Lithospheric Structure of the Moon and Correlation with Deep Moonquake Source Regions

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Introduction: A major scientific result from the Apollo Passive Seismic Experiment (APSE) was the detection of several thousand moonquakes that occur with tidal periodicities and emanate from distinct source regions with depths of 700–1200 km [1]. These deep moonquakes (DMQ) have provided first order information on the interior deep structure of the Moon; however little is known about the actual source regions, except that they appear to be less than a few km in spatial extent [2]. Observed DMQ source regions are confined to the lunar nearside, due to the placement of the 4 APSE seismometers. However, as has been noted previously, it is clear that the deep source regions are not distributed randomly even within some nominal region of sensitivity about the centroid of the Apollo seismic network [3]. In particular, DMQ source regions generally occur in association with the major nearside basins and few are located below the nearside highlands, suggesting the influence of long-lived spatial variations in thermal and/or compositional structure [3]. Here we investigate relationships between the DMQ source region locations and lithospheric and crustal structure.

Approach: The response of the lithosphere to transverse surface and internal loads can be approximated as that of a thin spherical elastic shell [4]. One efficient approach to estimating lithospheric response relies on calculating spectral ratios (admittance and correlation) between gravity and topography, and matching the response to a known or estimated loading structure [4]. Recently, a novel application of the spherical wavelet transform has been used to compute admittance and correlation on the Moon [5]. In this paper we use analytical models for loading of a thin elastic shell to estimate lithospheric parameters from the wavelet functions: elastic thickness (T_e), crustal thickness (T_c), crustal density (ρ_c), subsurface to surface load ratio (f), and degree-correlation between initial surface and subsurface loads (α). Simplicity of the model and the small number of free parameters allow its use in a directed Monte Carlo search using the neighborhood algorithm. Lithospheric parameters are estimated on a 4 degree grid and goodness of fit is calculated with a reduced chi-square (χ^2_ν) from a joint inversion of wavelet admittance and correlation.

To investigate correlations of the lithospheric parameters with DMQ source locations, we use the DMQ locations of [6]. We use only those source regions with quoted uncertainties in latitude and longitude less than 10^o and with at least 10 events. For each DMQ cluster we generate a probability distribution (pdf) of N events about the mean DMQ location, assuming the location uncertainties are gaussian. N is given by $N = 1000N_{DMQ}$, where N_{DMQ} is the observed number of individual DMQ at that location. Our events are then binned into 4 degree bins and normalized by the total number of events overall. In this way, our pdf weights each source region by the number of recorded DMQ and is an estimate of the likelihood of measurable activity at any geographical location. DMQ occurrence can then be compared with the various lithospheric parameters.

Results: Preliminary results are shown in Figure 1. Masked regions coincide with locations where $\chi^2_\nu > 3$. Large misfits are generally found in nearside lowlands and mascons, implying that model approximations may be invalid, or that loading structure is more complex. Crustal structure (T_c and ρ_c, Fig. (1a)) is only loosely constrained by the wavelet admittance and correlation functions, and is likely biased by a simple mass-sheet approximation for radial gravity anomalies. Nevertheless, the results reproduce the first-order pattern of crustal thickness variations with a thin crust underlying nearside lowlands and thicker crust underlying farside highlands. Elastic thickness (Fig. (1b)) varies over short wavelengths and does not follow the first-order crustal pattern. Farside highlands (including South Pole-Aitken) are characterized by equal surface and subsurface loading (Fig. (1c)), whereas subsurface loading dominates nearside lowlands. DMQ are found preferentially beneath regions of thin crust (as expected), where the elastic lithosphere is less than the global mean value and where subsurface loading exceeds surface loading. In addition DMQ appear to occur where there are regional-scale transitions in T_e, that may also be accompanied by regional scale transitions in the thickness of the thermal lithosphere. These results collectively, together with correlations of DMQ source regions with mare basalts [7], suggest that DMQ source regions are likely to be concentrated on the lunar nearside and reflect long-lived deep thermal and compositional heterogeneity.

