The biggest hole in the MOON

A gigantic impact basin holds the keys to the solar system's past — and may also provide a base for human exploration. /// BY JAMES OBERG

Sixteen-hundred miles wide and nearly 8 miles deep, the South Pole-Aitken basin sprawls across the Moon's southern farside. It's the largest, deepest, and probably the oldest, impact basin in the known solar system.

For scientists, investigating the basin would provide a look into what may be the Moon's mantle, conveniently exposed at the surface. Also, dating the impact that created the feature will nail down a major point in the history of the Earth and Moon system and, by extension, the entire solar system.

For mission planners looking ahead to humankind's return to the Moon and eventual missions to Mars, the South Pole-Aitken basin provides a natural target — one that has a "climate" as benign as any the Moon has to offer. Additional reasons include the possibility of siting radio telescopes near the Moon's south pole, which stands on one edge of the basin.

Finally, there's the possibility of finding water ice in the soil of nearby craters. Besides its scientific attraction, ice could be mined to produce air and fuel for a Moon base.

James Oberg, *a former NASA space engineer specializing in shuttle orbit operations, has been following everyone's space programs for decades.*

Shadows and ice

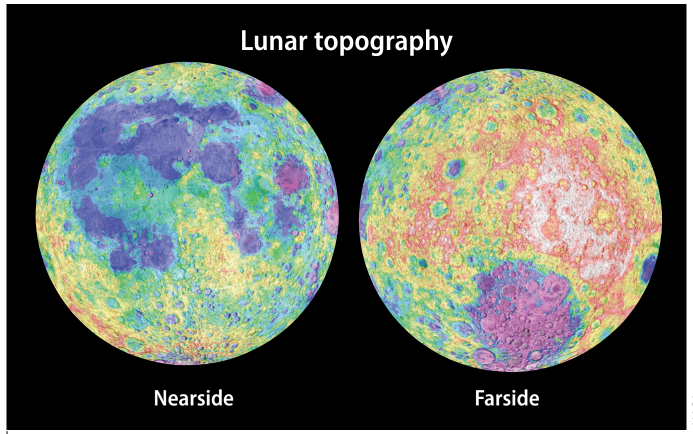
The notion of lunar ice sounds outlandish. Why should the Moon — a world with no atmosphere and whose rocks contain almost no volatile materials, especially water — have any ice at all?

Here's the secret. By a fortuitous coincidence, the Moon's rotation axis tilts only 1.5° to the ecliptic plane, the path of the Earth-Moon system around the Sun. If astronomers' calculations are correct, it has been that way for at least 2 billion years, and perhaps twice as long — right back to the last major impacts that shaped the lunar surface.

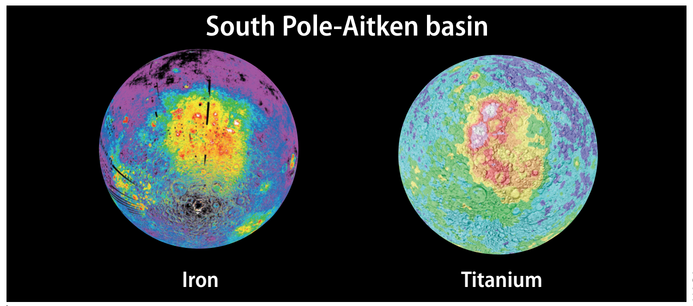
At the Moon's north and south poles, no portion of the half-degree-wide Sun ever rises higher than about 2° above the horizon. This means some craters close to the poles have floors that are eternally in shadow. These should become very cold, with temperatures of –280° Fahrenheit (–173° Celsius) or so.

The cold floors of these craters will trap random molecules of water. The molecules might come from the tails of passing comets, or even comet impacts, which would give the Moon a transient atmosphere loaded with water vapor. Other sources include impacting meteorites with water-rich rock, or even occasional lunar outgassing.

