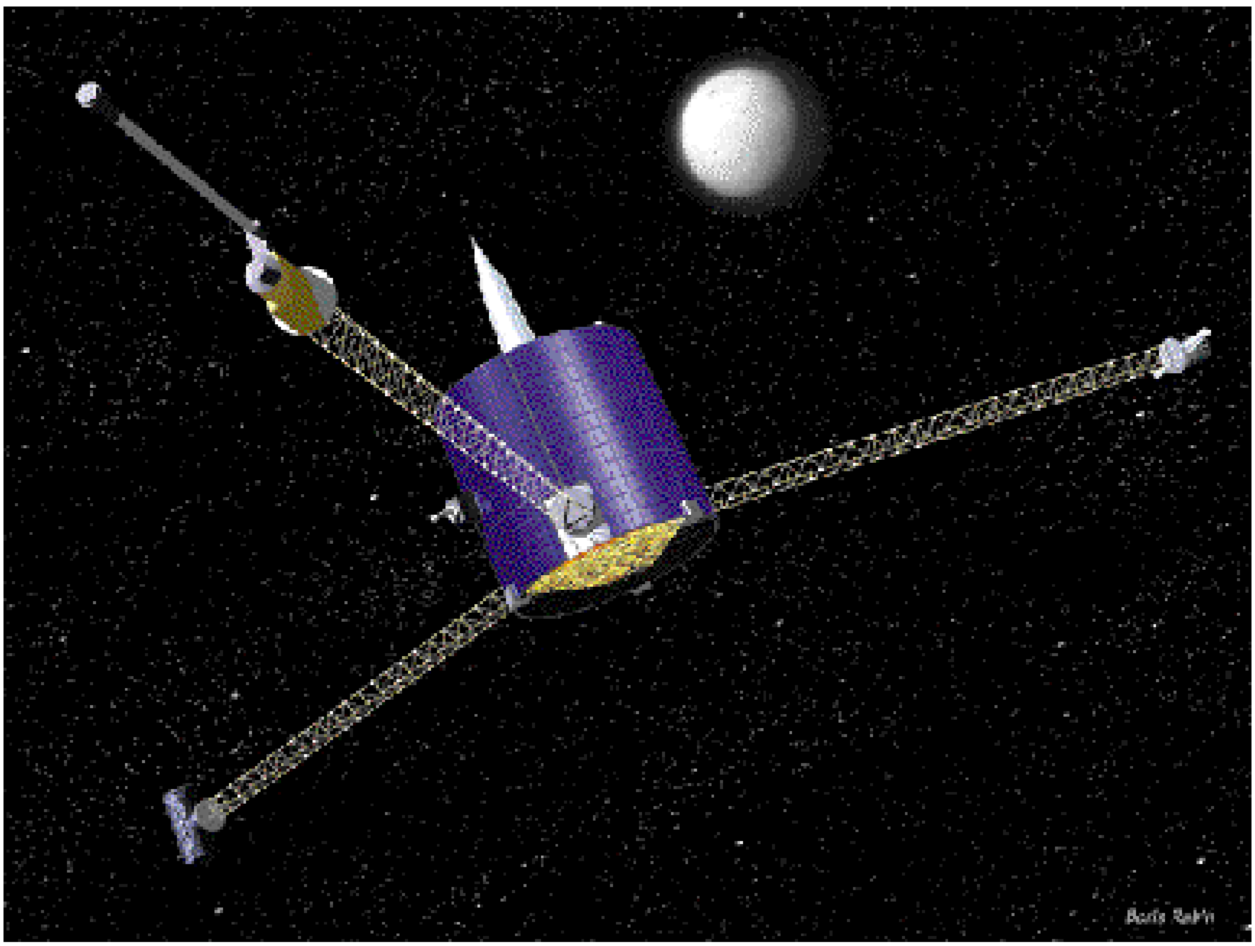
LUNAR PROSPECTOR

Science Data Return

A summary of results from the set of papers printed in the September 4, 1998 edition of *Science*, Volume 281

Press Kit

September, 1998



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Results taken from the set of science papers published in the September 4, 1998 issue of *Science*.

D. J. Lawrence, W. C. Feldman, B. L. Barraclough, A. B. Binder, R. C. Elphic, S. Maurice, and D. R. Thomsen, Global Elemental Maps of the Moon: The Lunar Prospector Gamma-Ray Spectrometer, Science, Volume 281, (1998).

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Introduction

Lunar Prospector, the first dedicated lunar mission in 25 years, has already been a tremendous success. Following a near flawless launch on Jan 6, 1998, a four-day journey to the Moon and entry into lunar orbit, the tiny spin-stabilized spacecraft has been sending data back to Earth. Lunar data from the circular polar-mapping orbit has been arriving since January 15.

