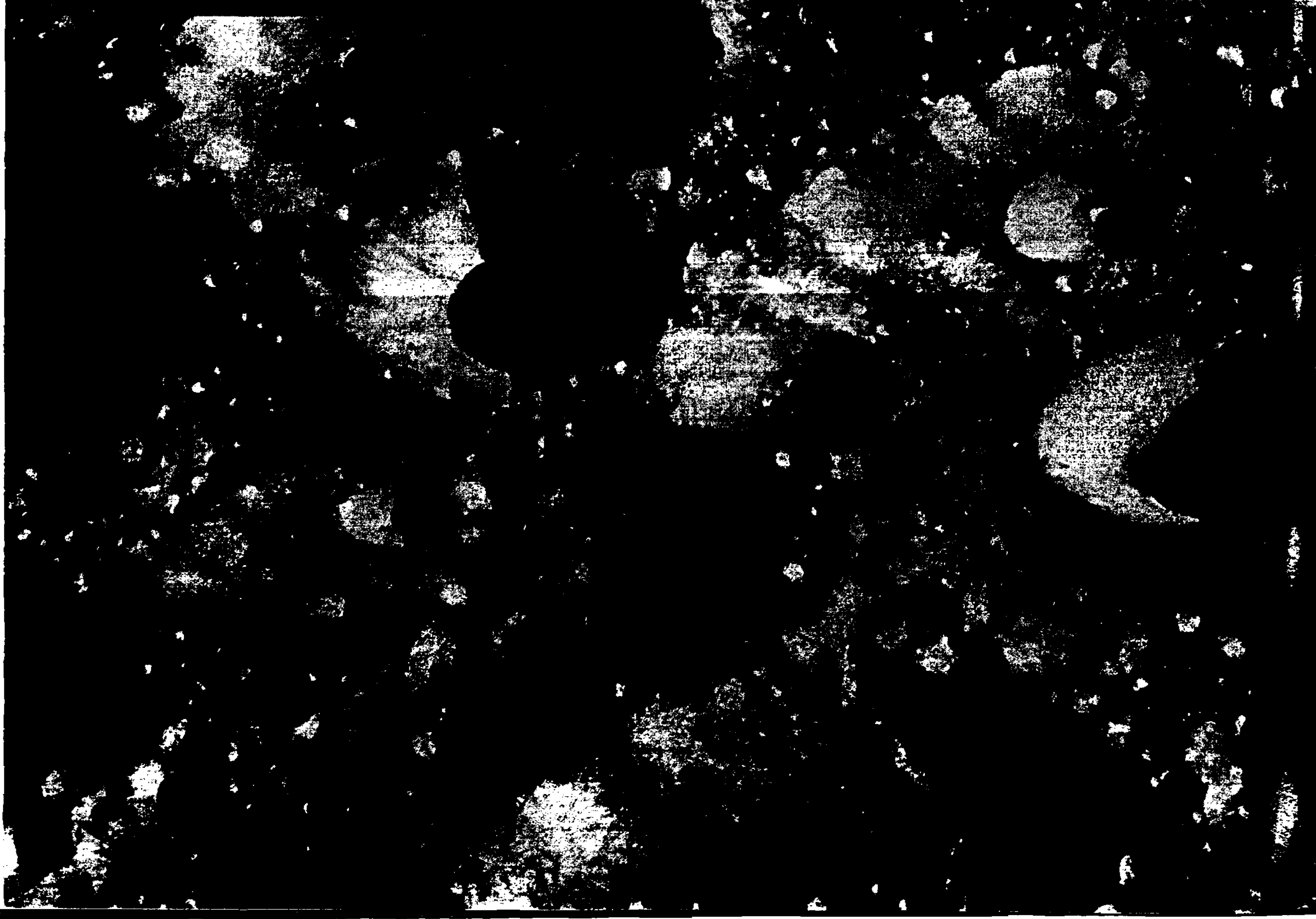
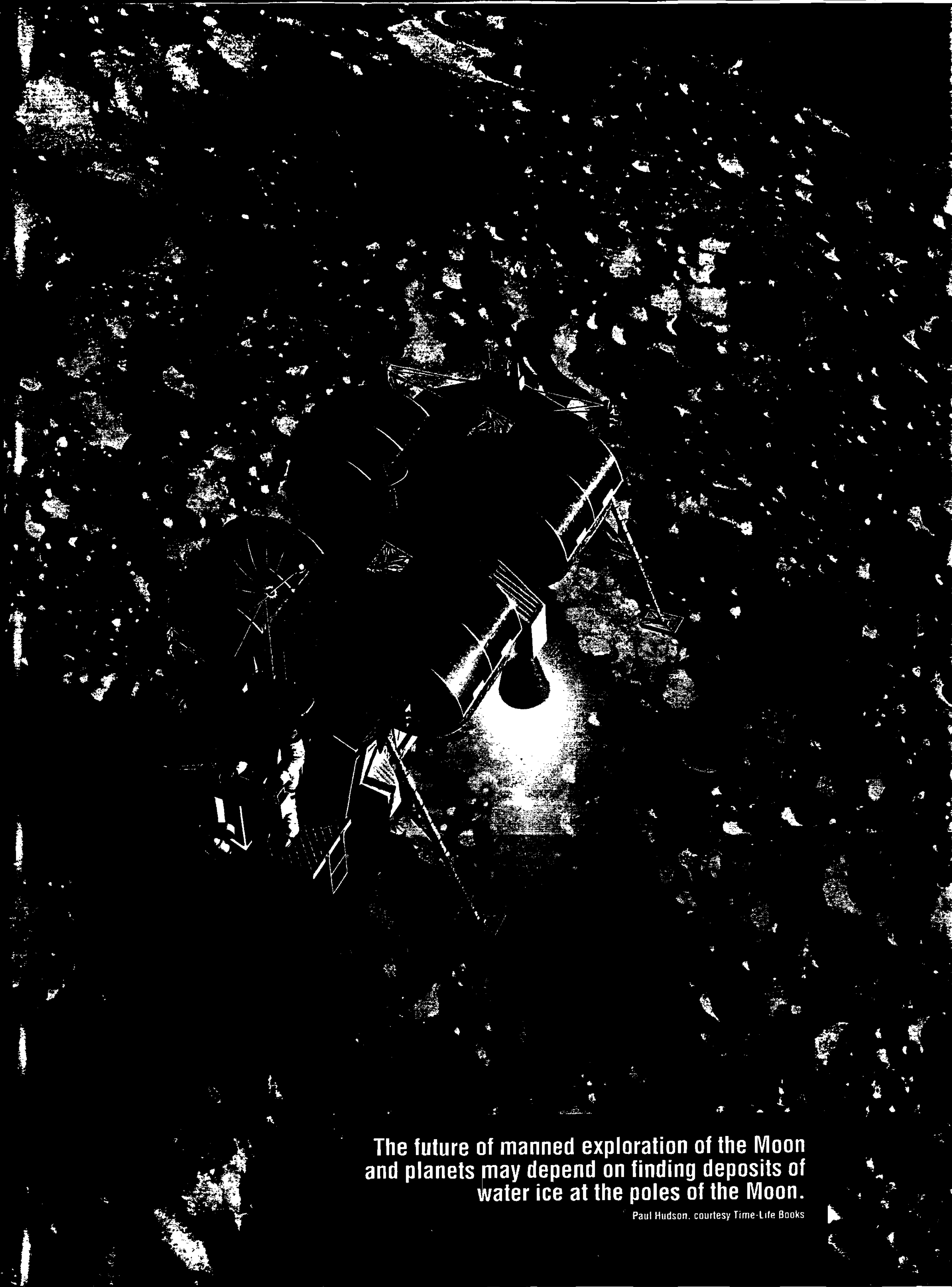
SEARCH FOR THE Lost Lunar Lakes

