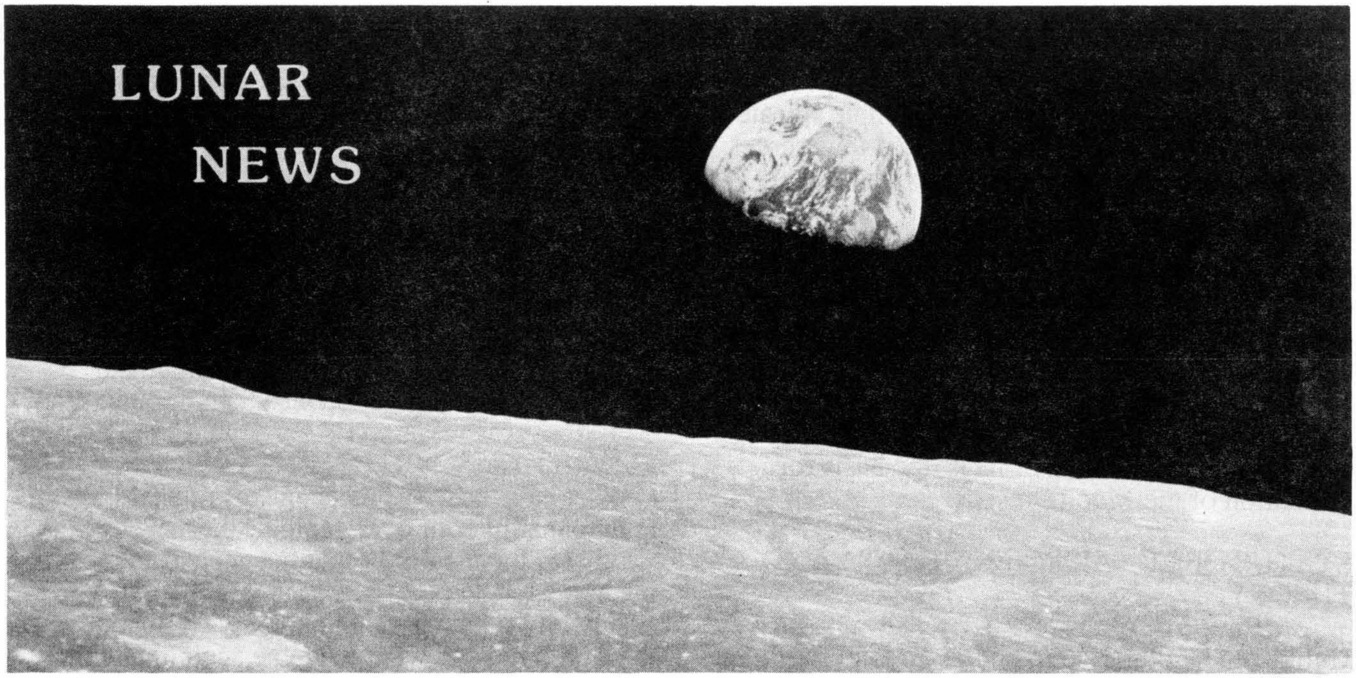


EXECUTIVE SUMMARY OF THE LGO SCIENCE WORKSHOP REPORT

Editor's note: A group of fifteen lunar scientists (Roger Phillips, chairman) met twice in 1985 at the Jet Propulsion Laboratory to consider the scientific objectives and potential contributions of an Observer class mission to the Moon. Their report, "Contributions of a Lunar Geoscience Observer Mission to Fundamental Questions in Lunar Science," is now available. Below, the Executive Summary of this report is reprinted.

THE IMPORTANCE OF LUNAR SCIENCE

The Moon is the keystone in the interlinked knowledge that forms the foundation of our understanding of the silicate bodies of the solar system. The Moon is remarkable in that it remains the only other planet for which we have samples of known spatial context. Basic considerations are:

Planetary Crusts:

• The concept of primary differentiation of planetary crusts was established by lunar studies, and this has become the framework for studying the evolution of all planetary crusts and establishes crustal recycling (as on Earth) as an exceptional phenomenon.

