The Lunar Seismic Network: Mission Update. C. R. Neal[1], W.B. Banerdt[2], H. Chenet[3], J.Gagnepain-Beyneix[3], L. Hood[4], B. Jolliff[5], A. Khan[3], D. J. Lawrence[6], P. Lognonné[3], S. Mackwell[7], W. Mendell[8], K. Miller[9], Y. Nakamura[10], H.H. Schmitt[11], C.K. Shearer[10], M. Wieczorek[3], [1]Dept. of Civil Engineering & Geological Sciences, University of Notre Dame, Notre Dame, IN 46556, USA (neal.1@nd.edu). [2]Jet Propulsion Laboratory, Pasadena, CA 91109. [3]Institut de Physique du Globe de Paris, UMR7096-CNRS-IGP-Université Paris 7. [4]Lunar & Planetary Lab, University of Arizona. [5]Dept. Earth Planet. Sci., Washington University, St. Louis, MO. [6]Los Alamos National Laboratory, Group NIS-1, MS-D466, Los Alamos, NM 87545. [7]LPI, Houston, TX 77058. [8]NASA-JSC, Houston, TX. [9]Ball Aerospace & Technologies, Inc., Boulder, CO. [10]Institute for Geophysics, UT-Austin, TX 78759. [11]Dept. of Aerospace Eng., Univ. Wisconsin, Madison WI.

Introduction: At LPSC 34, the concept of a new mission to the Moon to deploy a seismic network was presented [1]. Since that time, a group has been formed to further develop this idea with the goal of putting together a Discovery-type mission, which would build upon the Japanese LUNAR-A mission [2-5] by deploying 8-10 seismometers around the Moon. This would give a much greater coverage, including the lunar farside, than was the case during Apollo.

The Apollo Passive Seismic Experiment: The Apollo Passive Seismic Experiment (PSE) placed 5 highly sensitive seismometers on the Moon, 4 of which operated until the end of September 1977. Each seismometer weighed 11.5 kg and was 23 cm in diameter and 29 cm high [6]. Each seismometer contained 3 long-period (LP) seismometers with resonant periods of 2 seconds (aligned orthogonally to measure surface motions in 3 dimensions) and a single-axis, short period seismometer sensitive to vertical motion at higher frequencies. The frequency response of the LP instruments could be set to a flat-response mode or a peaked-response mode [7]. However, due to LP noise in the flat mode and to the very low amplitude of the deep moonquakes, the LP seismometer was mainly used in peaked mode, due to an increased sensitivity reaching about $0.5\ 10^{-10}$ m at 0.45 Hz. In consequence, the recorded data have practically a small frequency bandwith, making impossible all data processing and modeling techniques developed in modern broadband seismology. Each unit sat on a "mounting stool" to raise it off the surface. A Mylar "skirt" surrounded each unit to reduce thermally induced tilts of the surrounding local surface. Leveling of the instruments was conducted by the astronauts, although leveling motors were operated from Earth to level the low-frequency sensors to within 2 seconds of arc and to reposition the units after astronaut departure.

The PSEs on Apollo 12, 14, 15, and 16 were powered by Radioisotope Thermoelectric Generators (RTGs), which allowed them to keep recording and sending data back to Earth for >5 years; these produced a power source of >70 $W_{electric}$. In an attempt to turn the Apollo seismometers back on in 1986, it was found that there was not enough operating power.

The seismic signals recorded by the PSEs were very different from those seen on Earth [8,9] in a number of characteristics, such as duration, onset, and shape of the envelope. For example, the signals from the impacting lunar modules lasted much longer than would have been the case on Earth.

The Apollo PSEs defined four categories of natural seismic events [10]: shallow moonquakes, deep moonquakes, meteorite impacts, and thermal moonquakes. Each of these moonquakes produces distinctive seismograms [10, 11] (Fig 1). Latham et al. [7] reported that deep moonquakes (~800 km) repeated in monthly cycles triggered by lunar tides. It appears that such deep events originate from distinct regions within the lunar mantle; more than 3000 deep moonquakes have been assigned to 109 separate hypocentral regions [10] and more recent work has increased this number [12] In addition to the repeated moonquakes, moonquakes swarms also occur, maybe as frequently as one every 2 hours over intervals lasting several days. A swarm was defined as 8-12 seismic events per day compared to the usual 1-2 events per day [7].