BY BRUCE CORDELL

At the Moon's north and south poles, the perpetually dark floors of lunar craters could hide deposits of a substance rare on the Moon — water.





The future of manned exploration of the Moon and planets may depend on finding deposits of water ice at the poles of the Moon.

Paul Hudson, courtesy Time-Life Books

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The Audit Bureau

An adventure worthy of Indiana Jones is taking center stage in the world of space exploration — the search for the lost "lakes" of the Moon. The outcome of the search will affect how we conduct manned exploration of the planets in the coming decades.

If the lakes are found, the Moon becomes the initial goal for human space exploration, even settlement. If they aren't, NASA could launch a direct-to-Mars movement that might leave the desiccated Moon in the backwaters of space exploration. NASA's current interest in return missions to the Moon spotlights the possibility that water brought to the Moon by the impacts of comets might exist at the lunar poles.

Seekers of the Lost Lakes

In 1610 Galileo thought he had discovered lunar lakes. And based on the lunar place names — such as the Sea of Tranquillity and the Ocean of Storms — other early explorers of the Moon concurred. Although the lunar maria were soon proven to be dry beds of lava, the optimism for finding water everywhere on the Moon continued until the first Apollo landings more than 20 years ago. Early plans for lunar bases published in the 1960s suggested that rocket propellants might be produced from moisture expected in the lunar soil. Mission planners hoped then (and as we shall see, still hope) that not having to import water from Earth would dramatically reduce the cost of lunar operations and facilities.

But the Apollo verdict was "no water." All the Apollo lunar samples were completely dry except for a few "rusty" rocks brought back by Apollo 16 that were probably contaminated by water in Earth's atmosphere. Indeed, we have no direct evidence for water deposits anywhere on the Moon. Nevertheless, the hopes of finding water still remain.