On March 5, 1998 Prospector scientists captured the public's imagination by announcing the discovery of a definitive signal for water ice at both of the lunar poles. At that time, a conservative analysis of the available data indicated that a significant quantity of water ice, possibly as much as 300 million metric tons, was mixed into the regolith (lunar soil) at each pole, with a greater quantity existing at the north pole. The first competitively selected Discovery class mission had conclusively demonstrated that, not only could a cost-capped, fast-development mission succeed, it could do ground-breaking science in the process.

The first operational gravity map of the Moon was announced at the same time. Since then, Lunar Prospector engineer's have taken advantage of the missions own science results and the gravity data have been used to facilitate orbit maintenance.

With nearly two thirds of Prospector's one-year primary mission completed, the most recent look at Prospector's data reveals several remarkable insights into lunar science and resources.

Mission Profile

At 9:28 p.m. (EST) on January 6, 1998, Lunar Prospector (LP) blasted off to the Moon aboard a Lockheed Martin solid-fuel, three-stage rocket called Athena II. It was successfully on its way to the Moon for a one-year, polar orbit, primary mission dedicated to globally mapping lunar resources, gravity, and magnetic fields, and even outgassing events. About 13 minutes after launch, the Athena II placed the Lunar Prospector payload into a "parking orbit" 115 miles above the Earth. Following a 42-minute coast in the parking orbit, Prospector's Trans Lunar Injection (TLI) stage successfully completed a 64-second burn, releasing the spacecraft from Earth orbit and setting it on course to the Moon, a 105-hour coast. The official mission timeline began when the spacecraft switched on 56 minutes, 30 seconds after liftoff. Shortly after turning the vehicle on, mission controllers deployed the spacecraft's three extendible masts, or booms. Finally, the spacecraft's five instruments -- the gamma-ray spectrometer, alpha particle spectrometer, neutron spectrometer, magnetometer and electron reflectometer -- were turned on. On Sunday, January 11, at 7:20 a.m. (EST), Lunar Prospector was successfully captured into lunar orbit, and a few days later began its mission to globally map the Moon.

Lunar Prospector is a small,* spin-stabilized spacecraft in a polar orbit with a period of 118 minutes at a nominal altitude of 100 km (63 miles). Since the Moon rotates a full turn beneath the spacecraft every lunar cycle (~27.3 days) as it zips around the Moon every 2 hours, Prospector visits a polar region every hour and completely covers the lunar surface twice a month. Prospector's one-year-long primary mission with an optional extended mission of a further 6 months at an even lower altitude enables large amounts of data to collect over time. For some science instruments, a significant amount of time is required to obtain high quality usable data. Thus, Prospector's polar orbit and long-mission time render it ideal from the standpoint of globally mapping the Moon.

*(1.3m in diameter X 1.4m tall bus with three 2.5 meter science masts carrying its five science instruments and isolating them from the spacecraft's electronics)

Lunar Prospector Scientific Goals

As a Discovery-class mission, Prospector's scientific goals were carefully chosen to address outstanding questions of lunar science both efficiently and effectively. In the Post-Apollo era, NASA convened the Lunar Exploration Science Working Group (LExSWG) to draft a list of the most pressing, unanswered scientific riddles still facing the lunar-science community. In 1992, LExSWG produced a document, entitled "A Planetary Science Strategy for the Moon." The following lunar science objectives were listed: How did the Earth-Moon system form? How did the Moon evolve? What is the impact history of the Moon's crust? What constitutes the lunar atmosphere? What can the Moon tell us about the history of the Sun and other planets in the Solar System?

Lunar Prospector mission designers carefully selected a set of objectives and a payload of scientific instruments which would address as many of LExSWG's priorities as possible, while remaining within the tight budget confines of NASA's "faster, better, cheaper" Discovery Program.

Lunar Prospector's identified critical science objectives are:

- ⇒ "Prospect" the lunar crust and atmosphere for potential resources, including minerals, water ice and certain gases,
- ⇒ Map the Moon's gravitational and magnetic fields, and
- ⇒ Learn more about the size and content of the Moon's core.

The six experiments (five science instruments) which address these objectives are:

- ♦ Neutron Spectrometer (NS) --Map hydrogen at several signature energies and thereby infer the presence or absence of water.
- ♦ Gamma Ray Spectrometer (GRS) -- Map 10 key elemental abundances, several of which offer clues to lunar formation and evolution.
- ♦ Magnetometer/Electron Reflectometer (Mag/ER) -- These two experiments combine to measure lunar magnetic field strength at the surface and at the altitude of the spacecraft and thereby greatly enhance understanding of lunar magnetic anomalies.
- ♦ Doppler Gravity Experiment (DGE) -- Make an operational gravity map of the Moon for use by future missions as well as LP by mapping gravity field measurements from changes in the spacecraft's orbital speed and position.
- ♦ Alpha Particle Spectrometer (APS) -- Map out-gassing events by detecting Radon gas (current outgassing events) and Polonium (tracer of recent, i.e. 50 years).