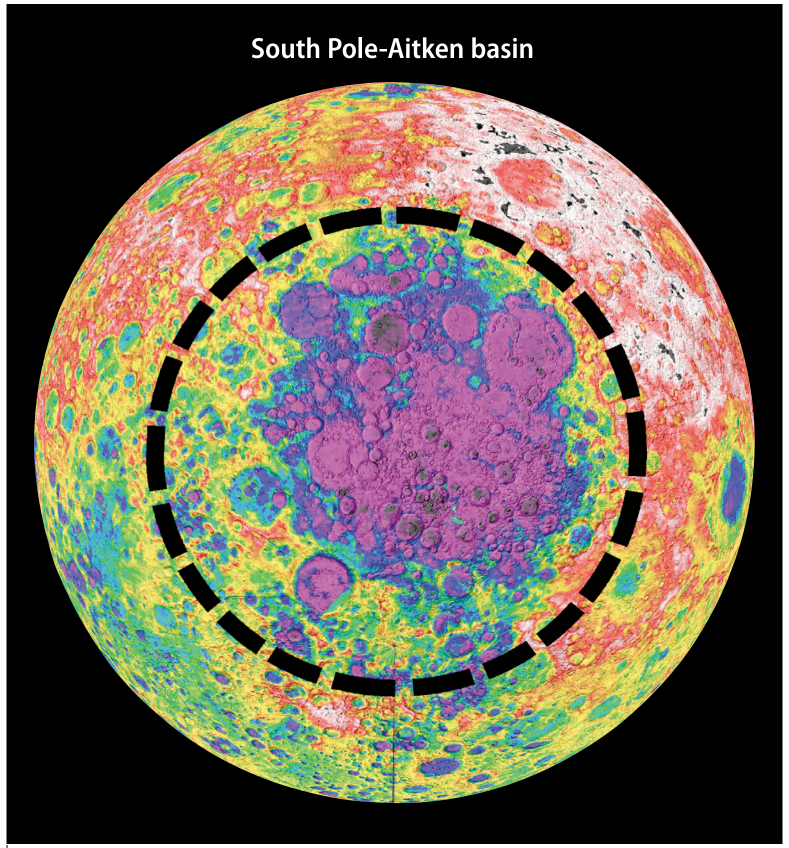
A MEDIUM-SIZE ASTEROID struck the Moon billions of years ago, creating the South Pole-Aitken basin. Knowing when the impact occurred is one of planetary scientists' most-wished-for dates. RON MILLER



LAVA FLOWS FILLED many basins on the Moon's nearside. But a 50-percent-thicker crust on the farside made it more difficult for magma to reach the surface. Note the "hole" in the southern farside: the South Pole-Aitken basin.



IT'S AN ANOMALY, ALL RIGHT. The basin stands out in elemental maps that show abundances of iron and titanium.



ASTRONAUTS CAUGHT GLIMPSES of the South Pole-Aitken basin from orbit, yet remained unaware of what they were seeing. Finally, altitude measurements from the Clementine probe revealed the basin's true size. NASA

Impacts elsewhere on the Moon would redistribute rock and soil and other surface materials, so any ice would be mixed with lots of dirt. And impacts within the ice field itself would gouge out older deposits and throw them atop younger ones.

Until about 10 years ago, lunar ice was all speculation. From Earth, and from the mostly equatorial orbits of the Apollo missions, the Moon's polar regions are literally out of sight. The ice-cap theory couldn't be tested until specially equipped polar-orbiting spacecraft reached the Moon during the 1990s.

Slippery target

Hints of lunar polar ice came in 1996, when radio data from the Clementine probe indicated the wall of a south polar crater was more reflective than expected — and ice was the most likely explanation. The spacecraft took data on four passes over the south pole, and one pass showed an enhanced, tightly beamed backscatter of radio signals, indicating ice. That pass was the only one where the beam included large amounts of permanent darkness, including Shackleton Crater, which is not visible to Earth-based observers.

Two years later, neutron spectrometer data from the Lunar Prospector spacecraft suggested the presence of hydrogen (and by inference, water) about a yard underground at both poles. The observations correlated directly with passes over permanently shaded areas.

But radar astronomers using the Arecibo radio telescope at 12-centimeter wavelengths were skeptical, and remain so.

In 2003, the Arecibo radar probed the floors of two craters in permanent shadow at the lunar south pole, Shoemaker and Faustini. It also examined the floors of Hermite and several small craters within the large crater Peary at the north pole.