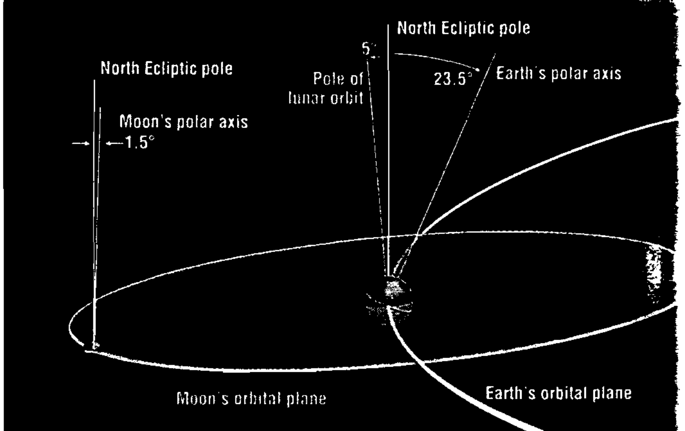
Recent ideas for a moist Moon originated back in 1837, when German astronomer Johann Mädler explained the significance of Mountains of Eternal Light at the Moon's north pole. Most locations on the Moon receive 14.75 days of sunlight in each 29.5-day cycle of phases, but mountains at or near the poles receive nearly continuous sunlight because the Moon's equator is inclined only 1 1/2 degrees to the plane of the solar system. This also implies there are crater floors or valleys that never see the Sun and must be extremely cold. These polar cold traps might capture gases such as water vapor and retain them as ices for millions of years or longer.

Could lost lakes be hiding in the Moon's polar regions? In 1961, Kenneth Watson, Bruce Murray, and Harrison Brown of the California Institute of Technology said yes. They proposed mechanisms that showed how cold traps could capture gases such as water vapor released from deep within the Moon. For cold-trap temperatures of 100 K or less (–173° C), their model predicted water could remain frozen at the lunar poles for the Moon's entire lifetime.

Ten years after the first Apollo lunar landings, James Arnold of the University of California, San Diego, commented that like the lunar lakes, "an important paper by Watson, Murray, and Brown (1961) seems to have been lost."

Arnold reexamined Watson, Murray, and Brown's 18-year-old study in light of the flood of data from

The south pole and the north pole, which is seen here in a 1967 image from Lunar Orbiter 4, are illuminated by sunlight at a very shallow angle. As a result, the lunar poles harbor permanently shadowed craters that could trap ice for millions of years.



There are no "seasons" on the Moon because the Moon's rotation axis is tipped by only 1.5°. Sunlight grazes the polar regions at the same low angle throughout the year, producing areas of permanent shadow.

ASTRONOMY: Thomas L. Hunt

Apollo. The original study had assumed the only source of lunar water was the Moon itself, from gases vented from the interior. Arnold proposed a second source of water: the impact of water-rich meteors and icy comets.

