ALGEP: AN AUTONOMOUS LUNAR GEOPHYSICAL EXPERIMENT PACKAGE. W. B. Banerdt[1], P. Lognonné[2], and the ALGEP Science Team. [1]Jet Propulsion Laboratory (M.S. 264-422, 4800 Oak Grove Dr., Pasadena, CA 91109, bruce.banerdt@jpl.nasa.gov), [2]Institut de Physique du Globe de Paris (4 avenue de Neptune, 94107 Saint-Maur cedex, France, lognonne@ipgp.jussieu.fr).

Introduction: The geophysical exploration of the Moon, particularly its interior structure and processes, has been recognized as a high scientific priority from the time of the Apollo project planning to the present [1]. The Apollo Lunar Surface Experiments Package (ALSEP) that was deployed by the later Apollo missions was enormously successful in furthering our understanding of the Moon and its history through seismic, magnetic, and geothermal measurements. Along with lunar sample analyses, these data, now over 30 years old, still largely define our knowledge of the Moon beneath its visible surface. By modern stadards, however, this information is quite limited due both to the technology of the instrumentation available at the time and by the limited geographic extent of the Apollo landing sites (Fig. 1).

We are conducting a concept study to delineate the scientific value and define the technical feasibility of a modern follow-on to ALSEP: the Autonomous Lunar Geophysical Experiment Package (ALGEP). In principle, this package could be taken to the surface of the Moon either by a robotic mission or installed by astronauts. It comprises a comprehensive suite of geophysical instruments, with a seismometer covering both long and short period bands, a shallow seismic sounder, a magnetometer, a heat flow probe and a laser retroreflector or transponder. This package would enable the extended exploration of the lunar interior, from the upper few meters of the regolith to the core.

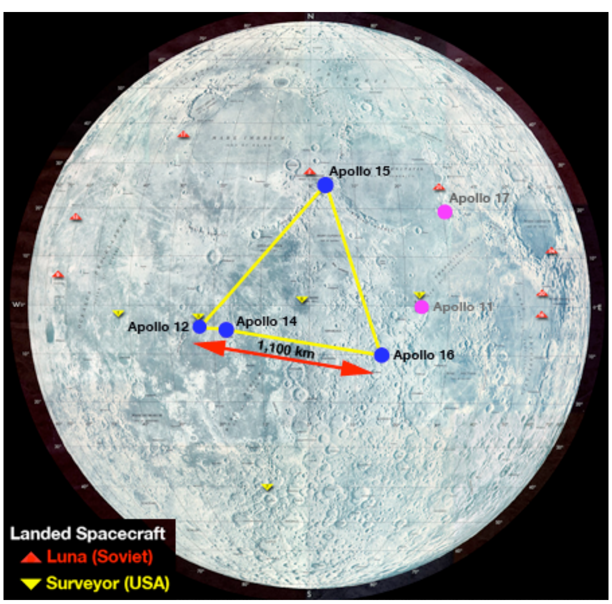

Fig.1: Apollo landing sites. ALSEP locations (blue) outline a region encompassing only a few percent of the lunar surface

Although such instruments can produce useful information from a single installation, the full value comes from a network of such stations distributed across the Moon's surface operating simultaneously for an extended period of time. Thus in order to maximize its effectiveness, ALGEP should be implemented such that it is relatively easy to include on any mission to the lunar surface and must be able to survive for an extended period (perhaps up to a decade).

Geophysical analyses typically utilize distributed data collected over the surface of a planet (e.g., seismic, magnetic, gravity, topography) to determine such properties as composition, density and temperature of the materials located in its inaccessible depths. Although all such determinations are non-unique, combining different data sets can be particularly effective in removing ambiguities. Thus the combination of geophysical measurements envisioned for ALGEP will be much more powerful than the sum of the individual investigations.

In the following sections we discuss the value of additional measurements for three of the primary measurement approaches in ALGEP: seismic, magnetic, and thermal.

Seismometer: Apollo performed two types of seismic experiments: Active and Passive. The Active Seismic Experiment (ASE) on Apollos 14 and 16 utilized arrays of three geophones, grenades and thumpers to investigate the shallow regolith structure, while another active experiment (LSPE: Lunar Surface Profiling Experiment) on Apollo 17 used an array of four geophones and explosive packages to probe shallow structure during the mission as well as to listen to high-frequency signals for an extended time after the mission. The Passive Seismic Experiment (PSE) consisted of a network of seismic stations deployed during Apollos 11, 12, 14, 15 and 16. All but the first operated until the data acquisition was terminated in 1977.

The main purpose of PSE was to investigate the Moon's natural seismic activity and to infer its internal structure. It discovered 4 classes of seismic events (thermal moonquakes, meteoroid impacts, deep moonquakes and shallow moonquakes) and provided key constraints on the composition and structure of the crust and mantle (see review in [2]).