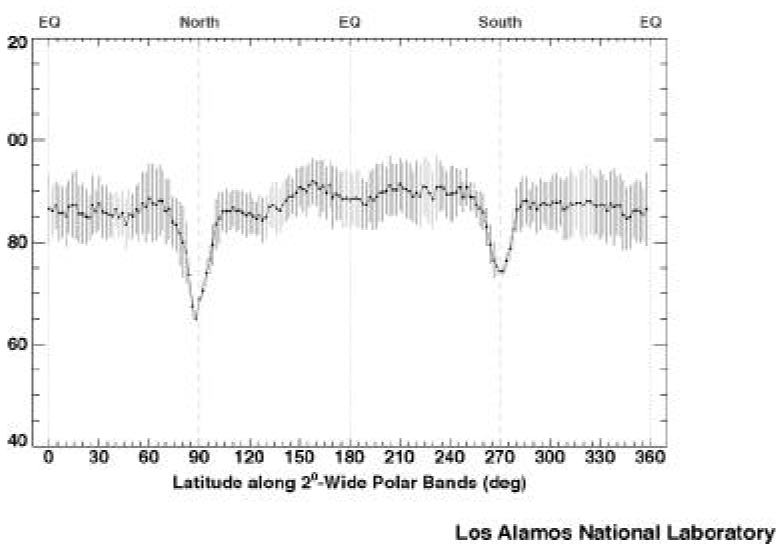
Summary of Scientific Results to Date

Since early results were reported in March of 1998, scientists have continued to collect and process data from the spacecraft which continues to perform flawlessly. Based on the first five months of data processed to date out of a total planned mission duration of 18 months, LP scientists have been able to fill in more detail concerning previously reported results as well as announce exciting new findings.

Neutron Spectrometer Experiment Results:

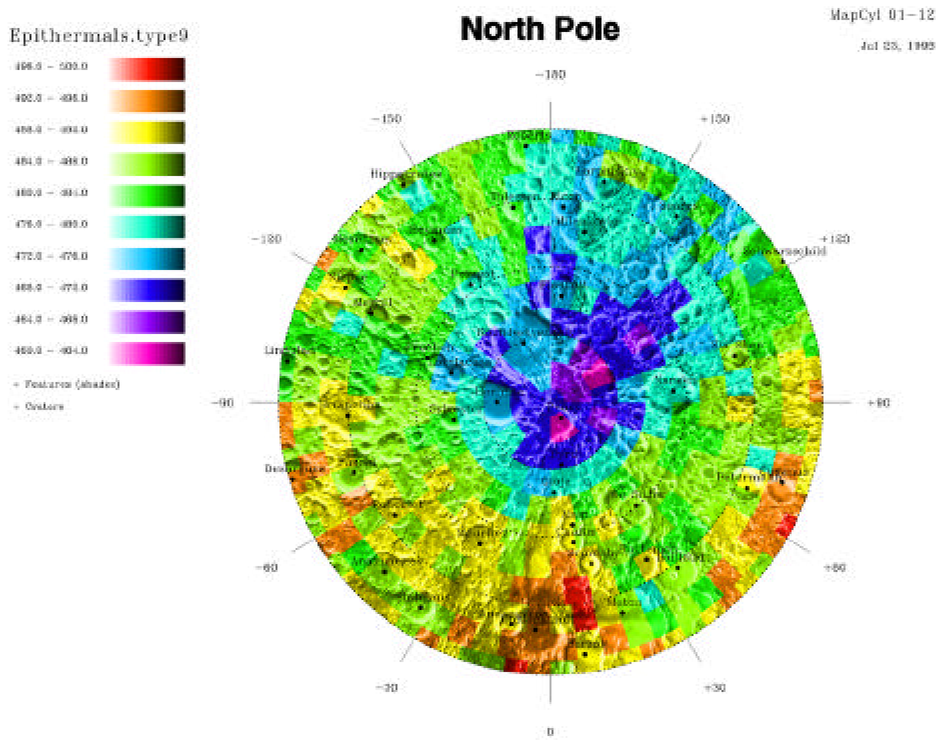
As reported at the March 5, 1998 press conference, based upon telltale dips in the epithermal neutron energy spectra sent back to Earth by Prospector's NS, mission scientists estimated that there might be 10 to 300 million metric tons of water ice (2.6 to 26 billion gallons) buried in permanently shadowed craters at the lunar poles. It was stated that the range could possibly be as much as an order of magnitude (factor of 10) too high or too low, because of the fact that Lunar Prospector was the very first interplanetary mission to use neutron spectroscopy to detect water, and thus there existed no precise models describing exactly how neutrons on the lunar surface behave. Further extensive analysis of the NS's reams of data -- with the help of newly constructed computer algorithms -- have allowed scientists to advance the accuracy of their estimates of the amount of water buried in the lunar polar regions. Specifically, the latest findings of the Neutron Spectrometer experiment include:

