**RECENT ADVANCES IN LUNAR SEISMOLOGY.** A. Khan, P. Lognonné, J. Gagnepain-Beyneix, H. Chenet, *Département de Géophysique Spatiale et Planétaire, Institut de Physique du Globe de Paris, France (khan@ipgp.jussieu.fr)*, and K. Mosegaard, *Dept. of Geophysics, Niels Bohr Institute, University of Copenhagen, Denmark.*

**Introduction:** The most detailed knowledge that we have on the interior structure so far concerning planetary bodies besides the Earth is the Moon. The Apollo seismic data have provided us with a unique opportunity to elucidate the internal structure of the Moon. The primary data set employed here are the Apollo seismic data which were obtained in the period from 1969 to 1972 when the US Apollo missions landed seismographs on the lunar surface.

The Apollo-era saw a great effort in trying to obtain information on the internal structure of the Moon from the seismic data concentrated mainly around two groups (Galveston and MIT). Lunar seismology has recently undergone a renaissance with a number reanalyses of the Apollo lunar seismic data set given new modern techniques and far greater computer capability [e.g. 1, 2, 3, 4]. Global average 1D seismic velocity models have principally been constructed from the primary data set which constitutes first $P$ and $S$-wave arrivals from a number of distinct events including, of external origin, artificial and meteoroid impacts and of internal origin, shallow and deep moonquakes. While more than 12000 events have been recorded in the 8-year period that the experiment was underway [5] only 81 events were deemed suitable for inversion in the last Apollo-era study [6]. The intricate nature of the seismic data has since the first recordings proven somewhat of a stumbling-block in erecting detailed models of the internal structure of the Moon.

The Apollo-era seismic studies concentrated mainly on the use of linearised methods in dealing with the inverse problem, thereby obviating the analysis of resolution and uncertainty which are important items when having to infer scientific conclusions from inverse calculations. Generally these studies [e.g. 7, 8, 9, 10] were successful in determining the gross features of the lunar interior with details remaining perfunctory. Recent investigations [1, 2] using the same data set as Nakamura [6] as well as employing a much more adequate inverse Monte Carlo sampling scheme in having to deal with the non-linear inverse problem of estimating structural parameters from a set of arrival times, has resulted in the enhancement of some details. However, with the given data set a truely detailed lunar velocity structure remains at present outside our reach.

Recent investigations have not only been limited to applying more adequate inversion methods to the lunar problem, but have also focussed on the data set itself, that is, the particular problem of picking arrivals as well as assessing the uncertainty on each pick [4]. Studies conducted during the 70s and early 80s considered all arrivals time readings equally uncertain. This has the unfortunate consequence of confering equal weight to all data points. Good as well as bad arrivals are thus equally probable leading to inconsistencies as was shown in [2].

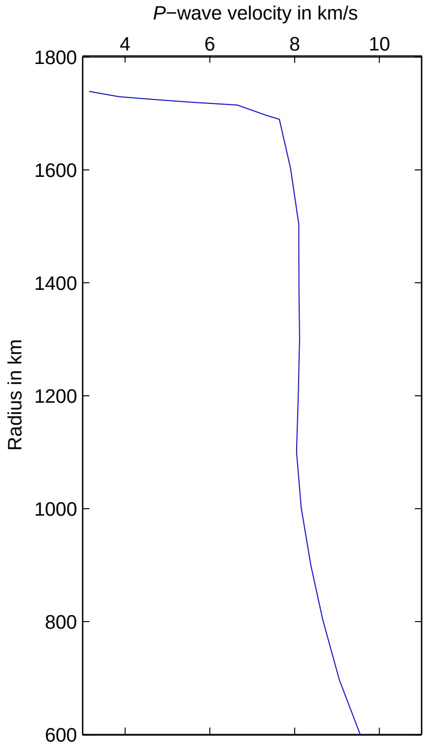
The purpose of the present study is twofold. On the one hand we want to present results from a Monte Carlo inversion of a slightly different set of arrival times obtained by Lognonné et al. [4] (henceforth abbreviated IPGP data set) through a complete reanalysis of the entire Apollo lunar seismic data. On the other hand we want to discuss the differences among the two data sets, since the IPGP data set consists of 59 events of which 8 are artificial impacts, 19 meteoroid impacts, 8 shallow moonquakes and 24 from deep moonquakes, whereas the Nakamura data set consists of 7 artificial impacts, 18 meteoroid impacts, 14 shallow moonquakes and 41 deep moonquakes. The significance of this difference as well as its implication for the inversion will also be discussed.