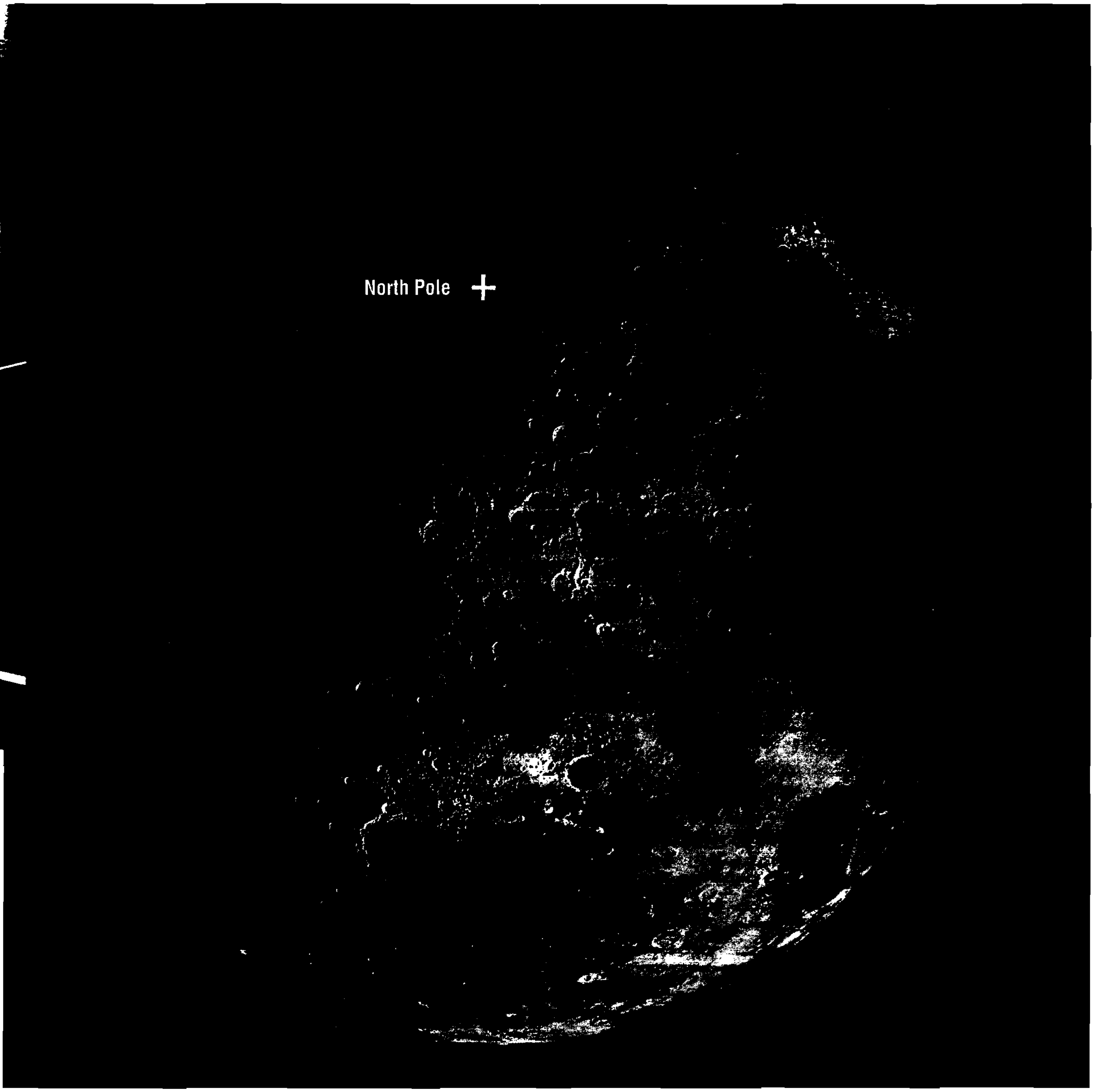
Raiders of the Lost Lakes

Arnold also pointed out ways that ices trapped on the Moon could be eroded. For example, both ultraviolet radiation and the impact of atomic particles from the solar wind could destroy water molecules by splitting them into their constituent hydrogen and oxygen atoms. These would then escape from the Moon.

Despite uncertainties about how well any of the water sources and destruction mechanisms might work, Arnold concluded that polar ice deposits probably exist. He also suggested that so-called gardening of the lunar soil by the constant impact of meteoroids might mix the water through the regolith to a depth of 2 meters and produce a typical concentration by weight of 1 to 10 percent.

That's the optimistic estimate. Other researchers found the erosion mechanisms might be more effective than Arnold had estimated. Experiments conducted by Louis Lanzerotti of Bell Laboratories revealed that unlike sunlight, which shines from one direction and forms shadows, solar wind particles bombard the Moon from all directions and rain down on even permanently shadowed regions.

Lanzerotti estimates that interplanetary space, including that surrounding the Moon, is filled with