⇒ A ten-fold increase in the detected amount of water ice at the poles than previously reported. That is, current estimates are 3 billion metric tons of water ice at each pole. The earlier, conscientiously conservative, estimates were based on the detected dips in medium energy (epithermal) neutrons at the two polar regions. These dips of 4.6% for the North pole and 3% for the South pole, remain essentially unchanged. The additional accuracy comes from an analysis of "fast" neutron data which indicates "confined," that is discrete, deposits of pure water ice buried beneath roughly 50 cm of dry regolith.



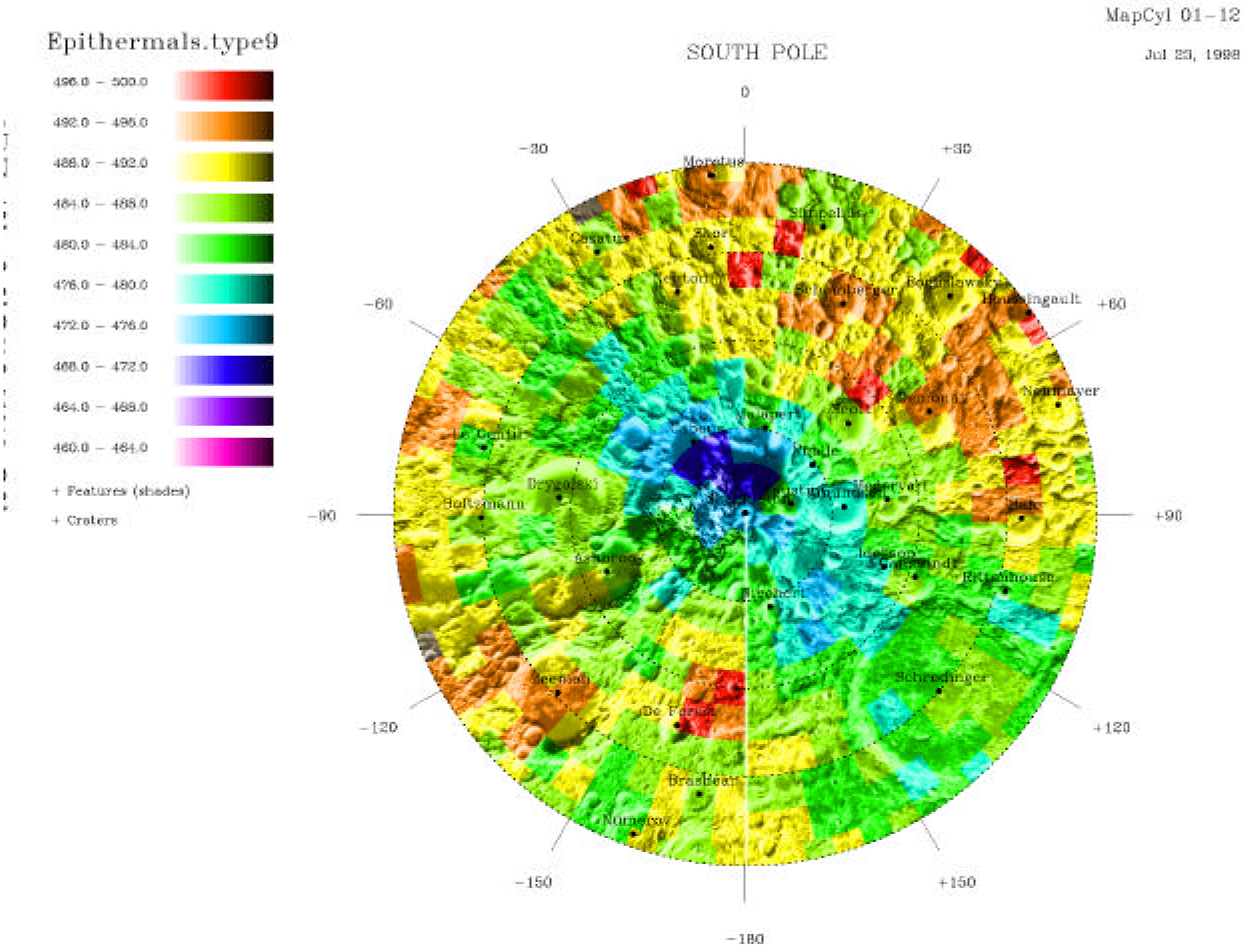
Medium energy neutron counts (LP data) showing the two polar dips which indicate water ice.