Planetary Surface Ages and Bombardment Histories:

• The Moon, because we have samples of its crust, serves as the basis for age estimation by crater statistics of all other crustal surfaces in the solar system, save Earth.

Record of Exogenic Processes:

• Because its igneous differentiation was relatively rapid, the Moon formed a solid crust that retains a record of events that occurred early in solar system history.

• The Moon has recorded more than 4 billion years of exogenic processes in the solar system.

LUNAR NEWS NO. 46 SPRING 1986

CONTENTS:

Baseline Silicate Planet:
• The Moon represents a relatively simple silicate system in terms of differentiation, and thus serves as a baseline to study more complex planetary processes.

Key to Early Earth History:
• The origin and early evolution of the Earth is inextricably tied to lunar genesis.

Utilization of Moon:
• An understanding of the structure and composition of the lunar crust is the basis for utilization of the Moon's resources.

STATUS OF LUNAR SCIENCE DATA AND THEORY

Unlike other solar system bodies beyond Earth, the moon has been intensely studied by telescope, unmanned spacecraft and manned missions. Most of the lunar missions however were very early in the history of space science and led to later technical advancements that have been used to explore other planets including the Earth. Both the data quality and coverage of the Moon from orbit for example are less complete than Mars for some primary data sets, such as imaging. Nevertheless, the availability of returned rock samples from the Moon has dramatically sharpened scientific questions about the evolution of our nearest neighbor. The returned lunar samples provide the essential geochemical and petrological basis for extrapolation of remote sensing data for the Moon as a planet. Because of the knowledge gained over the last twenty years, we are able to pose a set of interrelated and sophisticated questions of planetary origin and evolution that are fundamental in nature and to which a global remote sensing survey of the Moon promises to contribute significant answers.

FUNDAMENTAL QUESTIONS IN LUNAR SCIENCE

Understanding the Moon's structure, composition and history will permit us to obtain a much better appreciation of fundamental processes that operate on all planets. Some of the major problems in lunar science are:

Origin:
• What is the origin of the Moon and how does it relate to the origin and early evolution of the Earth?

Differentiation:
• Was there a global magma ocean or was the crust formed by serial igneous intrusion?
• What was the volume fraction of primordial lunar melting?
• What is the composition and structure of the mantle?
• Is there an iron-rich lunar core?

Magmatic History:
• What were the nature and style of highland igneous activity and mare volcanism through time?

Thermal History:
• What have been the mechanisms of heat transfer in the lunar interior over geological time?
• What is the history of magma genesis in the mantle?
• How did lithospheric thickness vary spatially and through time, and what were the accompanying tectonic styles at the surface?
• What are the present-day lunar temperature profile and surface heat flow?

Impact Processes:
• What was the effect of the intense lunar bombardment in obscuring primary compositional and lithological variations in the crust?
• How much of the crustal column was exposed by giant impacts and how were materials dispersed across the lunar surface?
• What are the mechanics of crater and basin formation and what is the makeup of ejecta in terms of the impacting body and the crustal target?

Paleomagnetism:
• What are the relative contributions of an internal dynamo and impact processes to the origin of lunar paleomagnetism?

Regolith:
• How do lunar soils mature?
• What is the relationship of regolith composition to that of the underlying igneous crust?

REQUIRED SCIENTIFIC CAPABILITIES OF A LUNAR GEOSCIENCE OBSERVER

The driving scientific basis of a Lunar Geoscience Observer (LGO) mission centers on questions involving the origin of the Moon and the origin and evolution of the lunar crust. At the heart of this quest is a capability to map globally the distribution of minerals and elements on a scale of five hundred meters to one hundred kilometers.