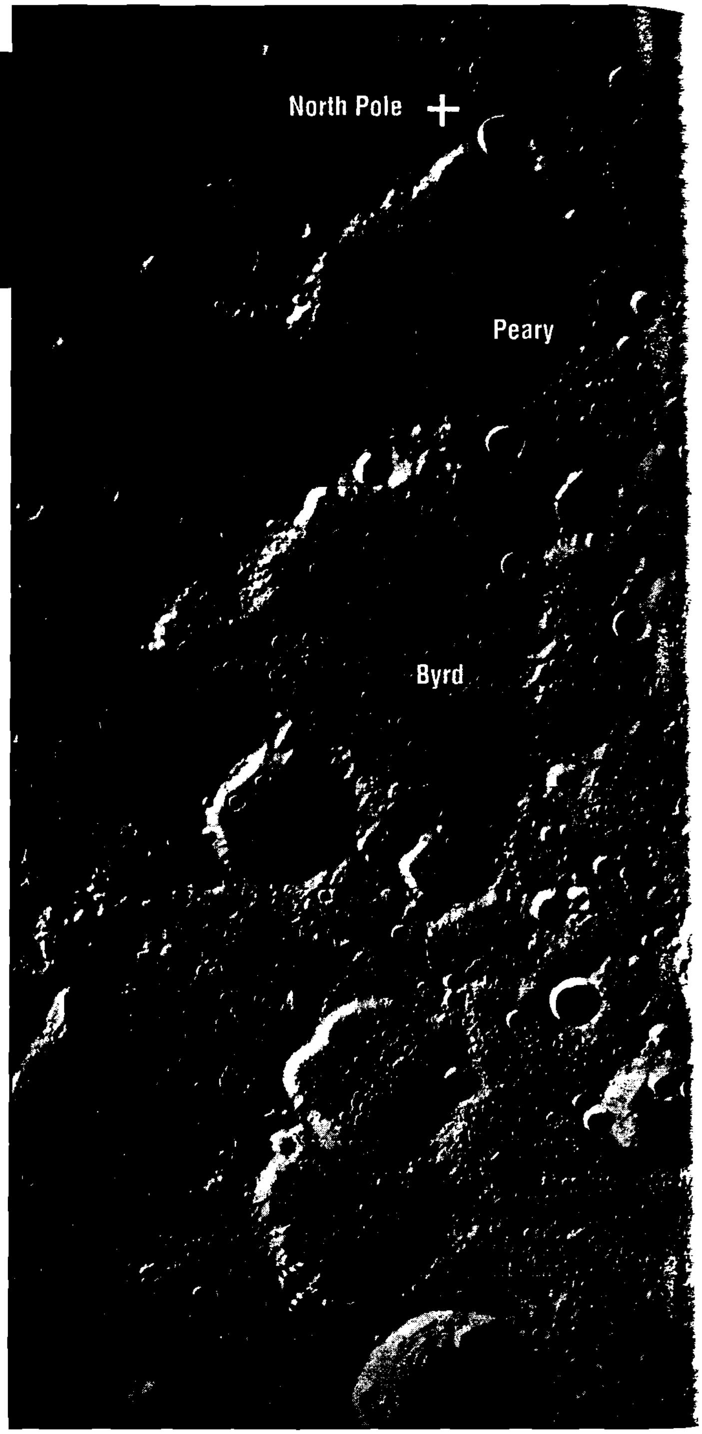
NASA

energetic particles from solar flares about one-third of the time. Also, for a few days each month the Moon passes through the Earth's magnetic tail and is exposed to charged particles (mostly hydrogen ions) trapped in the tail. All these particles might reach any portion of a polar cold trap and erode exposed frozen water. According to Lanzerotti, water would be removed as fast as it was deposited. Gardening of the soil by the spray from local meteor impacts would offer little protection.

There's more bad news for water-seekers. Richard Hodges, Jr., of the University of Texas at Dallas, finds that bowl-shaped craters with diameters less than 20 kilometers produce most of the permanently shadowed areas at the Moon's high latitudes. But surprisingly, his calculations show that bowl-shaped craters do not provide significant storage areas for polar water. This is because their permanently shadowed floors are heated to above 100 K (except at latitudes above 85 degrees) by infrared radiation from their surrounding walls.

Flat-floored craters are another matter. Hodges' analysis shows that flat-floor craters above latitudes of 80 degrees have significant areas with cold-trap potential. However, he concluded that the total surface area on the Moon cold enough to provide permanent water traps is much less than that estimated by Arnold and Watson. But because large amounts of water can be held on the surfaces of soil grains, Hodges still agreed with Arnold's tentative conclusion — a sizable reservoir of water could be stored near the lunar poles, if there is an adequate supply of water.

Before Galileo, our last glimpses of the Moon's north pole (right) and south pole (far right) were 26 years ago in these shadowy images from Lunar Orbiter 4.



Springs of the Lost Lakes

Astronomers now think the most probable sources for lunar lakes are the impacts of comets and eruptions of gases from the Moon's underlying mantle. Most of the lunar outgassing should have occurred very early in lunar history, when the Moon was much hotter and molten regions were closer to the surface. When volcanic gases, including water, encountered the polar regions they should have been trapped there. Could 4-billion-year-old lunar lakes have survived to the present?

S. K. Runcorn of the University of Newcastle upon Tyne has suggested that the Moon's rotational poles wandered about early in the Moon's history. The force of the impacts that created the large basins near the equator could have shifted the entire outer skin of the Moon around. The crust could have slipped away from the Moon's rotation pole by as much as 50 degrees of latitude. Regions previously near the poles and permanently shadowed would be relocated closer to the equator. Any ices frozen in the soil would be lost.