A glance at the current neutron data map clearly reveals the increasing definition of the target areas --- the likely water deposits. The North pole region, in particular, shows evidence of water deposits in permanently shadowed craters.



LP Neutron Spectrometer data from the north pole showing evidence of water ice (dark blue to magenta)

The NS instrument aboard Lunar Prospector can detect water (actually, hydrogen) to a depth of a half-meter (a foot and a half). However, since the lunar soil has been effectively "gardened" to a depth of two meters (six and a half feet) by meteoritic impacts over the past two billion years, the water could theoretically be present to that depth (two meters). If the water is in the form of ice crystals mixed with the regolith, pure water-ice deposits could potentially exist at much greater depths. Lunar Prospector scientists are still determining exactly how many craters at the North and South poles contain the millions of tons of water ice measured by the neutron spectrometer. Further data analyses, as well as data from another of Prospector's instruments, the gamma ray spectrometer, will help mission scientists sort out the precise distribution of lunar ice. The most informative data is expected to be gleaned in just under a year, when the spacecraft begins its extended mission and dips down into a very low orbit of approximately six miles (10 kilometers) above the lunar surface. At this altitude, Prospector's instruments will be able to gather extremely high resolution data.



LP Neutron Spectrometer data from the south pole showing evidence of water ice (dark blue to purple)

Gamma-Ray Spectrometer Experiment Results:

Lunar Prospector's gamma-ray spectrometer (GRS) is mapping the abundances of ten elements on the Moon's surface:

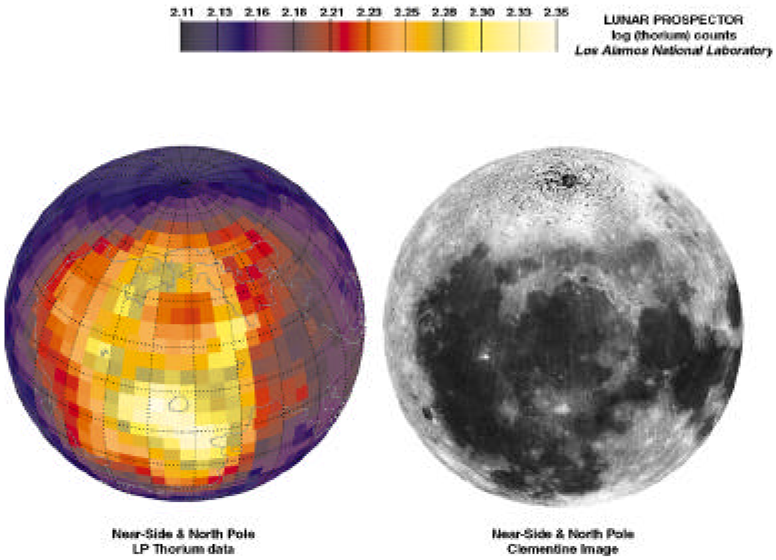
thorium (Th)
potassium (K)
uranium (U)
iron (Fe)
oxygen (O)
silicon (Si)
aluminum (Al)
calcium (Ca)
magnesium (Mg)
titanium (Ti)

The GRS is especially sensitive to the heavy, radioactive element thorium and the light element potassium. These are particularly plentiful in the last part of the crust to solidify. Thus, mission scientists are able to determine the global distribution of KREEP (K-potassium, Rare Earth Elements, and P-phosphorous), a chemical "tracer" of sorts which helps to tell the story of the Moon's volcanic and impact history. The data produced by the GRS are helping scientists to understand the origins of the lunar landscape, and may also tell future explorers where to find useful metals like aluminum and titanium. Specific results of this experiment include:

⇒ The Lunar Prospector Gamma-Ray Spectrometer (GRS) has acquired the first global measurements of gamma-ray spectra from the lunar surface. Since gamma-rays coming from the lunar surface carry information about lunar elemental composition, this data set comprises the first direct elemental composition measurements that have been made for the entire lunar surface. Specifically, preliminary information has been gathered on the distribution of key elements, including Iron and Titanium, along with trace elements associated with lunar KREEP (K-potassium, Rare Earth Elements, and P-phosphorous) material. The global distribution of three major lunar rock types (mare basalts, noritic rocks, and anorthositic rocks) has been compiled.

