An inquiry into the lunar interior: A nonlinear inversion of the Apollo lunar seismic data

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[1] This study discusses in detail the inversion of the Apollo lunar seismic data and the question of how to analyze the results. The well-known problem of estimating structural parameters (seismic velocities) and other parameters crucial to an understanding of a planetary body from a set of arrival times is strongly nonlinear. Here we consider this problem from the point of view of Bayesian statistics using a Markov chain Monte Carlo method. Generally, the results seem to indicate a somewhat thinner crust with a thickness around 45 km as well as a more detailed lunar velocity structure, especially in the middle mantle, than obtained in earlier studies. Concerning the moonquake locations, the shallow moonquakes are found in the depth range 50–220 km, and the majority of deep moonquakes are concentrated in the depth range 850–1000 km, with what seems to be an apparently rather sharp lower boundary. In wanting to further analyze the outcome of the inversion for specific features in a statistical fashion, we have used credible intervals, two-dimensional marginals, and Bayesian hypothesis testing. Using this form of hypothesis testing, we are able to decide between the relative importance of any two hypotheses given data, prior information, and the physical laws that govern the relationship between model and data, such as having to decide between a thin crust of 45 km and a thick crust as implied by the generally assumed value of 60 km. We obtain a Bayes factor of 4.2, implying that a thinner crust is strongly favored. *INDEX TERMS:* 6250 Planetology: Solar System Objects: Moon (1221); 5430 Planetology: Solid Surface Planets: Interiors (8147); 3260 Mathematical Geophysics: Inverse theory; 5455 Planetology: Solid Surface Planets: Origin and evolution; *KEYWORDS:* Moon, inverse theory, seismology, interior structure, terrestrial planets

1. Introduction

[2] Using seismology to obtain information about the interior of the Moon saw its advent with the U.S. Apollo missions which were undertaken from July 1969 to December 1972. Seismic stations were deployed at five of the six locations (Apollo 17 did not carry a seismometer) as part of the integrated set of geophysical experiments called the Apollo Lunar Surface Experiment Package (ALSEP). Only four of these five stations (12, 14, 15, and 16), powered by radioactive thermal generators, operated concurrently as a four-station seismic array, which was operative from April 1972 until 30 September 1977, when transmission of seismic data was suspended. Each seismic package consisted of three long-period (LP) seismometers aligned orthogonally to measure one vertical (Z) and two horizontal (X and Y) components of surface motion. The sensor unit also included a short-period seismometer which was sensitive to vertical motion at higher frequencies (for more instrumental details, see *Latham et al.* [1969]). Digital data were transmitted continuously from the lunar surface to receiving stations on Earth and were stored on magnetic tapes for subsequent analysis. All the seismic data were then displayed on a compressed timescale format from which lunar seismic signals were identified [*Nakamura et al.*, 1980].

[3] The lunar seismic network spans the near face of the Moon in an approximate equilateral triangle with 1100 km spacing between stations with two seismometers placed 180 km apart at one corner (see Figure 1) and covers most geological settings on the front side of the Moon. Since the first mission, more than 12,000 events have been recorded and catalogued over a period of 8 years, and it has taken several more to evaluate the data [*Nakamura et al.*, 1981]. Since the compilation of the recorded seismograms, it has been shown that the Moon is very aseismic compared to the Earth. In comparison to the Earth the energy released in seismic activity is 8 orders of magnitude less, being about 10^{10} J yr^{-1}, compared to 10^{18} J yr^{-1} by earthquakes [*Goins et al.*, 1981a], although *Nakamura* [1980] has pointed out that the actual average lunar seismic energy release could be as high as 10^{14} J yr^{-1}. Most of the moonquakes are very small

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