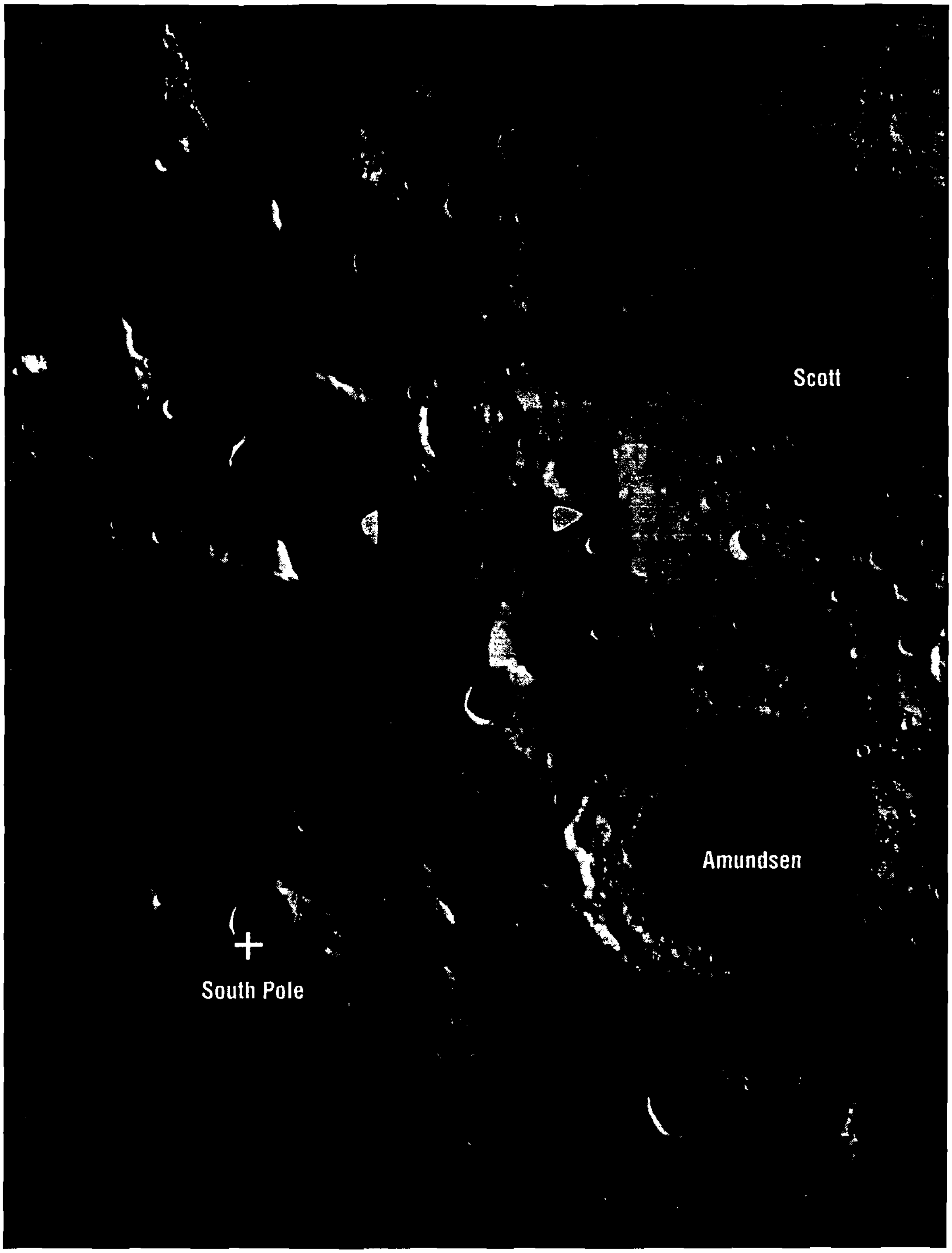
Runcorn bases this model on the observed orientations of ancient magnetized lunar rocks, which seem to document three such monumental shifts during lunar history. However, attempts by others to confirm Runcorn's model have been inconclusive. If Runcorn is correct, the crust didn't settle into its present orientation relative to the rotation axis of the Moon until about 3.2 billion years ago. Any lunar or cometary gases trapped at the poles prior to 3.2 billion years ago would have been lost due to polar wandering and exposure to the Sun.

So if we want to find lunar lakes we need to look for sources of water that have been active since that time. Volcanic activity is one source but a controversial one. As far back as the late 18th century, William Herschel observed several localized red glows and suggested they were volcanoes. Other observers have reported strange glows on the Moon, which have become known as Lunar Transient Phenomena, or LTPs.

Astronomers have now catalogued over 1,200 LTP observations, some made recently by reliable observers. A spectrum taken in 1958 by Russian astronomer Nikolai Kozyrev documented an event in the crater Alphonsus that suggested gas emissions. LTPs have been reported at several sites, although 40 percent of all LTPs occur near the crater Aristarchus. The glows seem to be correlated with deep and shallow moonquakes. All appear related to tides raised by the gravity of Earth. Although the cause of LTPs is uncertain, it is possible they are evidence of the release of volcanic gases from deep within the Moon. Even so, their contribution to the lost lunar lakes is probably minor relative to the contribution of comets.

Comets appear to be the most likely source of lunar polar waters. A comet can deliver as much water in one impact as lunar outgassing or meteors can in billions of years. A comet impact is rapid and produces an appreciable but temporary atmosphere around the Moon which might then condense at the poles. Arnold calculates that comets may have delivered as much as 100 million million kilograms of water to the lunar surface over the last 2 billion years.

There is growing evidence for swarms of comets that occasionally invade the inner solar system from a distant reservoir of comets called the Oort Cloud. On Earth, the signatures of alleged comet storms include mass extinctions, impact crater clusters, and reversals in the geomagnetic field. Scott Tremaine and his colleagues at the University of Toronto have suggested that intense comet showers occur at random times in response to close encounters with nearby passing stars. Others think that comet showers are regular occurrences triggered by an as yet unseen companion star orbiting the Sun.