"Lunar Prospector found significant concentrations of hydrogen at the lunar poles equivalent to water ice at concentrations of a few percent of the lunar soil," says Bruce Campbell of the Center for Earth and Planetary Studies at the Smithsonian Institution. "There have been suggestions that it may be in the form of thick deposits of ice at some depth, but the new data from Arecibo makes that unlikely," he continues. "There are no places that we have looked at with any of these wavelengths where you see that kind of signature."

Icy or rough?

Instead, Campbell's team concludes the backscatter it observed is caused by surface roughness, not water ice. But Paul Spudis of the Johns Hopkins University's Applied Physics Laboratory disputes Campbell's interpretation. "In fact, they do detect zones of high backscatter," he says. "They claim it's roughness, not ice. We claim that it's consistent with the idea that it is ice."

The latest radar results, Spudis continues, show the same as earlier Earth-based radar studies, and they are just as susceptible to different interpretations. "We have basically three separate data sets," he explains. "Two show positive for ice and one is ambiguous. Judge for yourself what the answer is."

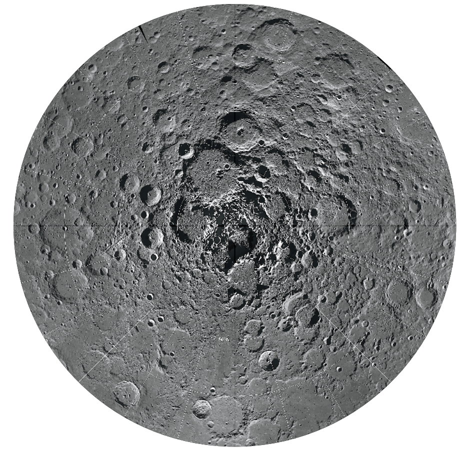
Campbell replies, "If there is ice at the poles, the only way left to test it is to go there directly and melt a small volume around the dust and look for water with a mass spectrometer." Spudis agrees that more orbital and lander missions are called for.

If there is any water at all near the lunar poles, Campbell and his colleagues continue, "It is widely scattered and permanently frozen inside the dust layers."

From the resources point of view, says Spudis, "It doesn't matter whether there's ice there or not — there *is* a hydrogen enrichment at the poles."

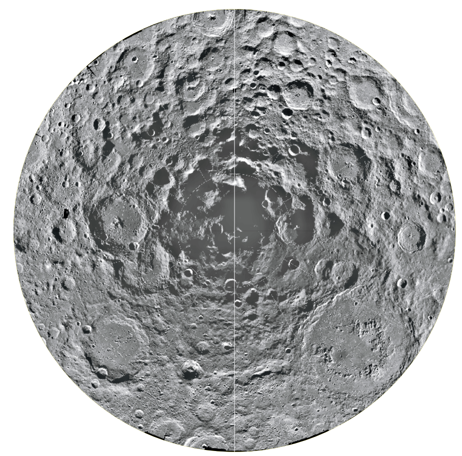
The form of the hydrogen — either as molecules of H_2 or H_2O — affects only the kind of processing required; it doesn't

North polar region



CLEMENTINE IMAGES stitched together yield a view of the lunar north pole. The amount of permanently shaded terrain is less in the north than the south. NASA

South polar region



SHADOWS GATHER in south polar craters, many of whose floors never see sunlight. Dropping to temperatures of hundreds of degrees below zero, such cold terrain can trap passing molecules of hydrogen and water. NASA

/// ROBOTIC MOON MISSIONS

AFTER ORBITING THE MOON for a year, the Selene probe will detach its propulsion module, which will make an automated soft landing on the Moon.

MOONWATCHERS

The renewal of scientific interest in the Moon has spurred several countries' development of lunar spacecraft.