Three instruments provide this capability, the X-Ray and Gamma-Ray Spectrometers (XGRS) for elemental mapping and the Visible-Infrared Mapping Spectrometer (VIMS) for mineralogical mapping. In addition, an imaging capability is required to place the geochemical data in a geological context, particularly as regards the interpretation of these results in the face of a crust heavily disturbed by impact processes. The data rate of the LGO spacecraft should not preclude the possibility of a reasonably sized imaging data set, as well as a robust set of information from VIMS. A Radar Altimeter (ALT) and a nearside Doppler tracking gravity experiment are key geophysical instruments for extrapolating the surface geochemical results throughout the whole crust. Equally important geophysically are the Magnetometer and Electron Reflectometer (MAG/ER), which are needed to determine, either by direct detection or remanent field mapping, if the Moon possesses an iron-rich core. The existence of a core directly bears on hypotheses of lunar origin. The geophysical capabilities could be extended by a Microwave Radiometer (MRAD) experiment to map surface heat flow and determine the bulk uranium content, and a Satellite Gravity System (SGS) to measure the farside gravity field.

RELATIONSHIP OF LGO TO FUNDAMENTAL LUNAR PROBLEMS

Given the set of instruments described above, LGO can contribute to lunar science in several ways.

Lunar Origin:

Global compositional estimates principally from the XGRS, and possibly from the MRAD, should eliminate some hypotheses while remaining permissive of others.

The MAG and ER instruments should provide limits on the radius of a metallic lunar core which, if detected, may be used in concert with depletions of siderophile elements in the lunar mantle to constrain hypotheses of lunar origin.

Evolution of the Crust and Mantle:

Global geochemical and petrological maps from XGRS and VIMS, coupled with gravity data and topography from ALT should provide (i) evidence for the existence, extent, depth, and differentiation products of a global magma ocean; and (ii) estimates of crustal thickness and density variations.

Magmatic History of the Moon:

Global geochemical and petrological maps from XGRS and VIMS should permit identification of the regional extent of known and unknown rock types and provide insight into (i) the nature and duration of highland igneous activity; and (ii) the nature and extent of mare volcanism.

Impact Processes:

Imaging, XGRS, VIMS, ALT and gravity data will enable studies of crater and basin structure, morphology, and composition of deposits. Specifically, these data can be used to reconstruct: (i) pre-impact target composition and structure; (ii) formational conditions and dimensions of the excavation cavity; and (iii) post-impact ejecta deposition and modification.

Thermal History:

The MRAD instrument should provide estimates of the present day surface heat flow. High resolution imaging

"Lunar News" is produced three times a year by the Planetary Materials Branch of the Solar System Exploration Division, Johnson Space Center of the National Aeronautics and Space Administration. "Lunar News" is intended to be a forum for discussion of facts and opinions regarding lunar sample study, Lunar Geochemical Orbiter and Lunar Base activities. It is sent free to a mailing list of more than 700 individuals; to be included on the mailing list, write to the address below. Your contributions to "Lunar News" on topics relating to the study, exploration and utilization of the Moon and comments about "Lunar News" and material appearing in it should be sent to:

Doug Blanchard, Lunar Sample Curator
Code SN2, NASA JSC
Houston, TX 77058

of tectonic features associated with lithospheric loading, and improved global topography from the ALT instrument and improved gravity data should permit investigation of variations in lunar lithospheric thickness. Together these observations may be used to infer lunar thermal history.

Lunar Paleomagnetism:

A combination of the MAG and ER instruments should measure the orientation of regional surface magnetic fields as a function of age. The measurements will help distinguish whether an intrinsic magnetic field, an external source, or both, were responsible for lunar paleomagnetism.

Regolith Studies:

Imaging, XGRS, and VIMS will establish the distribution and the composition of the lunar regolith as well as identifying new rock types, and should provide insight into the processes occurring during regolith formation, and the relationship of regolith to underlying bedrock.

LGO IN RESOURCE EXPLORATION AND LUNAR BASE SITE SELECTION

The remote sensing instruments on LGO are ideally suited for resource exploration and discovery, and lunar base site selection. Examples of known and potential lunar resources are:

- High concentrations of titanium and of iron in certain basalt flows.
- High concentrations of aluminum that would occur in the major expanses of nearly pure anorthosite.
- The possible existence of ore bodies, e.g., chromium in layered magnesium-suite intrusions.
- Possible trapped water in permanently shaded polar craters.

