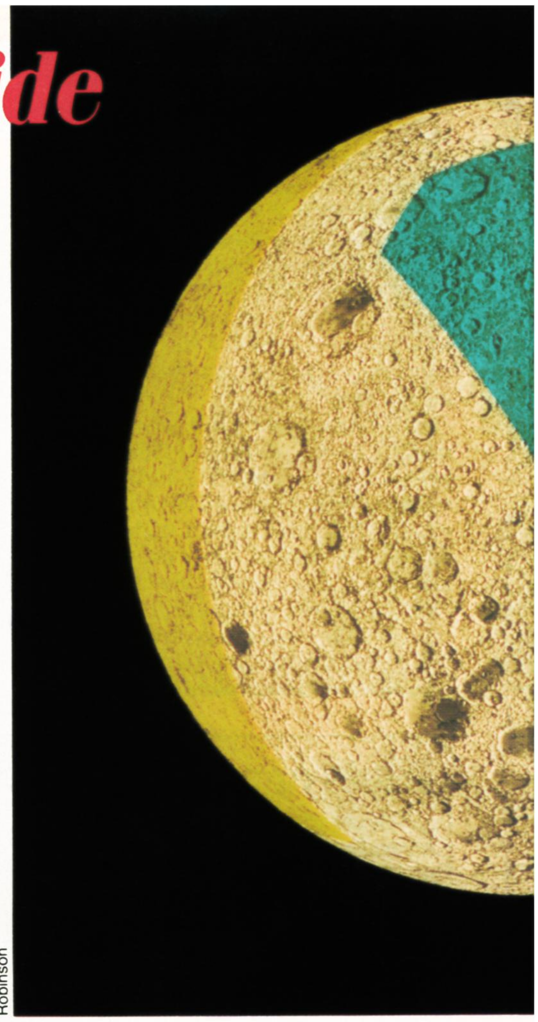
A Look on the Far Side

Unveiling the composition of the moon's hidden half

By RON COWEN


Robinson

"Everyone is a moon, and has a dark side which he never shows to anybody."
— Mark Twain

Nearly three decades after spacecraft began orbiting the moon, that crater-pocked body has become one of the most extensively explored objects in the solar system. Yet the moon hasn't surrendered all its secrets. Lunar scientists are still in the dark about the composition of its far side — the elusive hemisphere that always faces away from Earth.

U.S. and Soviet lunar-orbiting craft have photographed portions of the far side, but nearly all with limited imaging ability — they viewed the moon only in white light, not in any of its component colors. "It's a little like flying blind," says geologist James W. Head of Brown University in Providence, R.I. Although white-light photos reveal the shapes and relative brightness of surface features, they do not identify chemical composition. Surface composition, Head and others say, provides a crucial clue to the nature of volcanic eruptions, meteorite impacts and other upheavals that shaped the surface of the moon.

Identifying minerals on the lunar surface and their abundances requires an imaging system that can view a given region at several different wavelengths, or colors, notes Carle M. Pieters of Brown University. For example, a surface that reflects a higher intensity of green light than near-infrared light may contain a high concentration of iron compounds; a region that reflects relatively more blue light than red hints at high levels of titanium oxide. That's because each mineral has its own spectral "fingerprint" — absorbing a unique combination of light at varying wavelengths.

Scientists have already mapped much of the chemical composition of the moon's near side, thanks to the ability to view this part of the moon from Earth and to the lunar rock samples gathered by U.S. astronauts and unmanned Russian craft. But exploring the composition of the far side has proven more challenging.

Only two of the many lunar missions carried extensive color filter systems or spectrometers that could analyze both visible- and near-infrared light, a prerequisite for studying surface chemistry. Thus, researchers are working hard to glean what they can from images taken by a camera aboard the Jupiter-bound Galileo spacecraft, which in December 1990 photographed the western edge of the far side and part of the near side at several visible-light and near-infrared wavelengths. These images complement others taken with two television cameras aboard the much earlier Mariner 10 mission, which in 1973 obtained pictures of the eastern edge of the moon's far side as it sped by to rendezvous with Venus and Mercury.

At the time, researchers dismissed the Mariner pictures as virtually useless because they had been taken after an onboard heater, designed to keep the temperature of the cameras within a stable operating range, failed. Scientists assumed the resulting temperature fluctuations would cause brightness differences in the images that would bear little resemblance to the actual reflection properties of the moon's surface.