SMART-1
- European Space Agency (ESA)
- Launched: September 23, 2003
- Reached Moon: November 15, 2004
- Ion-drive propulsion
- Main instruments: imager, spectrometers
- Chief focus: testing ion drive, studying Moon, looking for polar ice

Selene
- Japanese Space Agency (JAXA)
- Launch: 2006
- Reaches Moon: 5 days after launch
- Thruster propulsion
- Main instruments: multi-wavelength imagers, spectrometers
- Chief focus: mapping elemental abundances, mineral composition
- Carries two relay and radio astronomy satellites

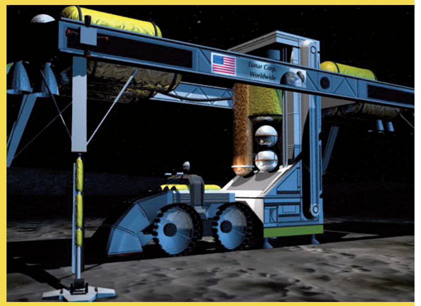
Chandrayaan-1
- Indian Space Research Organization (ISRO)
- Launch: September 1, 2007
- Reaches Moon: 5 days after launch
- Thruster propulsion
- Main instruments: terrain-mapping camera, spectrometers
- Chief focus: mineral and chemical survey of polar regions
- May include hard-landing impact probe

Chang'e 1
- China National Space Administration
- Launch: late 2007
- Reach Moon: few days after launch
- Thruster propulsion
- Main instruments: imager, altimeter, spectrometers
- Chief focus: testing technology, studying lunar environment

Lunar-A
- Japanese Space Agency (JAXA)
- Launch: TBA
- Thruster propulsion
- Main instrument: mapping camera
- Chief focus: studying Moon's interior with seismology
- Carries two surface penetrators with seismometers

Lunar Reconnaissance Orbiter
- NASA
- Launch: October 1, 2008
- Reaches Moon: 4 days later
- Thruster propulsion
- Main instruments: high-resolution imager, spectrometers
- Chief focus: looking for water ice, mapping surface in detail

SCOUTING FOR ICE-RICH RUBBLE, a robotic mining rover scavenges the floor of a shadowed crater.



THE ROVER-MINER DELIVERS the scooped-up mixture of ice and lunar soil to an automated refinery.

AT THE REFINERY, liquid oxygen and hydrogen are loaded into a robot tanker (left) for delivery to crews for use as fuel, air, and water.

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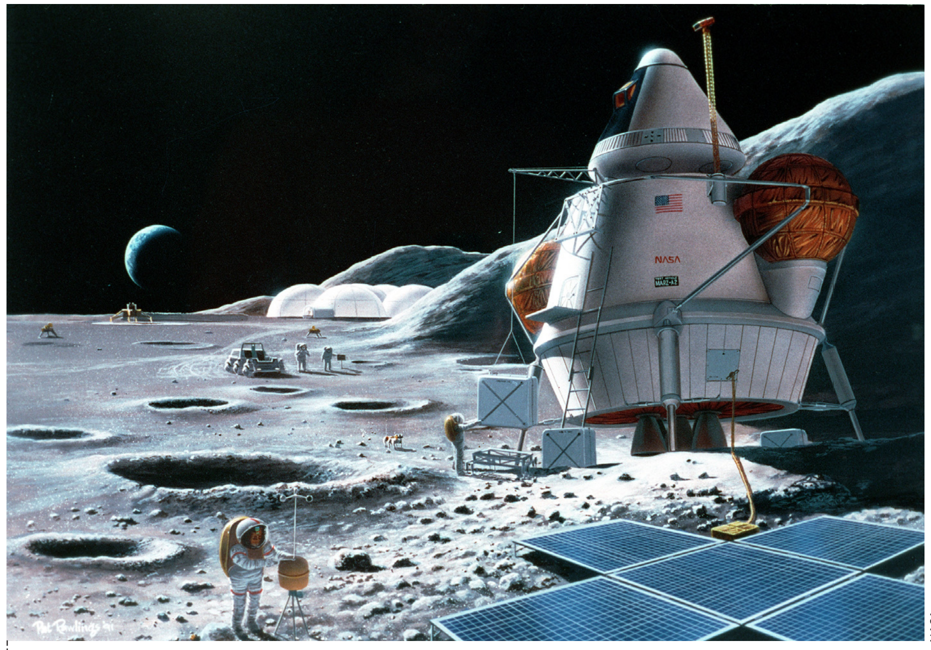
THE HYDROGEN TANKER fills a scouting ship's fuel pods in preparation for an exploration trip.



