MOONBASE MONS

NASA's return to the Moon entails selecting a landing site that would serve as a base for early lunar exploration and possibly as a permanent outpost. Based on data returned from Clementine and other missions, the agency has recommended the rim of Shackleton crater. Other experts, however, argue in favor of a different site, a "mountain" summit that might hold several key advantages over the agency's current choice.

Making the case

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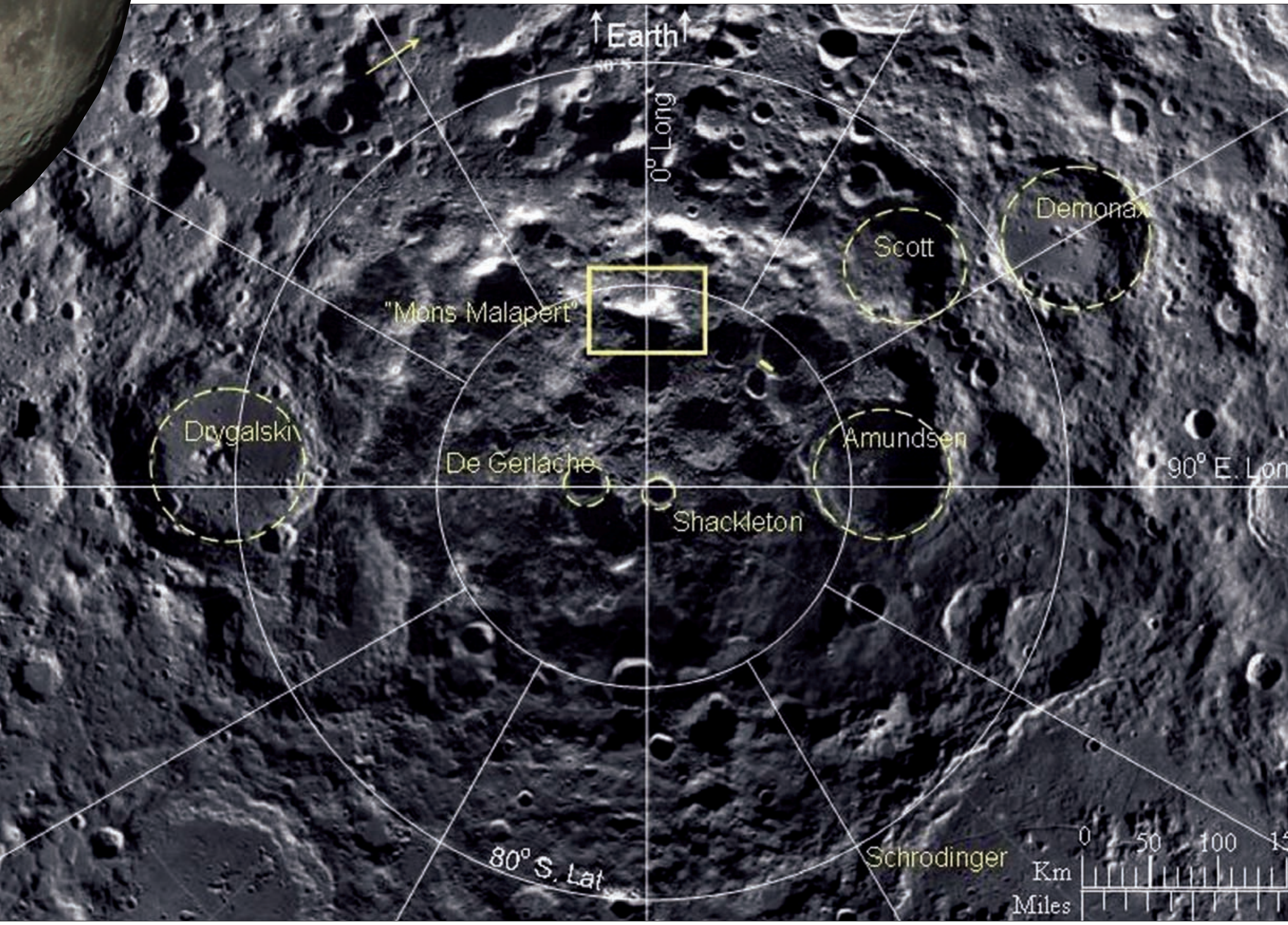
NASA's present plans call for returning humans to the Moon sometime before 2020 and establishing a permanent lunar outpost there. This base will have several purposes. First, it will be a central station from which to resume robotic and manned exploration of large areas of the Moon. Second, it will allow the Moon itself to serve as a base for study of the universe by accommodating astronomical instruments such as radio and optical telescopes, eventually in interferometric arrays. Third, through the process of its construction and operation, the base will provide valuable experience for Martian exploration (although allowance must be made for the different environment of Mars). Fourth, the outpost will allow development of the ability to use lunar resources for sustaining and

MALAPERT?



expanding human operations in space. This capability, called in-situ resource utilization, will be a key factor in the development of future large-scale interplanetary missions.