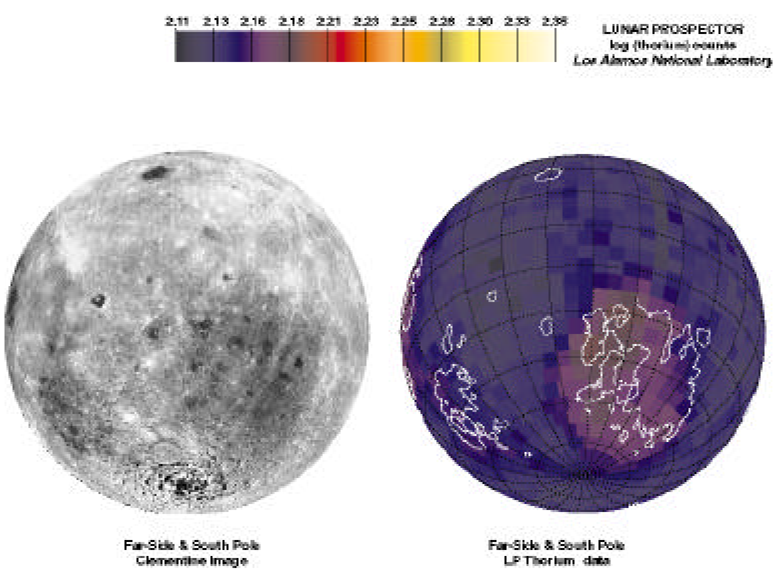
⇒ This global mapping has provided further insight into the mechanisms underlying the distribution of various elements about the Moon --- in particular the excavation and deposition of KREEP via lunar impact events.

It has long been known that a full understanding of the surface elemental composition of the Moon will significantly improve our understanding of lunar formation and evolution. For example, one long-standing issue of lunar formation that can be addressed with global composition data concerns the elements aluminum, uranium, thorium (refractory elements) and iron oxide content of the Moon. There are suggestions from Apollo, Galileo, and Clementine data that the Moon is enriched, that is has greater abundances of these refractory elements and iron oxide compared to the Earth. If the Moon indeed has such enrichments, then lunar origin models which assume that most of the Moon's material comes from the Earth's mantle (such as the giant impact hypothesis) would be incorrect. Another issue that can be addressed using composition data concerns the variability and evolution of the lunar highlands as traced by the material KREEP. KREEP, associated with thorium, is a material thought to have formed between the lunar crust-mantle boundary, so its distribution on the lunar surface can give information about how the lunar surface has evolved over time. The following two sets of images show LP thorium data side-by-side with Clementine images of the Moon's near and far sides. White outlines on the data half of the image delineate the lunar maria and highlands boundaries. The nearside LP image clearly indicates that most of the thorium is concentrated on the near-side mare in and around Mare Imbrium. In addition, while it is known from Apollo sample returns that some of the thorium south of Mare Imbrium was produced by volcanic activity, these images also appear to show that some part of the thorium was spread on the lunar surface as a result of the impact that produced the Imbrium basin.



A comparison of LP's nearside thorium data and a corresponding image of the Moon.

The far side image makes an interesting comparison to the nearside image. The South-Pole Aitken Basin, which is the largest known impact basin in the solar system, is located on lunar farside (as indicated by the dark area in the farside Clementine image). Because this basin is so big, the impact that produced it must have dug much deeper into the Moon than any of the impacts on the nearside. The LP data, however, only shows a small amount increased thorium in this area. Since the lunar crust is thicker on the farside than on the nearside, it is possible that the impact which produced the SPA basin never dug deep enough to dredge up much thorium.



A comparison of LP's farside thorium data and a corresponding image of the Moon.

In addition to mapping thorium and other elements, a number of other lunar science issues can be addressed using GRS data; these include: 1) Identifying and delineating basaltic regions in the lunar maria using maps of iron and titanium composition; 2) Determining the composition of hidden or "Cryptic" mare regions that were originally found in the lunar highlands using Clementine data; 3) Identifying and delineating highland petrological regions; and 4) Searching for anomalous areas with unusual elemental compositions that might be indicative of deposits with resource potential.

When this preliminary map is compared to data obtained by both the LP neutron spectrometer and earlier Clementine data, it is seen that all of the known regions of high-iron concentrations are identified with this LP GRS data. For example, high-iron concentrations are seen in the near-side mare, the south pole Aitken Basin, and Mare Australe. Interestingly, we also see high counts in regions not known for having high-iron content. There are indications from LP thermal neutron data that some of these discrepancies with the Clementine data may be the result of iron deposits in these regions having a mineralogical form not observable with the Clementine infrared spectra.

There also appear, however, to be regions of high-iron-count rates on the lunar farside that are not seen in either the thermal neutron data or the Clementine data. Most of this region is lunar highlands thought to be relatively high in aluminum abundance. Since the aluminum gamma-ray line (7.72 MeV) is one of the only gamma-ray lines that can produce an interference with the iron lines (7.6 MeV), this suggests that some of these high-count-rate regions may be due to high aluminum abundances. It should be stressed that this is only a preliminary conclusion. A full analysis of the entire gamma-ray spectrum needs to be completed before final conclusions can be drawn.