NASA

THE NEXT HUMANS TO GO to the Moon will likely establish manned bases in the polar regions. Such bases could provide access to volatile resources (for example, water ice or hydrogen) trapped in shadowed craters.

change the rationale for going to the poles to establish bases.

The long-term value of such a resource would be profound. Using solar power, water could be broken down into oxygen and hydrogen and stored cryogenically for use as propellant. Water and oxygen are also key components for life-support systems.

But however abundant polar hydrogen is, building Moon-based propellant refineries will require hauling massive amounts of apparatus from Earth to the lunar surface. Therefore, for the first human return to the Moon — and even for early expeditions to Mars — hauling the propellant from Earth may still cost less than first establishing a lunar-based "fuel mine."

The big hole

Looking beyond the immediate south polar region, the big basin remains at the center of attention for new missions. Even with no possibility of polar ice, it would draw much scientific interest.

The region's name, given by Don Wilhelms of the USGS, is a little misleading. "Neither the south pole nor Aitken Crater are actually inside the basin," says Michael Duke of the Colorado School of Mines. "They are simply the two most identifiable surface features that mark the boundary of the structure."

The South Pole-Aitken basin lies just over the limb on the Moon's farside. Heavily cratered by later impacts, it lacks the large, thick floods of dark lava that fill most basins on the nearside, some to overflowing. Thus, South Pole-Aitken appears indistinct when viewed by human eyes. Sheer size also contributes to the vague impression because it's hard to see all of the basin at once.

The existence of a "Big Backside Basin" was suspected as early as 1962, when William K. Hartmann and Gerard Kuiper noted tall mountains at the lunar south pole and thought these might form part of its rim. Other sections of the basin rim were photographed from lunar orbit by the Apollo 8 astronauts in 1968, but the overall picture remained murky.

A decade ago, however, images from the Clementine probe, assembled into mosaics to cover large areas, clearly showed the basin floor is distinct from surrounding terrain — in particular, it appears darker. Laser altimetry also put figures on the basin's gross properties: 1,600 miles (2,600 kilometers) wide and 7.5 miles (12 km) deep.

In Clementine surface-composition maps, the basin stands out prominently. Observations with a later generation of sensors on Lunar Prospector (1998–1999) showed the soil is more iron-rich and slightly more radioactive than the rest of the Moon's surface. It also generally lacks the typical anorthosite minerals retrieved from the nearside by Apollo astronauts.

Scientists want to get their hands — and instruments — on rock samples from South Pole-Aitken. "Sample return from the basin is one of the highest-priority science missions," wrote a team of lunar scientists in 2003. The mission, they added, comes "second only to Kuiper Belt-Pluto exploration."

Samples should help scientists answer the most fundamental question about the South Pole-Aitken basin: How old is it?

The many craters it bears indicate the basin is quite old. Graham Ryder of the Lunar and Planetary Institute said in 2000 that it may be as young as 3.92 billion years old — still older than all the nearside basins — or as old as 4.3 billion years.

Knowing where the basin's birth falls within that range will help scientists better understand the period called the Late Heavy Bombardment. Debate has raged for decades whether this period belonged to the final stage of planetary formation — or if it was a separate shower of asteroids and giant meteorites caused by some unknown disruptive event.

Probing the rubble

Scientists expect to find the basin full of well-mixed rocks of a type called melt breccia. This results from "gardening" by random impacts over the ages. The samples will include fragments from deep within the Moon's crust, possibly from the upper mantle. Orbital measurements indicate the basin holds minerals not found elsewhere on the Moon's surface. Although lunar geologists estimate about 20 percent of the basin's material comes from elsewhere on the Moon, they are confident they can identify the special local minerals.

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Spudis describes the process: "You take a lot of remote-sensing data and learn the properties of the basin floor in a regional sense. That would let you interpret the samples you get as belonging to that unit or not."

The long impact history introduces a lot of room for error. Cautions Spudis, "With a sample from the Moon, you never know if you're really sampling a regional unit or something else. Yes, you can grab samples and probably get pieces of the basin floor. But saying this or that piece comes from the impact melt sheet or is from the lower crust — well, that's more problematical."