EARLY MISSIONS; EARLY FINDINGS

Where should such an outpost be located? Beginning in 1994, as a result of the Clementine orbital mission, site selection for a lunar base suddenly began to focus on the Moon's south polar region. The Clementine spacecraft, in lunar polar orbit for about three months, performed a bistatic radar experiment, with the return from its radar altimeter received by the Arecibo radio telescope.

The radar experiment found backscatter similarities between the lunar polar regions and radar surveys of terrestrial glaciers and snow fields. This was interpreted as supportive of the idea that water ice might exist in permanently shaded craters at the lunar poles.

In 1998, the Lunar Prospector satellite confirmed the presence of significant amounts of hydrogen in permanently shaded craters found

Combined Clementine mosaic and Earth-based radar image shows the south polar region of the Moon. The geographic south pole is located near the rim of Shackleton Crater. Mons Malapert, located at 0° longitude and 86° S latitude, is highlighted.
Courtesy: NASA

The Earth-lit Moon (opposite page) is from the Clementine collection.

around the north and south poles of the Moon. This discovery triggered a controversy. Were the hydrogen deposits water ice, other hydrogen compounds, or simply hydrogen that had been implanted by the solar wind?

At this point, the issue remains unresolved, and "ground truth" analyses will be needed to obtain the answer. But if hydrogen is present in the form of water ice, as suspected, the timetable for establishing permanent human settlements can be greatly accelerated. Water—an absolute necessity for life support systems—and its hydrogen and oxygen components can be used for a host of other applications on the Moon.

NASA'S CHOICE

The south pole of the Moon is located on the rim of 19-km-diam Shackleton Crater. Because the Moon's rotational axis is almost perpendicular to the ecliptic plane, the rim of the crater receives long seasonal periods of sunlight, while its floor may be permanently shadowed.

Based on the evidence of hydrogen-rich resources, relatively long periods of sunlight for the operation of solar power devices, access to areas of geologic interest, and other factors, NASA recommended the rim of Shackleton Crater as the site for initial robotic landings and possibly for a permanent human outpost. That recommendation was issued in the 2005 NASA Exploration Systems Architecture Study (ESAS).

AN ALTERNATE RECOMMENDATION

But there is an alternate location that can be recommended as the preferred site for the first lunar base: the summit of Mons Malapert (MM). The feature was formerly known as Malapert Mountain (not an official designation of the International Astronomical Union).

This "mountain" is perhaps the rim of an ill-defined crater, although its location suggests that it may be part of the South Pole-Aitken Basin, the largest basin on the Moon. The mountain is a large, obvious feature at roughly longitude 0°, latitude 86° S, while its highest point appears to be near longitude 2° E, latitude 85.75° S.

The summit of the mountain has been estimated to project at least 4,700 m above the 1,738-km reference radius of the Moon, whereas the maximum vertical distance from terrain near the base of the mountain to the summit may be as much as 8,000 m. The reason for the difference in these elevations is that an area just northeast of the mountain is a depression that lies approximately 3,000 m below the reference radius of the Moon. To the south of the mountain lies an unnamed crater-depression, a possible "cold trap" that may contain water ice.

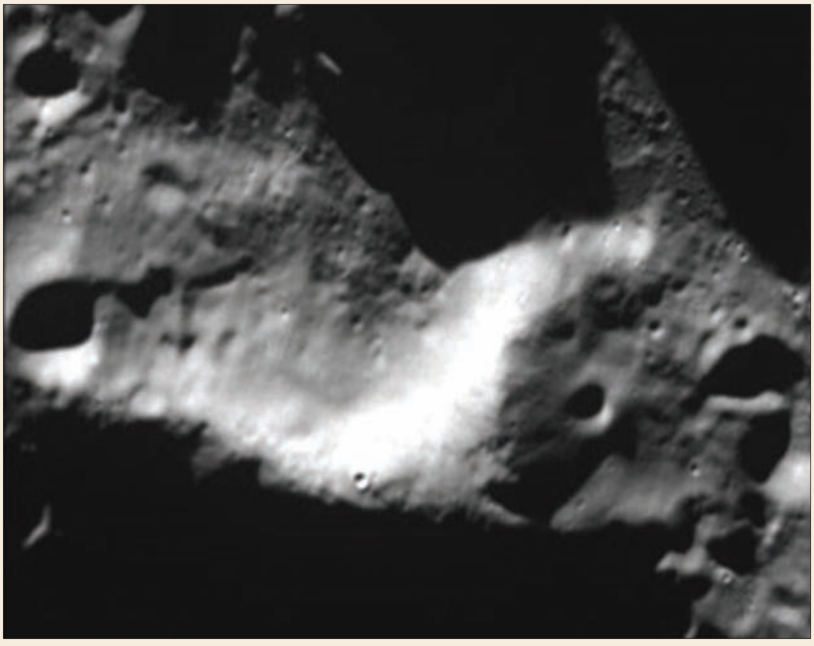
Detailed and precise topographic maps of the lunar south polar region are needed and presumably will be supplied soon by data from SMART-l and successive Chinese, Japanese, Indian, and U.S. orbital missions. However, even the available data, specifically the photographs from the 1960s Lunar Orbiter 4 missions, permit a comparison between MM and Shackleton. This imagery, although incomplete, reveals several features and conditions favoring MM as the site for a lunar outpost.