To summarize, the data collected by the Lunar Prospector GRS is of very high quality and contains a wealth of information about lunar composition. Yet, while the data presented here are very exciting, over half of the GRS data are yet to be collected. In addition, much work needs to be done in careful analysis of this data so that all the information it contains is fully revealed.

Magnetometer/Electron Reflectometer Experiment Results:

The MAG/ER experiment relies on a Magnetometer for measurements of the Moon's global magnetic field in space and an Electron Reflectometer for measurements of localized magnetic fields on the surface of the Moon. The ER derives information on the Moon's surface magnetic fields by analyzing electrons that emanate from the Moon. For the most part, however, such electrons can only be detected a few days each months (around full Moon periods) when the Earth passes between the Sun and Moon, thereby shielding the Moon from the constant stream of electrons generated by the Sun. Yet with only close to half of the surface magnetic field data expected over its one year nominal mission collected to date, already the following results have been observed:

⇒ Although it was previously believed that the Moon's magnetic field was too weak to repel the charged particles of the solar wind, an intriguing magnetic anomaly on the Moon's surface has been found that can stand off the solar wind, thus creating the smallest known magnetosphere, magnetosheath and bow shock system in the Solar System. While most planets' global fields create a large encompassing magnetosphere around the entire body, the Moon contains magnetized rocks on its upper layers, some of which are magnetized strongly enough to form small dipole magnetic fields scattered on the lunar surface. These mini-magnetospheres, around 100 km in diameter (the Moon is approximately 3500 km in diameter), can stand off the solar wind locally.

⇒ The presence of strong magnetic fields located diametrically opposite young large impact basins on the lunar surface have been detected. This discovery supports the theory that lunar crustal magnetization is associated with the formation of young impact basins. Two components of this model illustrate how such peculiar fields may have formed. A first component is that of an impacts' physical effects at the antipodes (or, opposite side). When large objects strike the Moon, seismic and surface waves are sent through the lunar material. This results in unusual looking terrain at the antipodes, where the rocks appear to have been temporarily fluidized and then resolidified. In addition, when ejecta from the original impacts are sent flying, secondary impacts occur where they land. Most of this ejecta lands near the periphery of the basin, but there is an increased amount found at the antipodes. The combination of the primary and secondary impacts' physical effects cause a shock, or pressure pulse, to be sent through the material of the lunar crust. Microscopic metallic iron particles in the soil carry this magnetization induced by this shock to the antipodal regions causing an increased magnetic field. A second component of the lunar impact model involves the build up of ionized gas. Impacts at velocities greater than 10 km/s will vaporize rock into hot gas, and this hot gas is partly ionized into electrons and positive ions. The ionized gas from the impact will expand around the Moon and exclude any ambient magnetic field from the ionized gas, forcing it around until it converges at the antipodes, thus compressing and amplifying the magnetic field at the antipodes.

⇒ The solar wind has been found to have non-uniformly (due to localized magnetic anomalies) implanted hydrogen in the lunar crust. Strong anomalies deflect the solar wind around local magnetic field, so we find concentrations of hydrogen around the peripheries of magnetic aberrations, but very little solar wind hydrogen is located directly at the center of these regions. Around the edges, where hydrogen exists in local concentrations, may be practical locations for possible future lunar bases.