He laughs. "We make a landing, we obtain some samples — and then we spend the next 30 years trying to figure out what they're telling us."

Within the basin are some unique features, and geologists want to sample them all — either with rovers or multiple fixed-lander missions. Central peaks of large craters should contain samples from below the basin debris. A feature dubbed Olivine Hill in the central region may be a deposit of the deepest rocks.

Northwest of there, according to Carle Pieters of Brown University, is a thorium anomaly she describes as "an enigma." It may be debris from the Imbrium impact on the exact opposite side of the Moon. Scientists have already mapped and sampled a region adjoining Imbrium that is rich in thorium and other radioactive minerals.

Dating the cataclysm

The first proposed sample-return mission to this area was developed in the late 1990s for NASA's low-cost Discovery program, but it was not selected. The mission would have used a stationary lander with a robotic arm and screening device to collect a pound or two of small rocks and dust.

A relay satellite placed in lunar orbit would have provided less than a week of communications between the lander on the farside and Earth; the lander would have needed to act quickly and then blast off with whatever it had collected.

In 2003, another robotic mission called Moonrise, proposed by Colorado School of Mines' Michael Duke, also failed to get the nod under a different NASA program.

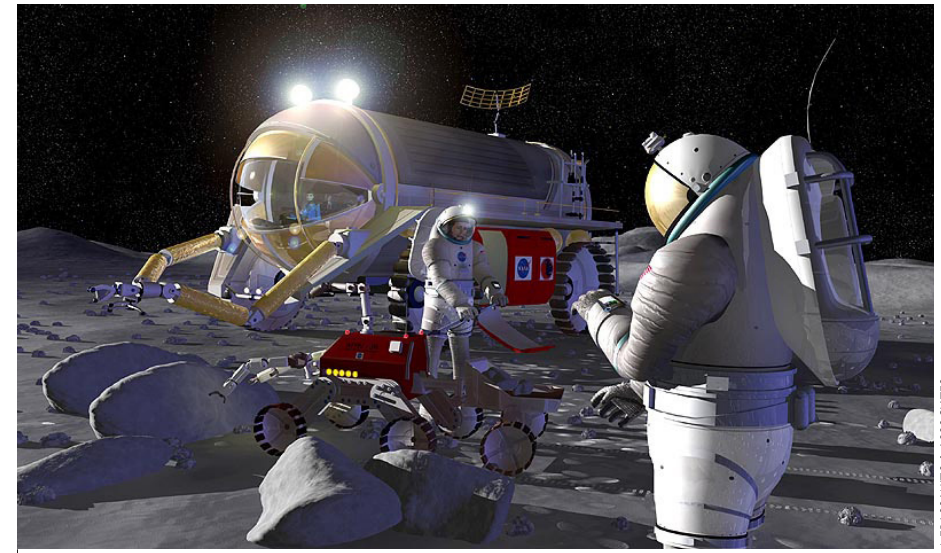
As Spudis observes, however, "With a robotic mission, you have a large chance of getting an ambiguous answer. The older the event on the Moon, the less certain you are that a sample you pick up is related to that. And going to the oldest feature on the Moon just magnifies the problem many times over. You can't be sure what you've got — even after you have it."

NASA's renewed emphasis on returning to the Moon may remove some of the hurdles scientists and mission planners have faced. And the possibility of having trained crews on the Moon opens many possibilities for pathbreaking science.

Says Spudis, "If you go back to the Moon permanently and can revisit sites to understand things in their true field context, I think that'll be a whole different ball game." Follow-up work, he notes, is extremely important in terrestrial geology.

"If people go to live at the south pole as part of a human return to the Moon," he says, "I think they'll have a very good chance of unraveling a lot of the South Pole-Aitken mystery." ▲

ONLINE EXTRA For more on dating the Moon's early history, go to www.astronomy.com/toc



J. FRASSANITO & ASSOCIATES

EXPLORING THE MOON will help scientists learn more about the solar system's history and our place within it. It's an essential step in the journey to Mars.