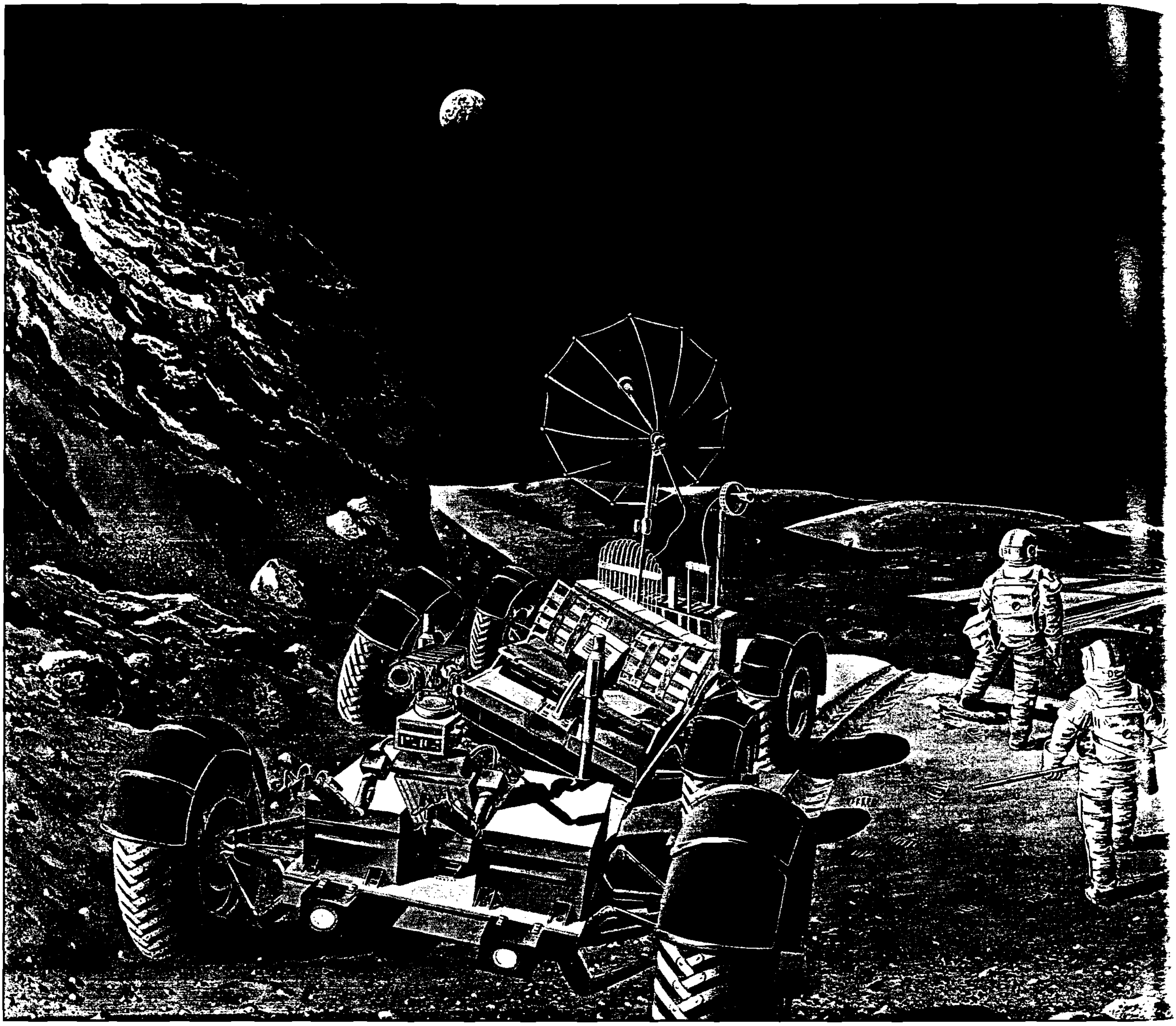
In any case, the "rain" from a comet storm could be intense — up to 10,000 comets per year swooping near the Sun. According to one model, the most recent cometary assault ended only 13 million years ago. Any resulting comet-derived polar ices on the Moon that were gardened into the regolith should still be there.

A Snowball's Chance

The prospect for lunar lakes received a boost in August 1991 when astronomers used radar to discover what may be a water ice cap at Mercury's north pole — remarkable on a planet where midday temperatures exceed 800 K, over 400 K hotter than the Moon.

Martin Slade of the Jet Propulsion Laboratory and his colleagues have converted the radar data into images of Mercury's surface. (See AstroNews, February 1992.) Without a doubt, a large, radar-bright feature in the shape of a polar cap adorns the north pole. Based on the radar appearance of Mars' south polar ice cap, the radar astronomers suggest the Mercurian cap is also composed of water ice. Critics counter by offering metallic evaporites such as tin, copper, and zinc as candidates for Mercury's cap. They believe an ice cap on Mercury is as likely as the proverbial "snowball in hell."

As with the Moon, ideas about the formation of Mercury's ice cap focus on permanently shadowed craters in the polar regions. Calculations suggest that polar temperatures may dip to 125 K or even lower inside crater walls on Mercury, assuming more than 50 percent of the sunlight is reflected from the surface. Due to Mercury's elliptical orbit and the lock between the length of its year and its day (Mercury's year is 1.5



times as long as its day), the Mercurian cap should be oblong, about 100 by 400 kilometers.