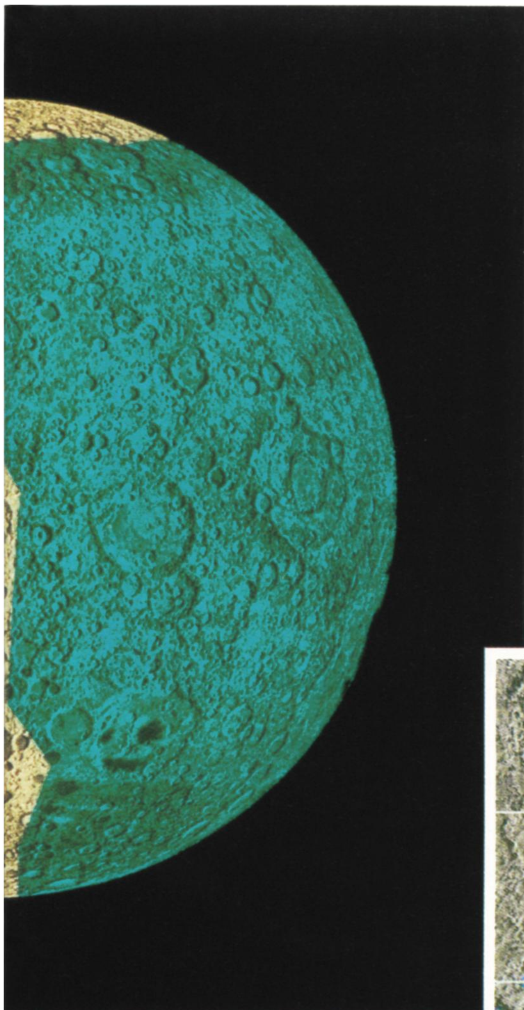
But a recent, painstaking analysis of old computer tapes now indicates that some of the Mariner images do provide an accurate, multi-wavelength portrait of parts of the far side.

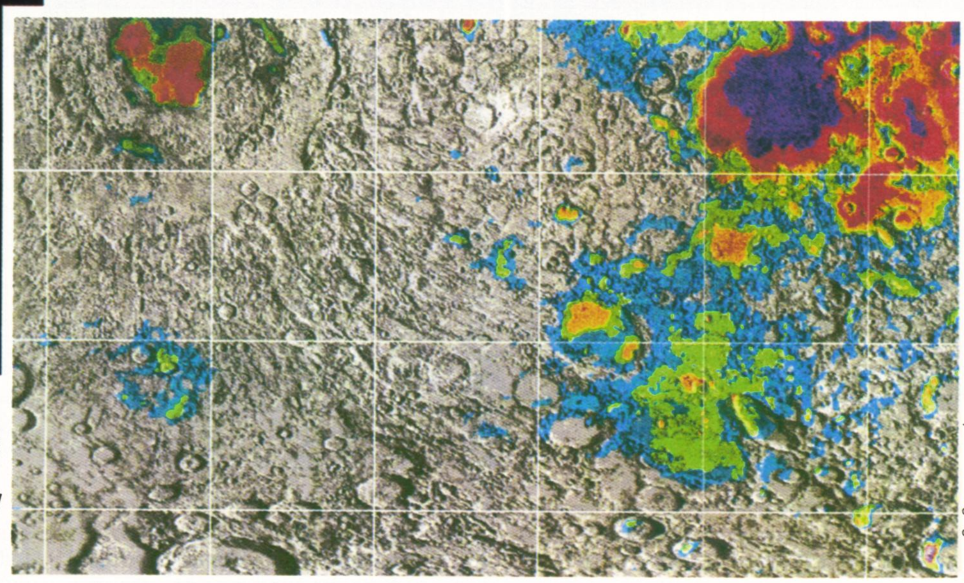
Together, images from Mariner 10 and Galileo, each depicting a different part of the far side, are helping astronomers decipher in detail the composition of the moon's hidden half. Researchers reported some of their newest findings in March at the annual Lunar and Planetary Science Conference in Houston.

Two types of terrain form the moon's outer surface, or crust. The light-colored highlands, believed to be the original crust, apparently represent the brighter, lower-density minerals that floated to the surface of a molten ocean of material early in the moon's history. In contrast, the dark plains — regions known as maria — formed later. The newly analyzed images may shed light on the evolution of both types of crust.

Maria means "oceans" in Latin; indeed, the astronomer Galileo and his Renaissance colleagues believed that the dark, splotchy plains visible from Earth represented large bodies of water. Researchers generally agree that maria represent the aftermath of volcanic eruptions — lava flows that rose to the surface 4 billion to 2.5 billion years ago and filled in the huge basins carved out when meteorites slammed into the lunar surface, excavating parts of the highlands.