CONTINUOUS COMMUNICATIONS LINK AND EARTH VISIBILITY

The summit of MM probably has the Earth always in view, enabling a direct and continuous communication link between the Earth and the Moon. The rim of Shackleton, by contrast, has the Earth in view for about half of each month, and a base at Shackleton would have to rely on relay stations, for example, at the summit of MM or in lunar orbit, for its communication link for the remainder of the time.

In the absence of a relay capability, data obtained during the periods of nonvisibility would have to be recorded and played back after each reestablishment of contact. The additional equipment and procedures required for this scenario introduce complexity, cost, and the possibility for error. (Earth visibility comes and goes every 28 days, with the Earth ascending and descending a total of about 12 degrees as seen from the Moon.) The communication advantage for MM over Shackleton is thus sig-

High-resolution radar image shows Mons Malapert. For size comparison, the prominent small crater near the summit measures approximately 1 km in diameter. Courtesy NASA.



The JAXA/NHK Selene satellite captured Shackleton Crater in the right foreground and Mons Malapert, over 100 km distant on the horizon, lying directly below Earth. For lunar base considerations, the terrain, communication, and illumination features of Malapert are predicted to be superior to those of Shackleton Crater. Sunlight illuminates Malapert's south face, which had never previously been imaged. Courtesy: JAXA

nificant, both in lower cost and complexity and in higher bandwidth capability and reliability. In addition, continuous observations of the Earth from the Moon should be possible from MM, but not from Shackleton.

SUNLIGHT AVAILABILITY FOR SOLAR POWER

Simulations of the dynamics of the Moon and the Sun indicate that the summit of MM receives full sunlight for as much as 88% of the lunar year for the operation of solar-powered devices, with periods of constant sunlight totaling over five months per year at the summit.

Estimates for the amount of sunlight at the rim of Shackleton are less certain because of unknowns with respect to the absolute elevation of the area. Using a "best case" elevation of 400 m, we estimate that the rim of Shackleton could receive full sunlight for up to 71% of the time, and theoretically could experience this condition for periods of up to eight months.

Neither of these estimates, however, takes into account the crucial effect of shadowing that occurs from adjacent high elevations in the south polar region. This is certainly a more serious concern at Shackleton, which is located in a basin. Moreover, for all polar region locations, the Sun will continually be traveling westward along the horizon, and always quite close to it. Designs for Sun-tracker solar collectors must take this particular fact of lunar life into consideration and either be sited at specific, unique locations (such as atop towers on high elevations) that can continuously rotate to keep the Sun in view, or employ some other means for traveling around in a monthly circuit.

In any case, the estimated availability of sunlight at the summit of MM is clearly superior to that at Shackleton, both for the near term and for permanent lunar base operations. MM has the added advantage of being a logical place to begin construction of a permanent solar-powered electric grid around the circumference of the south polar region as a long-term infrastructure development option. This does not appear to be a practical option for Shackleton.

LANDING AND RESOURCE ADVANTAGES

MM is much larger (some 50 km in its east-west dimension) than Shackleton (19 km across) and presents a much larger radar target for approach and landing. The summit of MM is relatively flat and has only one visible crater; it is estimated that 10 or more square kilometers of the summit area are suitable as a landing zone.

The MM summit is pre-Nectarian—in U.S. Geological Survey stratigraphic nomenclature, extremely old. Such old terrain, comparable to that visited by Apollo 16, will certainly be geomorphically mature, with a thick regolith (lunar soil) and subdued topography, except for occasional young impact craters.

Shackleton, in contrast, appears to be a relatively young crater with an irregular terrain, fairly steep slopes at the flanks of the crater rim, and a debris field similar to the 27-km crater Euler, located on Mare Imbrium. From the standpoint of size and terrain features, MM appears much more practical and a priori safer than Shackleton as a landing field.