In addition, the basic science results concerning the structure and composition of the lunar crust will lead to models of lunar ore genesis, which should greatly aid in the search for new mineral deposits. LGO will aid in lunar base site selection by mapping site geology, topography, resources and potential safety hazards.

CONCLUSIONS OF THE EXECUTIVE SUMMARY

Because of the well-studied lunar samples, it is clear that our current understanding of the Moon is at a more advanced state than that for any other body in the solar system, save Earth. Continued study of the Moon at this time is compelling because we know the right questions to ask and LGO is extremely well matched to providing some of the important answers.

The Moon is the centerpiece for the study of all silicate bodies in the solar system. The study of the Moon profoundly affects our views of the other planets. The knowledge about the Moon to be gained from the LGO mission will be immediately applicable elsewhere. We attempt to learn about processes, so we can understand better how the solar system came to be the way it is today. The Moon is the best place in the solar system to study the processes that affected the silicate bodies early in their history, and LGO promises to make substantial contributions to our understanding of the Moon. As the world expands its involvement with space science, the Moon will undoubtedly continue to be a centerpiece. Because of our initial investment and the long-term significance of the Moon, both scientifically and politically, it is important that we maintain a vigorous program of lunar science and exploration.

LGO AND OTHER MISSIONS

There are several ways that an LGO mission could interact with other missions, both U.S. and foreign. The ISTP (International Solar Terrestrial Physics) program will involve at least four spacecraft (WIND, POLAR, EQUATOR, GEOTAIL) placed in different Earth orbits, some involving lunar swingbys, to map various portions of geospace. One of these ISTP spacecraft might serve as a data-relay link to Earth from LGO for farside gravity mapping and as a platform for a second magnetometer, which is required to determine the electrical conductivity profile of the lunar mantle.

The Japanese have indicated plans for a lunar orbiter mission. They have indicated very informally some interest in a cooperative Japan/U.S. lunar mission. Discussions have occurred which envisage a U.S. LGO spacecraft in low-lunar orbit for global geochemical and geophysical mapping, and a smaller Japanese spacecraft in high elliptical orbit, carrying a magnetometer and acting as a communication link to LGO for farside gravity mapping.

The Soviets have plans for a two-phase mission. The first phase would put a single spacecraft in low circular orbit for low-resolution global surface mapping. The second phase would have the Soviet spacecraft raised to a high elliptical orbit to allow it to carry out solar observations. It is conceivable that during this latter phase a U.S. LGO spacecraft could utilize the high orbit Soviet spacecraft as a path link to Earth for farside gravity measurements.

****
****

NEW BOOK REVIEWS RECENT THOUGHT ON FUTURE SPACE INITIATIVES

Lunar Bases and Space Activities of the 21st Century edited by Wendell W. Mendell (Lunar and Planetary Institute $20.00; 863 pp.)

Within the general context of permanent human presence on the surface of the Moon, the book examines the issues of space development in 90 short papers arranged into 12 major sections. The topics addressed cover all aspects of the anticipated human space experience from formulation of national space policy to fundamental scientific discoveries waiting on the Moon. Thorny issues of space law and social change are raised, as are intriguing engineering and design problems associated with lunar habitation and industrialization. The brilliant technical and humanistic vision of lunar settlement from the late Dr. Krafft Ehricke complements the expression of humankind's dreams in the poetry of space as reviewed by Dr. Helene Knox. This scholarly publication presents an extraordinarily eclectic survey of the nascent space culture of the next millenium.

The majority of the papers derive from a public symposium, sponsored by NASA and hosted by the National Academy of Sciences in Washington, DC, October 29-31, 1984. Manuscripts submitted for publication were sent out for peer review by an editorial board. Following revision by authors in response to the referees, papers were accepted only after a final editorial review. The result is a scholarly collection of referenceable essays.