Images from both the Mariner 10 and Galileo craft confirm previous findings that the maria are much less abundant on the far side. This suggests that the far side may undergo milder volcanic activity because the thicker crust of this hemisphere prevents lava from reaching the surface, Head notes. But among these unknowns, a fundamental question re-





Mustard/Galileo imaging team

Above: In this view of the moon's far side, yellow denotes region mapped 19 years ago by Mariner 10; blue depicts region mapped in 1990 by Galileo; and brown indicates portion of the far side not mapped by any spectral instrument. Right: Color-coded image of the moon's southern hemisphere, straddling the near and far sides, shows relative abundance of maria compared with highland crust. Purple indicates regions containing pure maria; black-and-white indicates pure highland crust; and blue denotes a mixture of both materials. Some blue areas may contain cryptomaria – places where a thin layer of highland crust shrouds underlying maria.

mains: When did the maria, which cover 16 percent of the total lunar surface, first begin to form?

Galileo and Mariner 10 images suggest that some maria predate the development of huge impact basins. Observations made during the Galileo flyby, for example, strongly indicate the presence of maria partially buried beneath two large basins – one at the western edge of the near side, the other straddling both hemispheres at the western edge. Lunar scientists call such buried maria "cryptomaria," for hidden, or covered, maria.

Previous craft had found hints of cryptomaria on the near side. Images taken in white light had shown halos of dark material, resembling maria, that surrounded kilometer-size craters in some regions of the highland crust. But the Galileo photographs provide far stronger evidence. Images taken at several wavelengths readily reveal the dark, iron-rich fingerprint of maria extending for hundreds of kilometers at the site of old impact basins.

This finding, notes Brown University geologist John F. Mustard, suggests that some maria existed before the giant impact basins were created – more than 4 billion years ago, in an era sometimes called the Great Bombardment. In addition, he says, the new work hints that early volcanic activity that formed maria was more extensive than thought.

According to one model proposed by several researchers, meteorite impacts cast out highland debris from the lunar crust. The debris formed a kind of thin burial shroud for the ancient maria. Such buried maria would never have been seen clearly by any craft sensitive only to white light. But instruments that view the surface at several wavelengths can detect the relatively small amounts of dark, underlying maria mixed with the lighter-colored shroud of highland crust.

Head says he expects Galileo to uncover more cryptomaria when it returns to the moon this Dec. 7, flying over the far and near sides of the lunar north pole as it begins the final leg of its looping flight to orbit Jupiter in 1995.

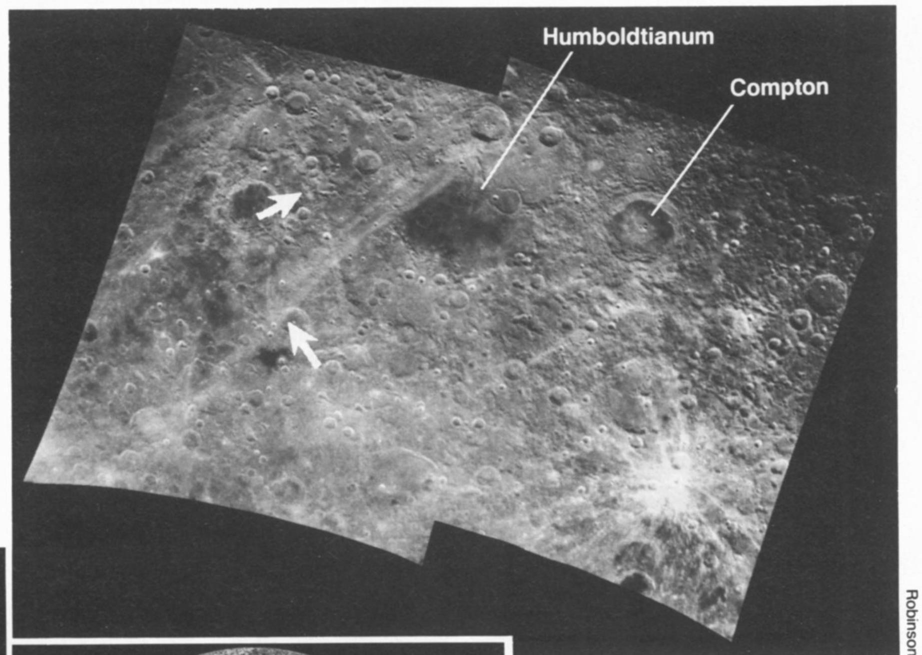
Galileo has already examined a huge, bizarre depression at the far side of the moon's south pole, called the South-Pole Aitken basin. Researchers have known about South-Pole Aitken since the late 1970s, but few of its features were well characterized. The craft found that the basin extends about 2,000 kilometers across, which makes it one of the moon's largest. South-Pole Aitken's iron content seems more similar to the assumed composition of the lunar interior than to that of the highland surface. Its floor also appears relatively dark, though not as dark as the near-side maria, Galileo found.

