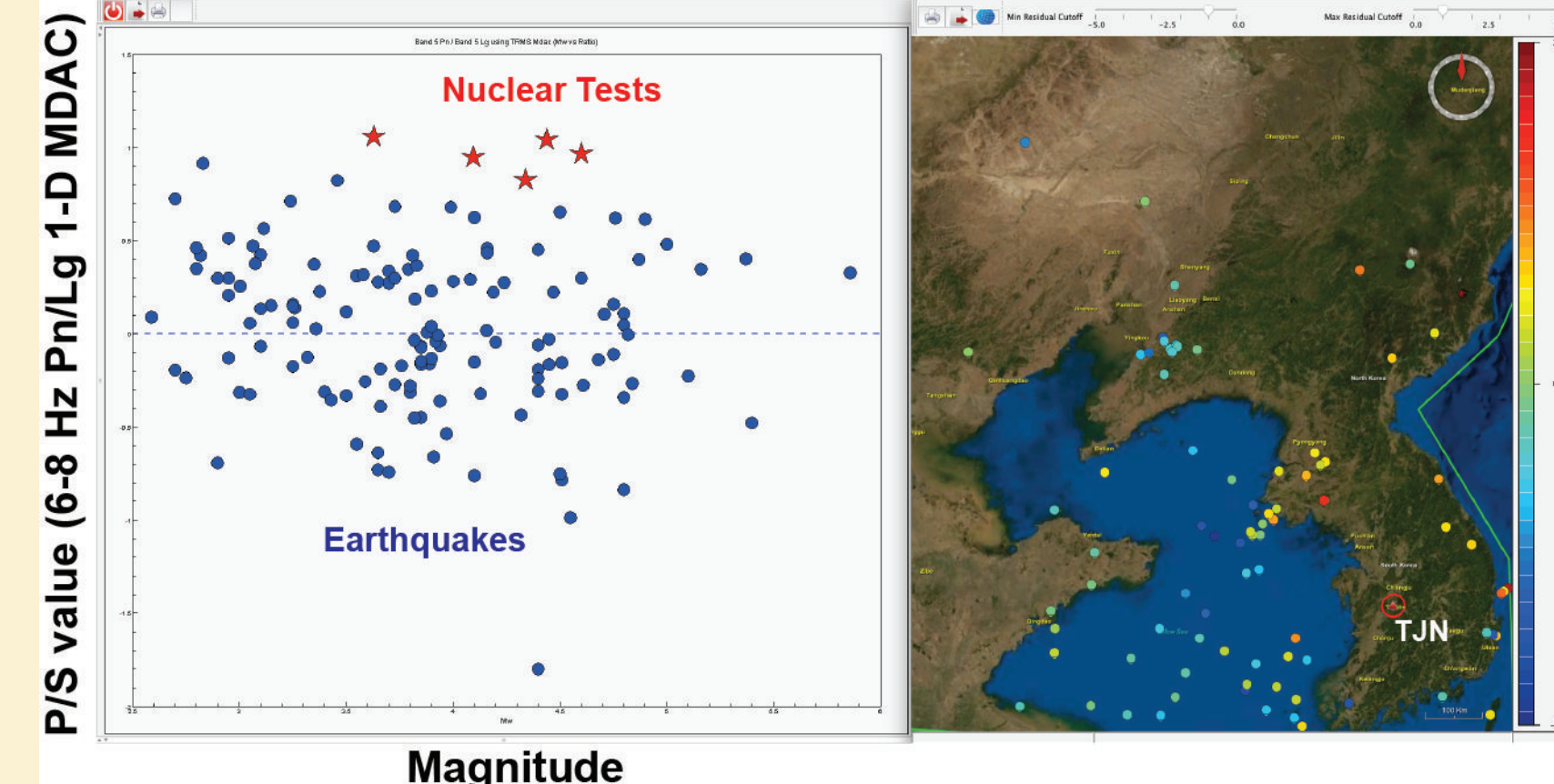
At regional recording distances (> 200 km) closely located events in similar media (e.g. water saturated for the explosions) show little magnitude dependence and the main limitation to how low in magnitude we can go is signal-to-noise levels.