Over the last few billion years, Mercury would have been subjected to the same water sources and erosion mechanisms as the Moon. But the higher temperatures and increased effects of solar wind particles should have made Mercury a less likely place to find polar caps. If Mercury does have water ice caps, it's possible the Moon has them too.

Expeditions to the Lost Lakes

The only way to settle the question of whether the Moon is wet or dry is to go there with a space probe dedicated to the task. The last spacecraft to explore the Moon in detail were the manned Apollo missions and Soviet Lunokhod robot rovers of the 1960s and early '70s. Since then, despite its proximity — or perhaps because of it — the Moon has received few visitors. And fewer still have ever explored the north or south poles of the Moon. The only spacecraft to orbit over the poles were the unmanned Lunar Orbiter 4 and 5 space probes in 1967. Their missions were simple: photograph the Moon so astronomers could produce detailed maps in preparation for the Apollo landings. The Lunar Orbiters had no instruments for analyzing the lunar surface, let alone for finding hidden water deposits.

In December 1990 the Jupiter-bound Galileo probe flew past Earth and the Moon and photographed the poorly observed lunar farside, the first spacecraft to do so since the early 1970s. (See March 1991 ASTRONOMY.) Then again, just a few weeks ago Galileo returned for another gravity-assist maneuver before heading off to the outer solar system. This time Galileo flew over the Moon's north pole, giving us our first look at that mysterious region since the days of the Lunar Orbiters.

Although Galileo bristles with sensors and cameras, its instruments are optimized for exploring the atmosphere of Jupiter. Galileo lacks the one instrument most needed to search for subsurface lunar ice — a gamma-ray spectrometer. As it passes above a planet,

Sites near the lunar poles with deposits of ice may become the choice locations for manned lunar bases in the 21st century.

Dennis Davidson/NASA

such an instrument can detect neutrons emitted from the soil below. Underground ice deposits slow down these neutrons, a telltale sign a gamma-ray spectrometer can detect. So while Galileo will certainly tell us about the mineral composition of the Moon's polar regions, it is unable to find direct evidence for any lost lakes that may be present.

The craft that would have settled the question was a mission called Lunar Observer, essentially a twin to the Mars Observer probe now on its way to the Red Planet. Mars Observer has a gamma-ray spectrometer, as would its lunar counterpart. But Lunar Observer never made it off the drawing boards.

As a lower-cost alternative, NASA proposed two small Lunar Scout missions for the late 1990s. One would have been dedicated to mapping the gravitational field of the Moon and measuring the height of lunar features. The other orbiter would have mapped the mineral and soil composition with cameras sensitive to different parts of the spectrum as well as with an all-important gamma-ray spectrometer. Both missions were part of NASA's Space Exploration Initiative, a program aimed at returning humans to the Moon and on to Mars. Congress slashed funds for the Initiative and with them went the Lunar Scouts.

One lunar mission is in the works, however — one that few people have heard of. It comes not from NASA but from the Department of Defense. In January 1994 the DoD will launch a small satellite toward the Moon called the Integrated Sensor Experiment (ISE). The mission is part of the Strategic Defense Initiative or "star wars" program and is designed to test new high-tech cameras in the environment of space. The small spacecraft contains three miniaturized camera systems, one sensitive to long-wavelength infrared, one for short-wavelength infrared, and one for visible and ultraviolet light. Department of Defense officials invited NASA scientists to work with them on the ISE mission (which the NASA astronomers have oddly dubbed "Clementine") to ensure ISE returns useful science.

For two months in early 1994, ISE will orbit the Moon at a distance of 400 to 3,000 kilometers. It will then leave lunar orbit and head off for an August 1994 flyby of the asteroid 1620 Geographos, one of the growing number of asteroids astronomers are discovering whose orbits approach Earth. The ISE probe will fly to within 100 kilometers of Geographos, giving us our first close look at a near-Earth asteroid.

During its lunar sojourn ISE's cameras will map the Moon at various wavelengths to a resolution of a few hundred meters. Like Galileo's instruments, ISE's cameras should tell astronomers about the mineral composition of the Moon but, unfortunately, they are unable to directly detect water. But with all other plans for lunar exploration by NASA on hold, missions such as Galileo's flyby and ISE are the only opportunities we have in the near future for finding the Moon's lost lakes.

If we ever do find water on the Moon, the icy locations may become the best sites for manned lunar bases. The water could be extracted from the soil using microwave ovens to heat the soil and release the water. Once free, the water would be used for life support systems and for manufacturing rocket fuel. In addition, the poles provide a useful combination of continuous sunlight for power generation and permanent darkness for keeping rocket propellants, ice, and other essentials in natural cold storage.

Certainly the advantages of a polar site make the Moon's north and south poles very attractive locations for future manned landings. Perhaps in the next century, we'll see the first human settlements on another world built on the shores of the lost lakes of the Moon. □

Bruce Cordell is a planetary scientist involved with planning advanced missions to the Moon and Mars.