The book begins with keynote speeches at the symposium by James Beggs, George Keyworth, Edward Teller, and others with active experience in the shaping of national policy in space and in technology. Next is a group of papers reviewing lunar base concepts, ranging from classical times through Project Apollo to the very latest plans. A section on space transportation discusses the networks that will be put in place at the end of this century and continues on to innovative concepts in general infrastructure as well as specialized systems that take advantage of unique qualities of the lunar environment.

Scientific research, both basic and applied, will be a major part of lunar surface activities. In a section on lunar studies, planetary scientists suggest a variety of investigations of the Moon which can be undertaken from a manned base. Physicists and astronomers describe a variety of other scientific experiments which can be best done from the lunar surface. On the side of applied research, the exploitation of lunar resources raises a number of questions in lunar engineering and surface operations. Finally, research problems associated with the production of liquid oxygen propellant as a model for industrial activity are covered in a separate section.

Lunar Construction deals with designs and technologies possibly applicable to surface habitation. The physiological barriers to long term settlement are addressed in a section on life support and health maintenance.

Although a manned lunar base is largely viewed as an exercise in engineering and technology, a long term facility will have political and cultural implications. In a section entitled Societal Issues, authors look at the impact on international relations and the limitations imposed by space law. The decision process for adoption of national space goals is analyzed, and the budgetary implications of large projects are discussed. Two authors point out historical analogies where communities were established in resource poor environments, having long supply lines. A final section presents a set of arguments relevant to the adoption of a Mars base as an alternate or as a follow on goal.

Lunar Bases and Space Activities of the 21st Century represents a benchmark in contemporary thought on the next twenty years of space development. In conjunction with the forthcoming report from the President's National Commission on Space, this book will point the way to the research issues in space technology for the next generation.

****
****

ASTRONOMY FROM THE MOON

G. Jeffrey Taylor
Institute of Meteoritics
University of New Mexico

The Moon offers wondrous opportunities for astronomy. Its environment allows higher resolution measurements and access to energy ranges difficult if not impossible to detect from Earth. Given a permanently staffed lunar base, a series of observatories could be established and maintained with relative ease. These were the major conclusions reached at the Workshop on Astronomical Observations from a Lunar Base, which was held January 10, 1986, following the annual meeting of the American Astronomical Society in Houston, Texas. The workshop was organized by Dr. Jack Burns of the University of New Mexico's Department of Physics and Astronomy.

The Moon's advantages as a site for observatories include the following:

Vacuum:
The total nighttime gas concentration is only 2 x 10^5 molecules/cm^3 and the lunar atmosphere's total mass is only 10^4 kg. This makes dramatically better seeing conditions because atmospheric twinkling is virtually absent. For example, on Earth, resolution is limited to slightly less than one arcsecond, whereas on the Moon resolutions of one micro- arcsecond are possible.

