OBTAINING ROBUST SEISMIC CONSTRAINTS FROM PLANETARY EXPLORATIONS: THE FULL WAVEFORM PERSPECTIVE.

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Introduction: Planetary analog studies allow assessment and refinement of geophysical methods for planetary exploration. The Geophysical Exploration of the Dynamics and Evolution of the Solar Systems (GEODES) SSERVI is focusing on the San Francisco Volcanic Field (SFVF), Flagstaff, AZ as an analog environment appropriate for developing geophysical exploration strategies for upcoming lunar science missions.

Seismic studies have been carried out on the Moon by the *Apollo* missions and on Mars by the *InSight* mission. Shallow subsurface properties of both bodies have been probed by identifying the arrival times of artificially generated seismic waves. While this approach allows a straightforward processing scheme and can map out discontinuities in the shallow subsurface, much more information about subsurface structures can be extracted from the complete waveforms. When interpreting seismic images of the subsurface in terms of physical properties and processes, it is crucial to adequately quantify uncertainty; however, this can be extremely challenging due to trade-offs and non-uniqueness inherent to seismic inversion.

The overarching goal of this research is to develop and evaluate an active seismic imaging approach that can maximize the utility of seismic waveform data while quantifying uncertainties of inferred subsurface properties. The successful implementation of this method and its validation in a planetary analog environment will inform future geophysical exploration of the SSERVI target bodies.

Approach: Seismology has been an essential tool for probing crustal structure on Earth since Mohorovičić first provided a seismological definition of its base. Recent technical advances, such as the use of portable 3-compoennt nodal seismometers, dramatically facilitate data acquisition and quality compared to technologies available to *Apollo* astronaut. In this study, we focus on active-source seismic data acquired on linear arrays of 51 nodes deployed in 1-km transects across several target structures in the SFVF.

We are developing a 2D probabilistic approach that inverts both amplitude and time measurements from body waves while incorporating more waveform constraints, including surface wave (Rayleigh wave) dispersion and ellipticity. This approach uses a Transdimensional Hierarchical Bayesian framework with a reversible-jump Markov Chain Monte Carlo (rjMCMC) algorithm to generate an ensemble of possible velocity models of the subsurface. Models in the ensemble are samples from the posterior probability distribution and enable full uncertainty quantification.

As a first step, we test our approach on a synthetic velocity model (Fig. 1A-B) that contains a range of structures thought to be relevant for the SFVF (e.g., topography, faults, lava tubes, deep reflector, etc.) while retaining the geometry of the active field survey. The synthetic dataset is constructed from measurements made on our wavefield simulations (e.g., Fig. 1C-D). Waveform predictions for individual rjMCMC steps are approximated in order to reduce the total number of computationally-costly wavefield simulations. We assess the suitability of various approximation schemes on rjMCMC convergence. Furthermore, we quantify how choices of which waveform constraints are used in the inversion affect model retrieval.

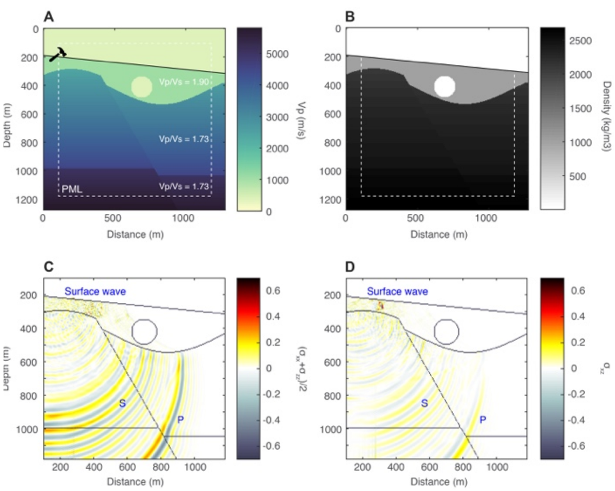

Figure 1. (A-B) Synthetic model of the SFVF field site as a planetary analog. (C-D) Simulated wavefield from an active source (propelled energy generator; IRIS instrument center) used in the SFVF, Flagstaff, AZ field experiment.

Summary: Our approach to seismic inversion for shallow structure aims to take advantage of the rich information contained in seismic waveform data through probabilistic modeling that enables meaningful uncertainty quantification. Crucially, our method allows straightforward extension to joint inversion with other available geophysical measurements (e.g., gravity, GPR, magnetics). The expected outcome from this study aligns with one of the primary goals of GEODES, developing geophysical detection and exploration methods to characterize subsurface structures of SSERVI target bodies.