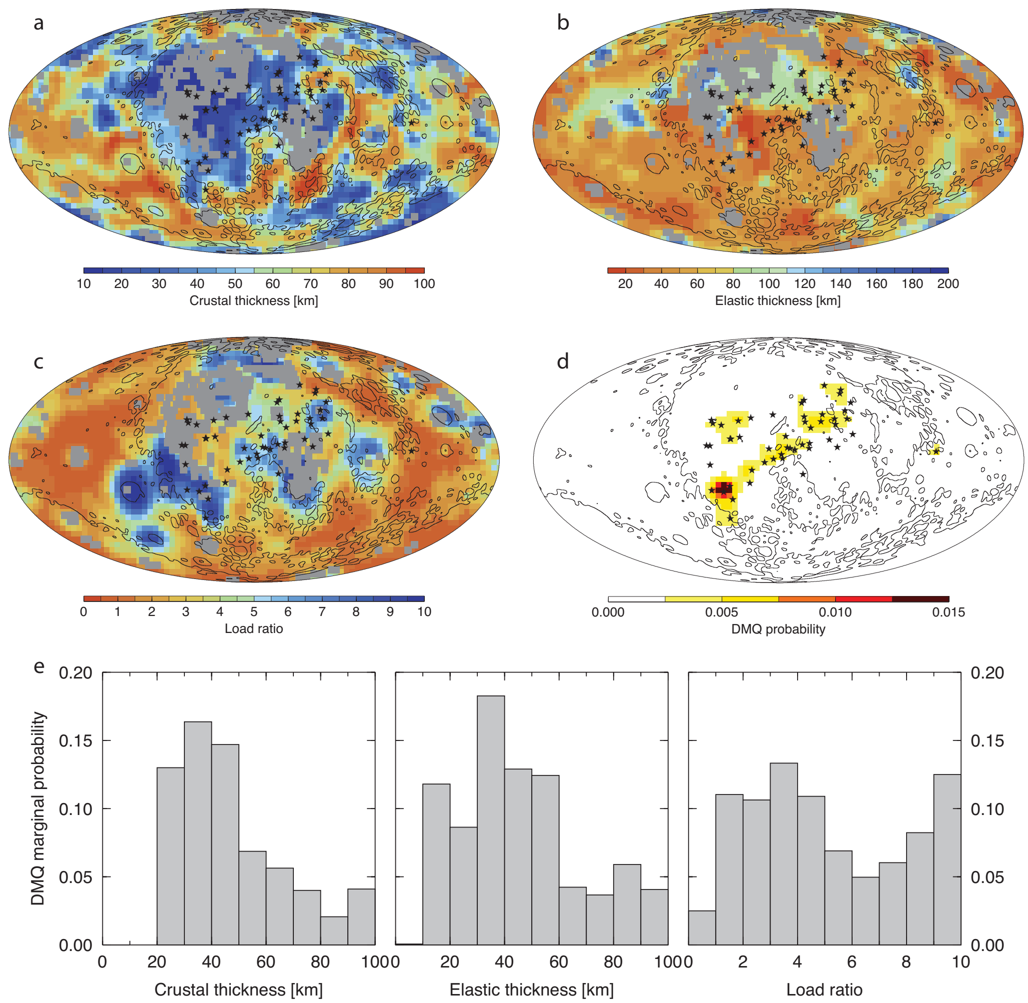

Figure 1: Preliminary results of lithospheric structure on the Moon from a joint inversion of wavelet admittance and correlation: a) crustal thickness; b) elastic thickness, and c) subsurface to surface load ratio, with deep moonquake locations shown as black stars. Black line is the zero topography contour. d) Probability distribution of deep moonquakes. e) Probability distribution of DMQ compared to distribution of a), b), and c).

References

[1] D. Lammlein, G. V. Latham, J. Dorman, Y. Nakamura, and M. Ewing. Lunar seismicity, structure and tectonics. *Rev. Geophys. Space Phys.*, 12:1–21, 1974.

[2] Y. Nakamura. A1 moonquakes: Source distribution and mechanism. In *9th Lunar Planet. Sci. Conf.*, pages 3598–3607, 1978.

[3] T. R. Watters and C. L. Johnson. Lunar Tectonics. In T. R. Watters and R. A. Schultz, editors, *Planetary Tectonics*. Cambridge University Press, 2010.

[4] M. A. Wieczorek. Gravity and topography of the terrestrial planets. In G. Schubert, editor, *Crust and Lithosphere Dynamics*, volume 6 of *Treatise on Geophysics*, pages 165–206. Elsevier, Amsterdam, The Netherlands, 2007.

[5] P. Audet. Directional wavelet analysis on the sphere: Application to gravity and topography of the terrestrial planets. *J. Geophys. Res.*, in press:doi:10.1029/2010JE003710, 2011.

[6] Y. Nakamura. Farside deep moonquakes and deep interior of the Moon. *J. Geophsy. Res.*, 110:E01001, doi:10.1029/2004JE002332, 2005.

[7] A. C. Muirhead and S. Zhong. Spatial correlation of deep moonquakes and Mare basalts and implications for lunar present-day mantle structure, magmatism and thermal evolution. In *Fall Meeting*. American Geophysical Union, 2010.