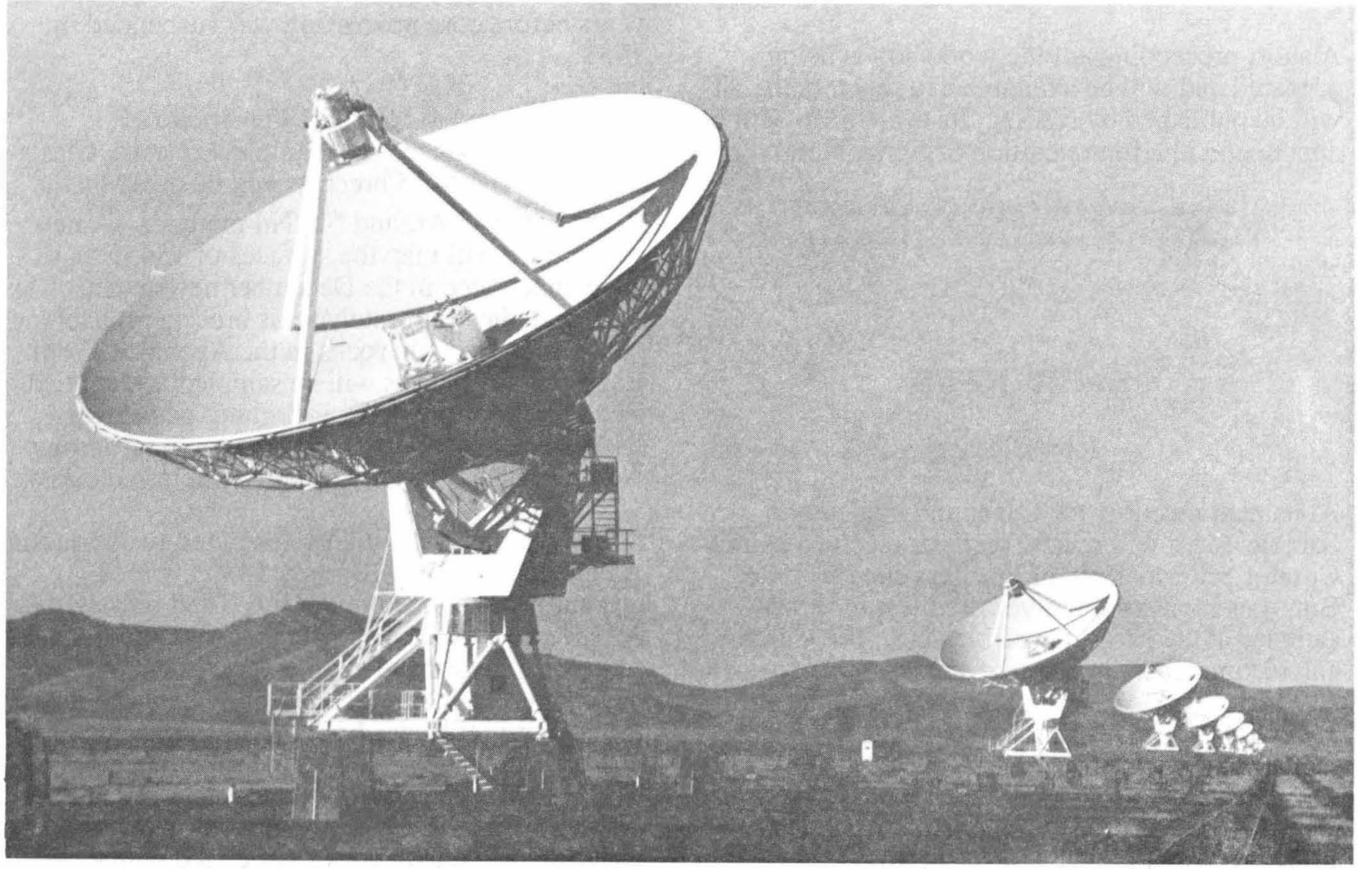
Stable platform:
The Moon's seismic activity is lower than any - where on Earth; the largest recorded moonquake is in the range of Earth's seismic background. Consequently, telescope arrays, even optical ones, can be built and kept in alignment. The stable platform, coupled with the Moon's slow rotation rate, make pointing telescopes easier than this task is on free-flying spacecraft.

Locked-in orbit:
The tidally locked lunar orbit results in a farside free of low-frequency radio interference, thereby permitting more sensitive radioastronomy. For example, an observatory on the lunar farside would make possible measurements below 40 megahertz, which is impossible from Earth.

Magnetic field:
No magnetic field is being generated inside the Moon, but there is a meager field from magnetized rocks in the upper lunar crust. This field ranges from 3 to 330 gamma at the lunar surface (one gamma is 10^{-5} oersted) compared to 30,000 gamma at the Earth's equator. This aids in the study of charged particles.

Surface temperatures:
The lunar night is frigid, ranging from about 100°K in equatorial regions to less than 80°K in polar regions. Permanently shadowed areas at the poles could be as cold as 40°K. This allows astronomical equipment, such as infrared telescopes, to be cooled passively. There is, however, a dramatic diurnal variation in tem - perature: in equatorial regions, temperature ranges from 385°K at noon to 100°K just before dawn. This presents challenges for telescope design.