Although the Apollo seismic experiments were highly successful and provided more information about the Moon than was anticipated, there remain several important unanswered questions:

Very deep interior. There is almost no reliable information on seismic velocities below ~800 km. What are the physical properties of the very deep interior of the Moon, in particular the lower mantle and core? Is there compositional layering in the lower mantle? What is the size, state and composition of the core?

Lateral heterogeneity. How do crustal and mantle structures vary from one region to another? Is there any correlation with surface compositional heterogeneity (e.g., PKT)?

Deep moonquakes. What is the mechanism of deep moonquakes? How are they distributed globally (we only have data for the front side), and what does this distribution mean in terms of lower mantle structure?

Shallow moonquakes. What causes shallow moonquakes? How deep are they? Do they pose any risk to future lunar bases?

Magnetometer: Electromagnetic subsurface sounding uses natural geophysical signals (such as are generated by the passage of the Moon through the Earth's magnetotail) to provide the sounding energy. It exploits the fact that eddy currents are generated on the surface of a conductor when it is presented with a changing magnetic field. These eddy currents shield the interior of the conductor from the primary alternating field and generate their own induction field which can be measured. The Apollo Moon landings and the accompanying orbital missions provided many opportunities for studying the interior of the Moon by using electromagnetic induction [3]. These investigations placed upper limits on the size of the lunar core between 360 km [4] and 439 km [5]. No direct evidence was obtained, however, for a highly conducting core.

A high-priority question in lunar science concerns the sizes and the compositions of the lunar mantle and core. One reason for the poor knowledge of the interior of the Moon is a general lack of reliable long-term simultaneous time series of the magnetic field from multiple sites on the moon. Even though the three Apollo magnetometers were often operated simultaneously, no extended simultaneous time series of the magnetic field is available because of telemetry and other infrastructural constraints.

Recent theoretical progress in modeling planetary composition and thermal state from inversion of long-period electromagnetic sounding data [6] can be further leveraged by using data from several sites separated over global scales. The advantage of using multiple sites is that the data can be uniquely separated into internal (induction field) and external (inducing field) harmonics over multiple frequencies. New modeling techniques coupled with reliable long-duration time series from multiple sites would provide direct estimates of the chemical composition and the thermal state of the lunar interior.

Uncertainties in the inversion of magnetic and seismic data could be reduced by performing a joint inversion of the two data sets. Whereas magnetic data is sensitive to a global response from the interior of a body, seismic data are particularly sensitive to interfaces within the body. In regions where the mineralogy changes gradually or if an interface does not have large density contrast, magnetic data may be helpful in reducing the uncertainty of seismic data inversion. Similarly the magnetic modeling, which suffers from intrinsic non-uniqueness, could be more objectively inverted by using specific information from seismic data about interfaces in the interior of the Moon.

Heat Flow: The Apollo heat flow experiment measured the present day lunar heat flow, placing constraints on the bulk concentration of heat-producing elements and models of the Moon's thermal evolution. Heat-flow probes were deployed successfully at the Apollo 15 and 17 landing sites to measure the local subsurface thermal gradient and conductivity.

To derive the heat flow from the lunar interior, daily and annual signals must be removed to obtain the time-averaged temperature gradient. After removing this long-term signal, temperature gradients in the range 0.79–2.52 K m^{-1} were obtained. Using these values, the heat flow at the Apollo 15 and 17 sites was finally estimated to be 21 and 16 mW m^{-2}, respectively, with estimated uncertainties of about 15% [7,8].

In retrospect, the Apollo 15 and 17 heat flow experiments were by chance performed near the boundary of two of the most prominent geochemical provinces of the Moon: the Apollo 15 site lies within the PKT, which has elevated abundances of heat producing elements, whereas the Apollo 17 site lies in the more anorthositic Feldspathic Highlands Terrane [9].

Reliable heat flow data from the Moon, both globally and locally, will provide important input into four basic questions: What is the internal thermal and mechanical structure of the Moon? How does the Moon compare to the Earth and chondritic meteorites in its heat producing elements (U, Th, K), and what are the implications for the origin of the Moon? Are there regional variations in heat flow associated with the major geological provinces, and what are the implications for asymmetrical thermal evolution and chemical fractionation of the incompatible elements into the lunar crust? 4) Can long-term monitoring of near-surface lunar heat flow be used as a baseline to measure variations in external solar radiation at the Earth's location?

References: [1] *Scientific Context for Exploration of the Moon*, NRC, 2007; [2] Lognonné and Mosser, *Surv. Geophys.* 14, 239, 1993; [3] Sonett, *Rev. Geophys. Space Phys.* 20, 411, 1982; [4] Hood et al., *JGR* 87, 5311, 1982; [5] Russell et al., *Sci.* 186, 825, 1974; [6] *Khan et al.,* EPSL 248, 579, 2006, [7] Langseth, et al., *Earth Moon Planets* 4, 390, 1972; [8] Langseth, et al., *Proc. Lunar Sci. Conf.*, *7th*, 3143, 1976; [9] Wieczorek et al., *New Views of the Moon*, 221, 2006.