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First seismic shear wave velocity profile of the lunar crust as extracted from the Apollo 17 active seismic data by wavefield gradient analysis

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We present a new seismic velocity model of the shallow lunar crust, including, for the first time, shear wave velocity information. So far, the shear wave velocity structure of the lunar near-surface was effectively unconstrained due to the complexity of lunar seismograms. Intense scattering and low attenuation in the lunar crust lead to characteristic long-duration reverberations on the seismograms. The reverberations obscure later arriving shear waves and mode conversions, rendering them impossible to identify and analyze. Additionally, only vertical component data were recorded during the Apollo active seismic experiments, which further compromises the identification of shear waves.

We applied a novel processing and analysis technique to the data of the Apollo 17 lunar seismic profiling experiment (LSPE), which involved recording seismic energy generated by several explosive packages on a small areal array of four vertical component geophones. Our approach is based on the analysis of the spatial gradients of the seismic wavefield and yields key parameters such as apparent phase velocity and rotational ground motion as a function of time (depth), which cannot be obtained through conventional seismic data analysis. These new observables significantly enhance the data for interpretation of the recorded seismic wavefield and allow, for example, for the identification of S wave arrivals based on their lower apparent phase velocities and distinct higher amount of generated rotational motion relative to compressional (P-) waves. Using our methodology, we successfully identified pure-mode and mode-converted refracted shear wave arrivals in the complex LSPE data and derived a P- and S-wave velocity model of the shallow lunar crust at the Apollo 17 landing site.

The extracted elastic-parameter model supports the current understanding of the lunar near-surface structure, suggesting a thin layer of low-velocity lunar regolith overlying a heavily fractured crust of basaltic material showing high (>0.4 down to 60 m) Poisson's ratios. Our new model can be used in future studies to better constrain the deep interior of the Moon. Given the rich information derived from the minimalistic recording configuration, our results demonstrate that wavefield gradient analysis should be critically considered for future space missions that aim to explore the interior structure of extraterrestrial objects by seismic methods. Additionally, we anticipate that the proposed shear wave identification methodology can also be applied to the routinely recorded vertical component data from land seismic exploration on Earth.