Investigation and evaluation of the polar hydrogen deposits in permanently shadowed craters is a major objective of early lunar missions. The rim of Shackleton and its interior are indisputably of great interest in this regard. However, MM is just as well situated. Its south base, which is permanently shaded, is in the area of highest hydrogen concentration. A rover

At the Apollo 16 landing site, the bright-rayed crater (lower left) is South Ray Crater; its ejecta were sampled by astronauts John Young and Charles Duke during the second EVA, along with material from the lower slopes of nearby Stone Mountain (center of bottom margin), part of the Descartes Mountains.

could therefore drive south from the MM crest and immediately encounter hydrogen-bearing (possibly water ice) terrain.

Furthermore, because of the greater physiographic age of MM, its south flank would almost certainly have gentle slopes and few craters. By contrast, the inner rim of Shackleton, as noted earlier, would probably be much less trafficable.

International Lunar Observatory mission, at the summit of Mons Malapert circa 2012, would involve astronomical observations at multiple wavelengths and communication services between the Earth and the Moon.
Courtesy: ILO Association

LUNAR SCIENCE AND OPERATIONS

A thick regolith such as that postulated for the summit of MM can be more easily excavated and used for resource extraction and shelter. The Apollo missions found that the regolith at geologically older sites, such as the Apollo 16 landing site at Descartes, was thicker than at younger sites such as Tranquility Base. In addition, because of its great age and long-term exposure to the solar wind, the MM regolith will likely have a higher proportion of implanted solar wind volatiles than that at Shackleton. One of the first objectives of a robotic landing on MM should be either sample return or in-situ analysis of the solar wind volatile content of the regolith.

MM and Shackleton would both be excellent locations for astronomy. Telescopes in both areas will be able to collect light for very long observation periods along the Moon's axis of rotation, and the bottoms of permanently shadowed craters are ideally suited to infrared telescope operations. An advantage of MM is that its south face is free of interference from Earth and Earth orbit communications and is thus an optimum location for radio telescopes. The south side of MM would be largely shielded from terrestrial low-frequency radiation (less than 30 kHz), although there would be some diffraction over the mountain top.

EXPLORING ADJACENT REGIONS

The summit of MM dominates the entire south polar region and is the logical site for command and control of extended exploratory missions. The Moon's south pole is an area of intense scientific interest, for several reasons in addition to those cited previously. The south pole Aitken Basin is not only the largest but also perhaps the oldest lunar basin. Thus understanding its origin and evolution would be invaluable in deciphering the Moon's origin, still an unsolved problem 39 years after Neil Armstrong's footprint first appeared on the lunar surface.

The elevation of MM may enable local line-of-sight communications across the entire south polar region, with no need to erect towers and other support structures. Using optical communications, high bandwidth will be available for a variety of applications, both locally and globally. Preliminary evidence also suggests that the rim of Shackleton Crater may be visible from the peak of MM, a bit over 100 km away. If this were confirmed, it would provide a line-of-sight link for communications and eventually, perhaps, power-beaming to the Moon's south pole.

The advantages for robotic operations at MM also apply to manned missions—perhaps

more so, because longer periods of sunlight and continuous Earth visibility will be of psychological value. In addition, the construction and shielding of permanent human habitats will be expedited if excavation of the more mature regolith at MM proves to be less challenging than at Shackleton, as predicted.

FUTURE LANDER MISSIONS

The ESA Smart-1 mission to the Moon, as well as current and planned lunar satellite missions of Japan, China, India, and the U.S., will provide the photogrammetric data needed for topography information and for assessing sunlight incidence at elevations in the south polar region. Assuming that orbital imagery and other data confirm most or all of the advantages of MM, we recommend the following initial lander missions at its summit:

•Demonstration of Earth-Moon communications capability for control of robotic devices and return of data.

•Mapping of horizon events, Sun angles, and topography; dispatch of rovers to place navigation aids, telescopes, and solar arrays.

•Demonstration of Sun-synchronous circumnavigation routes around the MM summit.

•Use of robotic devices to conduct in-situ resource utilization experiments, analyze the lunar regolith, explore off-mountain routes, and investigate cold traps.

Given the objectives and constraints for a return to the Moon as presented in the 2005 ESAS, Mons Malapert appears superior to the rim of Shackleton Crater as a landing site for initial robotic and manned missions and as a site for a permanent lunar outpost, particularly from an operational and future-value point of view. Therefore, we recommended that intensive study of Mons Malapert be carried out before mission plans are finalized. Our results are preliminary and qualitative, and should be followed by a detailed photogrammetric survey with imagery from the ESA, Chinese, Japanese, and Indian orbiters, and from NASA's planned Lunar Reconnaissance Orbiter.