**Method of Analysis:** Structural parameters determined from arrival times are typically the seismic wave velocities, $v_p$ and $v_s$ (pressure and shear, respectively). Since no general physical laws governing their relation can be set up, constraints are difficult to impose in case of simultaneous inversion. However, if we go one step deeper and resort to the elastic moduli and density as parameters, the relation between $v_p$ and $v_s$ becomes immediately apparent through the well-known equations

$$v_p = \sqrt{\frac{\kappa + 4\mu/3}{\rho}}, \qquad v_s = \sqrt{\frac{\mu}{\rho}}.$$

The structural parameters that we want to determine, given a number of prior assumptions, are thus $\kappa$, $\mu$ and $\rho$, these being bulk and shear modulus and density, respectively. Since the density structure is to be sampled we also add lunar mass and moment of inertia as determined by Lunar Prospector [11] as data points. The methodics underlying the Monte Carlo inversion are detailed elsewhere [2]. Briefly, the framework needed to formalise the inverse problem involves the use of probability density functions ($pdf$'s) to represent every single state of information in the problem [12, 13]. The outcome, given by the posterior $pdf$, is obtained by combining all available information. Samples from this posterior $pdf$ are then obtained by employing a Markov chain Monte Carlo method (MCMC) [e.g. 14].

**Results:** Figure 1 below depicts a single realisation of the seismic $P$ and $S$-wave velocities constructed using a sample of $\mu$, $\kappa$ and $\rho$ and the above equations. It should be noted that the figure only depicts long wavelength features of this particular realisation which satisfies data within uncertainties. All exploratory models are indicative of shallow crusts, with thicknesses lying more in the range of the Khan et al. value [1] than the Toksöz et al. value [8]. Velocity variations in the mantle are also palpable although less pronounced than those found in [2].



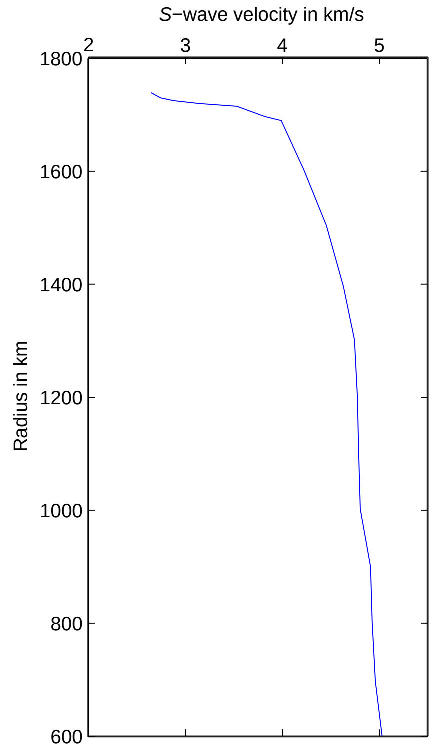




Figure 1: A sample from the posterior distribution showing a $P$ and $S$-wave velocity model. Note that only long wavelength features are shown. The central-most region is not shown given that no rays penetrate to this depth thereby not constraining it.

**References:** [1] Khan et al., GRL, 27, 1591, 2000. [2] Khan & Mosegaard, JGR, 107 (E6), 2002. [3] Chenet et al., LPSC XXXIII, abstract #1684, 2002. [4] Lognonné et al., EPSL, submitted 2002. [5] Nakamura et al., PEPI, 21, 218, 1980. [6] Nakamura, JGR, 88, 677, 1983. [7] Nakamura et al., JGR, suppl. 87, A117, 1982. [8] Toksöz et al., Rev. Geophys., 12, 539, 1974. [9] Nakamura et al., JGR, 81, 4818, 1976. [10] Goins et al., JGR, 86, 5061, 1981. [11] Konopliv et al., Science, 281, 1476, 1998. [12] Tarantola & Valette, J. Geophys., 50, 159, 1982. [13] Tarantola, Inverse Problem Theory, Elsevier, 1987. [14] Mosegaard & Tarantola, JGR., 100, 12431, 1995.