Speakers at the workshop were enthusiastic about the possibilities of observatories on the Moon, though some concern was expressed that massive programs for lunar astronomy might reduce funds for other space-based observatories. Wendell Mendell of the Johnson Space Center pointed out, however, that lunar astronomy, no matter what promise it holds, would not be the driving force in establishing a lunar base. But once the base is established, lunar astronomy will become feasible. Although the base will not be established until 2005-2010, it is not too early to plan. As Harlen Smith of the University of Texas Observatory reminded the audience, serious discussions about design of the Space Telescope began in 1962.



One arm of the Very Large Array stretches across the lunar-like plains of St. Augustine, near Socorro, New Mexico. Such arrays, including optical interferometers, could be built on the stable, airless lunar surface. Photo by Michael Zeilik, Department of Physics and Astronomy, University of New Mexico.

Two of the telescope systems described at the workshop clearly need the Moon's unique characteristics. One is an array of optical telescopes. Jacqueline Hewitt of the Massachusetts Institute of Technology described an optical version of the Very Large Array radiotelescope located in New Mexico. It would have 27 one-meter telescopes deployed over an area about 10 kilometers across. Because of the lack of a lunar atmosphere and the stable platform the Moon provides, the resolution would be good enough to transform stars from twinkling dots into disks on which sunspots would be visible. It would also allow study of other planetary systems. The other telescope that needs the unique lunar conditions is a low-frequency radiotelescope. James Douglas of the University of Texas, Austin, described the virtues of the lunar farside for such a device and said that observations at less than 40 megahertz are impossible from Earth.

Dan Lester of the University of Texas, Austin, described a simple infrared telescope that could be deployed even during the early stages of lunar base development. Jack Burns, Director of the Institute for Astrophysics at the University of New Mexico, described a Moon-Earth Radio Interferometer, which would use the 380,000 kilometers between the two bodies as a baseline. The system would have a resolution 10,000 times greater than the Very Large Array. Frank Drake of the University of California, Santa Cruz, described the large radiotelescope at Arecibo, Puerto Rico, and pointed out that this design is well suited to the Moon, where receivers could be constructed inside craters. Because of the Moon's lower gravity, one-sixth of Earth's, larger Arecibo-type dishes could be built. Drake estimates they could be 30 kilometers in diameter using conventional materials such as steel.

A short proceedings of the workshop is being prepared and will be available in a few months. It will be published by NASA. Its availability will be announced in a future edition of Lunar News.

****
****

LAPST NEWS

John Dietrich

At its next meeting, the Lunar and Planetary Sample Team will review requests received by the Curator prior to close of business June 6, 1986. But, you should submit your request for lunar samples at the earliest possible date. The Curator can recommend allocation of some sample categories between formal reviews; and, the allocation date and request receipt date are major factors in scheduling sample processing and delivery to the investigator.

LUNAR SAMPLE ACTIVITY: LAPST FEBRUARY ALLOCATIONS

The Lunar and Planetary Sample Team (LAPST) reviewed 13 requests for lunar samples from ten investigators at its meeting February 21-23, 1986. LAPST recommended allocation of 132 samples (weighing 27.81 grams) and 74 thin sections to six investigators, and recommended approval of two proposed consortium studies of lunar breccias with allocations of up to 20 grams of samples from each for thin sections and other analyses.

LAPST also reviewed and endorsed the Curator's allocation of 39 thin sections to four investigators who requested samples between the November 1985 and February 1986 meetings.

Two requests for samples and thin sections from the double drive tube 79001 and 79002 led LAPST to recommend the resumption of core processing on a limited basis. After reviewing comments received when the Curator proposed an abbreviated procedure in the December Lunar Sample Newsletter, LAPST recommended using the full dissection procedure developed during the several years before core processing was suspended in 1982.