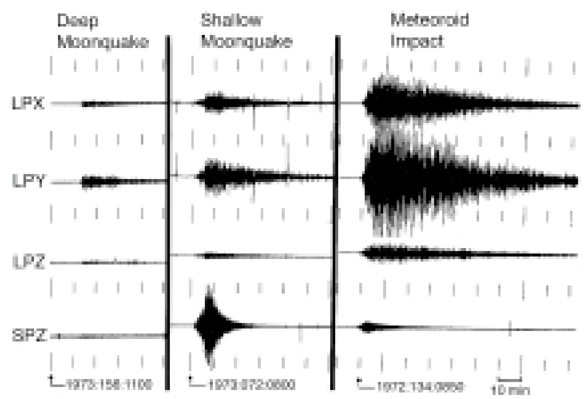

Figure 1: Representative lunar seismograms (taken from Nakamura et al. [10,11]) in compressed time. All are taken from the Apollo 16 station. LPX, LPY, and LPZ = 3 orthogonal components of a long-period instrument. SPZ = short-period vertical component. A typical thermal moonquake (not shown) would appear as a signal of very short duration only on SPZ.

What is the Need for a Lunar Seismic Network? The results of the New Views initiative have highlighted just how little we know about the nature of the lunar interior (cf. [1]). The existing Apollo seismic experiment data only provide us with clues about the interior of the Moon, primarily because the seismometers were set up in a relatively restricted area on the lunar nearside. This small seismic array "aperture" limited both the spatial sampling of seismic events (most lunar events are extremely small, and cannot be detected at a great distance) and the depth of the sampling of the interior by long-distance ray paths (Apollo seismic data provide little constraint on lunar structure and composition below ~800 km). Interpretations based on these limited data are ambiguous. For example, sample studies suggested some of the volcanic glasses may have been derived from a garnet-bearing source [13,14]. The Apollo seismic data indicated higher velocities in the middle lunar mantle (> 500 km) that have been interpreted to represent the presence of garnet [15-17], but also an increased proportion of Mg-rich olivine [18,19]. While innovative modeling approaches have refined the original data [e.g., 20-23], comprehensive and definitive interpretations of the lunar mantle remain elusive and fundamental questions regarding lunar origin, evolution, and structure remain unanswered.

Science Driving the Mission: The science drivers behind this mission as follows:

- What is the structure and thickness of the crust on the lunar near and far sides?
- Are crustal structure changes gradational or are distinct domains present?
- Is the upper lunar mantle pyroxenite (cf. [23])?
- Is garnet present in the middle and deep lunar mantle?
- Are “nests” producing periodic Moonquakes present on the far side?
- Is there a Moon-wide ~500 km discontinuity (magmasphere vs. magma ocean)?
- Are other Moon-wide or local discontinuities present within the lunar interior?
- Is there a definitive lunar core? If so, what is its size (~350 km [23,24]?) and composition (sulfide, metal, ilmenite)?
- Are the core and mantle completely solid or do “plastic zones” still persist?

The Mission Concept: In discussions over the last year, a general plan has been devised that would answer many of the scientific questions that are driving this mission. The ideal plan would be as follows:

- 8-10 seismometers deployed around the Moon (nearside and farside and at the poles and/or equatorial margins (see [1]);
- An orbiter for communications (particularly on the farside);
- A mission life of at least 5 years.

There are a number of engineering problems that are in the process of being addressed. These include:

Delivery: putting a large number of seismometers on the Moon using soft-landers would be cost-prohibitive. Penetrators, while being used on LUNAR-A to deliver seismometers that are 5 times as sensitive as those used during Apollo (albeit a limited bandwidth) [2-5], include a high degree of risk because if these hit sizeable boulders either on the surface or within the regolith, the seismometer would be seriously compromised. The delivery system we are exploring is a semi-hard landing (<20 m/s or < 200 Gs). This could be achieved by the seismometer package being “exploded upwards” off the down-facing base 20-50 meters from the lunar surface.

Seismometer Package: In order to minimize cost, the seismometers originally designed for the Mars Netlander mission [25] will be retrofitted to give the sensitivity and bandwidth required for detecting moonquakes. Each seismometer will require an autonomous leveling system that will need to be active over the life of the mission. In addition, upon landing and leveling, an insulating apron will need to be deployed in order to protect the immediate area from thermal expansion (cf. [6]). There will also be within each package a computer (for navigation during descent and for recording the seismic events), communications, and a power supply. Simple additional payloads, such as laser reflector and magnetometers will be considered.

Power Supply: Small RTGs are required to power each unit in order to meet the mission life. Mini RTGs can be produced [26] and development of an RTG that is shock-tolerant up to 500 Gs is underway [27]. The power output is only 40 mW and it is unclear at this time whether this will be sufficient.

Orbiter: This will be essential if seismometers are to be placed on the lunar farside. A communications satellite will collect and download data from each seismometer as it passes over each station. It is envisaged that the orbiter would carry a magnetometer to explore mantle conductivity down to ~100 km using the varying magnetic field impinging on the Moon. Although such a mission must remain focused, it would likely be possible to use the orbiter to carry instruments that would produce data related to the geophysical goals of this mission.

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