The SPE shots discriminate at MNV similar to nuclear tests



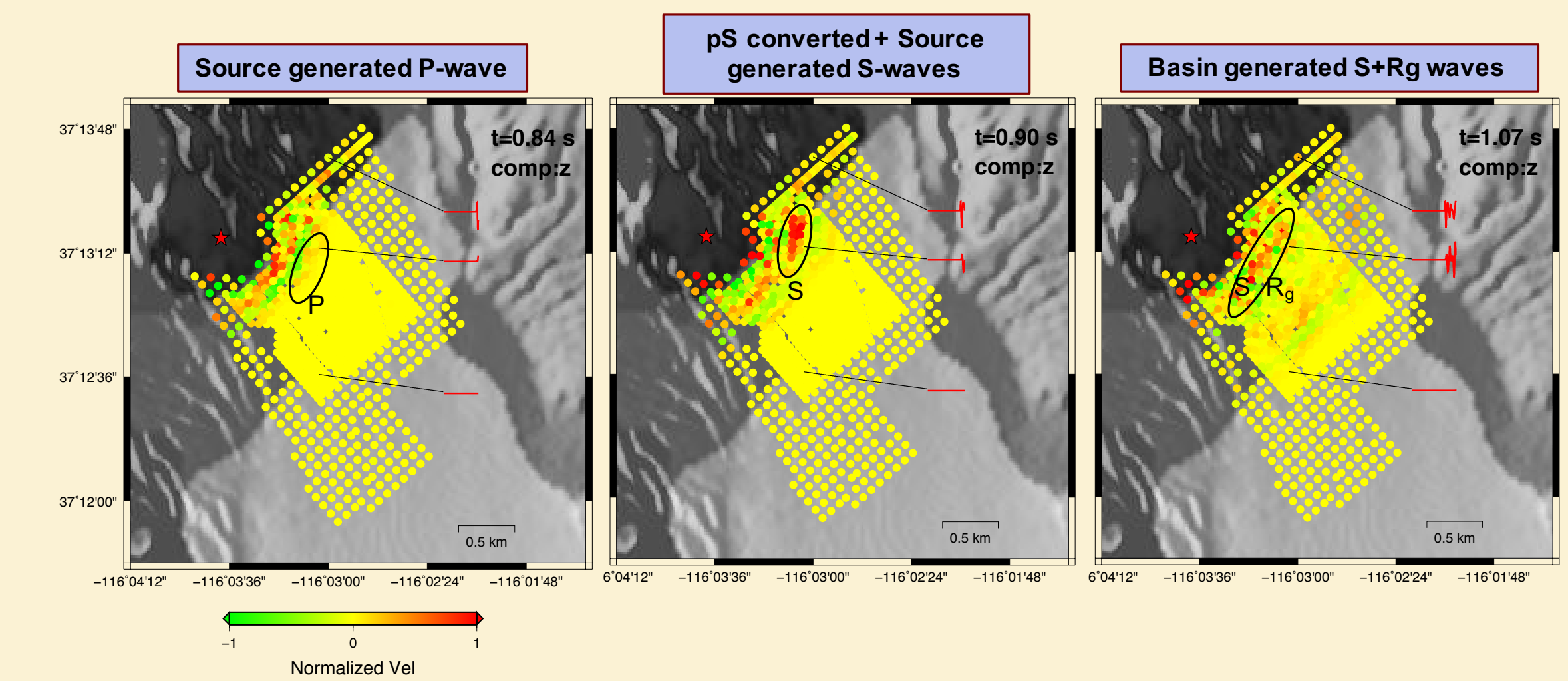
The SPE results are encouraging for small explosion discrimination using P/S ratios at frequencies greater than about 4 Hz. The lack of magnitude dependence rules out size varying models of S-wave generation such as proposed by Fisk (2006) and implies that some sort of scattering model such as that shown to the right appears to apply to all explosions in a given area, regardless of size.