Activity related to the Fall 1985 Apollo 15 Workshop produced two sample requests. Clasts from two Apollo 15 breccias will be dated by the Rb/Sr, $^{39}Ar/^{40}Ar$, and Sm/Nd methods. A new consortium will map the surfaces of 15459 that were announced in the December newsletter. Earlier studies suggest that this breccia probably contains clasts from rocks in the Apennine Front. Representative clasts will be sampled and studied by a variety of methods, including: petrography, INAA, electron microprobe, and ion microprobe. Argon ages will be determined for selected clasts.

Studies of Apollo 14 rocks generated two requests. A new consortium will study 14303, a rock originally announced in the July 1985 newsletter. After review of the slab maps prepared by a lunar sample processor and examination of cut and broken surfaces on other subsamples of the rock, the consortium leader will select samples for petrographic study, INAA, and other analyses. The second request identified clasts to be analyzed by members of an existing consortium that is studying the suite of rocks associated with Cone Crater.

Other requests supported:
• studies of the ancient lunar magnetic field
• Apollo 12 crustal rocks
• genesis of the lunar highlands breccias
• abundance and spatial distribution of boron in lunar rocks

After a thorough review of the studies proposed and samples requested, LAPST recommended denial of two requests.

****
****

CURATOR'S NOTES

Doug Blanchard

A NEW LOOK FOR "LUNAR NEWS"

The newsletter has changed (again). The name has changed from "Lunar Sample Newsletter" to

"Lunar News," and the scope has been broadened. The newsletter will not only to report what is happening in lunar sample studies now, but also it will keep an eye on the Moon in our future. Accordingly, you will find discussions in this and future issues of sample related issues, LGO (the near term future) and of Lunar Base (the longer term future). The mailing list has been significantly expanded.

Your contributions to "Lunar News" are invited. "Lunar News" is intended to be a forum for discussion on a broad range of topics and issues, scientific and otherwise, relating to the Moon. Send your suggestions and contributions to:

Doug Blanchard, Lunar Sample Curator
Code SN2 NASA JSC
Houston, TX 77058.

LUNAR CORE DISSECTION

In Lunar Sample News 45, December 1985, we suggested a shortened procedure for dissecting lunar cores. The procedure that was suggested was intended to shorten the time needed to open lunar cores and thus make more of the core samples available to the sample community in the next few years.

The consensus of the responses was that there is little to be gained by the new procedures, and there was concern for the long term integrity of the partially dissected cores under the suggested new procedures. Accordingly, LAPST and the Curator have decided to retain the standing procedures for core dissection. We thank those of you who took the time to express your views on the suggested change in procedures.

At its last meeting, LAPST recommended the dissection of 79001/2 core from Station 9, Apollo 17. There has been a long standing request for samples from that particular core to look for the possibility of anomalously heavy nitrogen isotopes at that station. There is some evidence in the surrounding surface soils that such an anomaly may be found in this core.

The commitment to open this particular core does not represent a commitment to open all remaining cores, but rather it is a specific response to a set of requests for core samples in general and from this core in particular. Future requests for samples from other unopened cores will also be considered on their individual merit.

We will extrude the top section of 79001/2 in June, work on the dissection passes through the summer months finishing in about October and make the epoxy impregnation and continuous thin section set in time to have thin sections available by late December or early January. Samples should be available for allocation by September. Our ultimate aim is to have the samples and thin sections available in time for investigators to be able to present their results at the March 1987 Lunar and Planetary Science Conference.

If you are interested in working on this core, please send your requests immediately so that they can be considered at the mid-June meeting of LAPST. Their next meeting is scheduled for early October.

PRINCIPAL INVESTIGATOR'S LUNAR SAMPLE INVENTORIES

Thanks to all you who have promptly returned your 1986 lunar sample inventories. So far that includes 85% of the labs with lunar samples. To the other 15% ... we haven't forgotten you!

****
****

☆ U.S. GOVERNMENT PRINTING OFFICE: 1986—659-014/40182