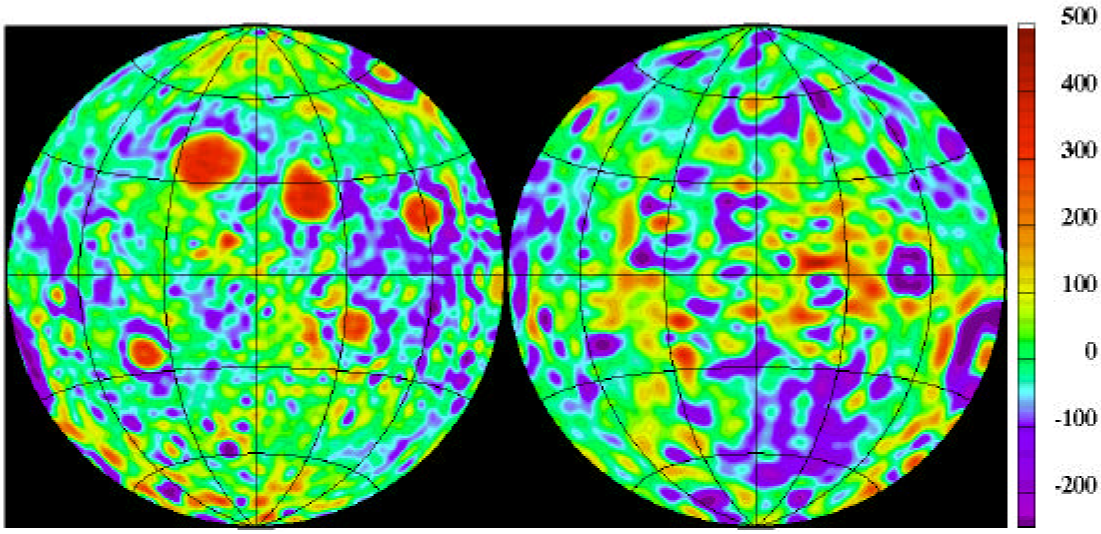
Of course, the process of completely mapping the lunar magnetic fields is still in progress, and many more questions can be addressed once the complete data set is analyzed. At that point, scientists will be able to investigate the existence of a core and more accurately determine its upper size limit. They can also determine the electrical conductivity and postulate about the composition of the core. In addition, mapping the direction of the magnetization, and therefore determining the orientation of the field lines at the time of magnetization, will help elucidate the origin of the lunar magnetic field. Another enigma waiting to be solved is the unexpected correlation between individual magnetic anomalies with unusual albedos markings in the antipodal zones -- the markings are lighter in color, and therefore higher in albedo. Answers to these and many other questions are anticipated as the mission develops.

Doppler Gravity Experiment Results:

As presented at the March 5 science return press conference, Lunar Prospector's Doppler Gravity Experiment (DGE) has provided the first low-altitude measurement of the lunar gravity field. This provided the spacecraft with the first truly operational gravity map of the Moon and immediately improved orbit control and fuel efficiency. Improved gravity information will not only help scientists build better models of the role of impact processes on the history and evolution of the Moon, but will also help in estimating the lunar core size and iron content. A more practical benefit of the new lunar gravity data provided by Prospector's DGE experiment is that a more precise gravity map of the Moon will inevitably aid future mission planners in planning fuel-efficient journeys to the Moon, and may even help identify potential resources.

The latest LP data continues to add to our knowledge of the Moon's gravity field and structure. Recent results include:

⇒ Recent measurements have revealed three new mascons ("mass concentrations") on the near side of the Moon coincident with the large impact basins Mare Humboltianum, Mendel-Rydberg, and Schiller-Zucchius. Furthermore, although there is no direct measurement of the lunar farside gravity, LP data indicate four additional new mascons in the large farside basins of Hertzsprung, Coulomb-Sarton, Freundlich-Sharonov, and Mare Moscoviense, and clearly show a central area of increased gravity in these basin centers.



Nearside **Farside**

The newest gravity map based on Lunar Prospector data

⇒ Lunar Prospector's high quality gravity data, improved by roughly a factor of five over previous estimates, indicate the existence of a lunar core, probably iron, with a radius of more than 300 km.

Such improvements to the lunar gravity field also offer the practical benefits of modeling long-term spacecraft orbits about the Moon, which allows more accurate planning of future mission fuel needs and enables the development of fuel efficient orbital maintenance strategies. LP engineers are currently relying on the improved lunar gravity model in devising strategies for maintaining LP's extremely low orbit during the extended mission phase.

Alpha-Particle Spectrometer Experiment Results:

Lunar Prospector has experienced a significant amount of solar activity which has caused an increase in the background noise that must be separated from measurements through the processing of large quantities of data. Repeating every 11 years, the solar cycle is a periodic phenomenon in which the overall extent of radiation (in the form of solar particles called protons) produced by the Sun varies in a predictable manner. A new solar cycle began in 1997, at which time sunspot activity peaked and solar radiation was at its 11-year maximum. As such, currently, there are no confirmed, analyzed results available for the APS experiment. Eventually though, scientists anticipate that with additional measurements, this intense solar noise will be subtracted out of LP’s rich data and outgassing events will be mapped.

GLOSSARY

gamma ray	a type of high-energy radiation
highlands	heavily cratered light-colored regions of the lunar surface (the Moon's oldest rocks)
KREEP	an elemental composite material (used by scientists as a chemical tracer) consisting of K-potassium, Rare Earth Elements, and P-Phosphorous
Lunar eclipse	period in which the Earth is positioned so as to obscure the Moon from sunlight
maria	smooth, dark regions of the lunar surface (the Moon's youngest rocks)
mascon	concentrations of mass on the lunar surface
outgassing	venting of gases from the lunar interior
regolith	a mixture of fine dust and rocky debris (produced by meteor impacts) covering the lunar surface
selenology	scientific study of the history of the Moon, as recorded in rocks