The DPRK tests discriminate at TJN in a similar way



USING MANY SENSORS TO IMAGE THE WAVEFIELD

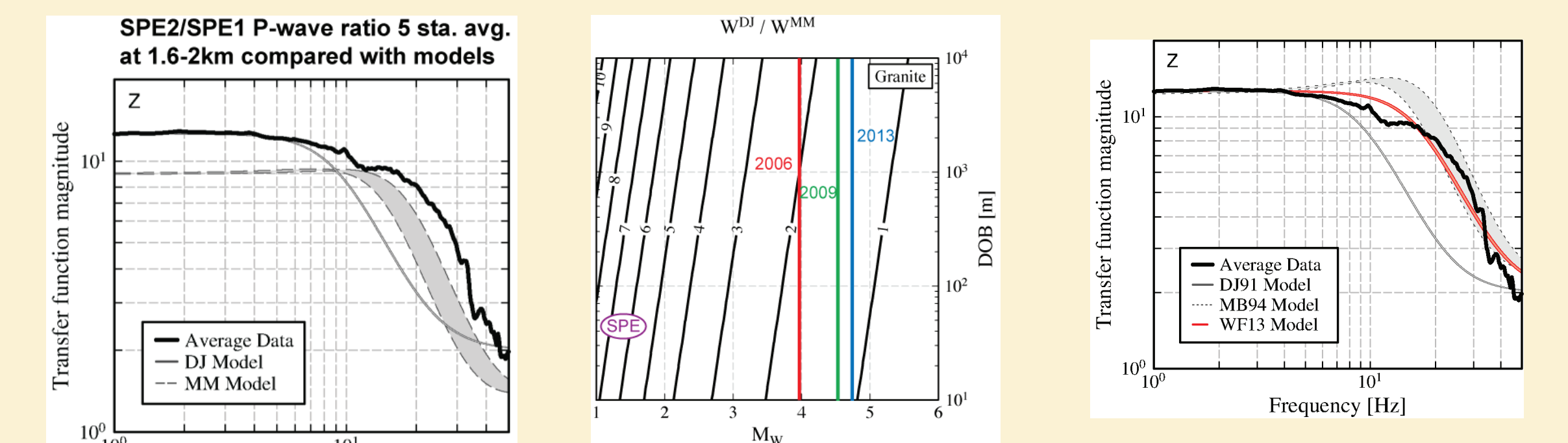
A temporary deployment of 996 geophones was installed from April 18 to May 20, 2016, near the site of SPE-5. Sensor spacing varied from 25 to 100 m and consisted of 500 Z and 500 3C 5 Hz geophones. Data was recorded continuously during the deployment at low-gain from April 18 to April 28 and high-gain (36 db) from April 29 to May 23. SPE-5 a 5 ton TNT equivalent chemical explosion was recorded on April 26. The array was deployed 400 to 3000 m from the shot, which was situated in a weathered granite body surrounded by volcanic tuffs, Paleozoic carbonates, and alluvium. A set of large weight-drops at 53 locations both inside and outside the geophone array were also recorded, as were local, regional, and teleseismic earthquakes. Data recovery was good, with 95% of data recovered from the shot and up to 99% in the following weeks.



Near-source structure significantly affects the far-field motion. In addition to explosively driven motion on the natural joints in the granite, P to S conversions and Rg waves are significant contributors to the observed far-field shear motion.

MODELS VERSUS OBSERVATIONS

Previous work showed the Mueller-Murphy (1971) and the Denny-Johnson (1991) explosion models do not agree with each other for small and/or over-buried explosions and are poor fits to the SPE data



Ford and Walter (2013) and others (e.g., Rougier et al. 2011; Rougier and Patton, 2015, Yang, 2016) show that the MM and DJ models are poor matches to the SPE data as shown above on left. The middle plot shows the MM and DJ models disagree with each other for small and/or over-buried tests. Right plot shows better fits to SPE ratios via a cube root scaling modified MM model Murphy and Barker, 1994 and with a new Walter and Ford (2013) model.

The revised model will need to be modified for the dry porous alluvium media we will be testing in SPE Phase II