South-Pole Aitken's unusual features may have a simple but provocative explanation, Head says. He and his colleagues on the Galileo imaging team, including Scott L. Murchie of Brown University, suspect the basin was formed by the impact of a meteorite so huge and forceful that it ejected material from the deepest part of the crust, perhaps even the underlying mantle. Confirmation of this model awaits new instruments – now planned for a 1995 mission to the moon – that will examine South-Pole Aitken in more detail and at many more wavelengths, Head notes. But if the theory proposed by Head and his co-workers proves correct, South-Pole Aitken may represent the prime site for studying exposed layers of material that originated many tens of kilometers below the lunar surface.

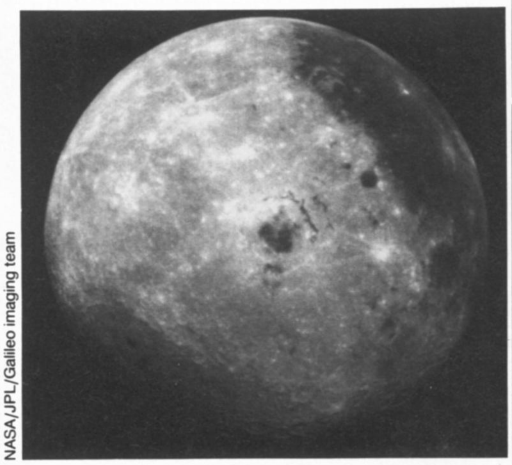
If lunar scientists had high hopes for the far-side images taken by Galileo, they had all but forgotten the images taken nearly two decades ago by Mariner 10. In 1988, Mark S. Robinson, a graduate student at the University of Hawaii in Honolulu, came across a booklet on Mariner 10 that mentioned its lunar imaging, long considered little more than a curiosity. For a class project on the moon, he decided to track down the pictures. A mission chart supplied by NASA's Jet Propulsion Laboratory (JPL) in Pasadena, Calif., further sparked Robinson's interest, since it indicated that Mariner 10 had taken several images of sites on the far side through different color filters – just the type of photographs that could reveal the composition of the lunar surface.

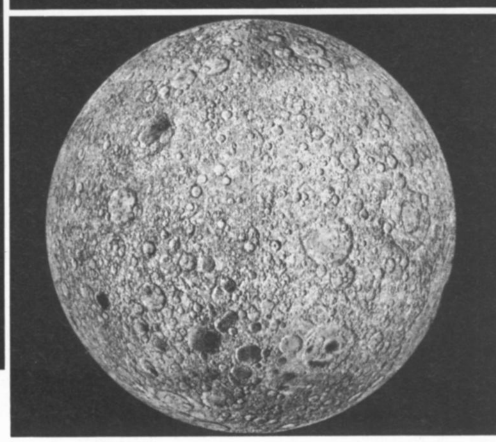
Researchers had concluded years ago

Right: High-resolution image of the moon's far side depicts two of the dark plains regions called maria – Humboldtianum and Compton – surrounded by the brighter highland regions. Several crater rays (arrows), features common on the moon, are places where meteorites slamming into the lunar surface have cast out material and dumped it on nearby surface areas. Bottom right: This view of the far side shows that the moon's hidden half contains far fewer maria than the near side. Below: An image taken by the Galileo spacecraft shows the moon's western limb and far side, centered on a dark plains region called Mare Orientale. Dark region at bottom left corner depicts South-Pole Aitken, one of the largest basins anywhere on the moon.



Robinson


NASA/JPL/Galileo imaging team


Robinson

that an investigation of lunar surface chemistry using the Mariner 10 images would prove fruitless, since the photographs lacked proper calibration. But such talk didn't faze Robinson. "If someone says you can't do it, that's just an invitation to try," he says. "I thought, 'I'm going to go ahead and check [the images] anyway, because I'm stubborn.'"

With assistance from JPL tape archivist Amy Hochstettler, who located valuable pre-launch calibration tapes of the cameras, and JPL scientist Bob MacKey, who translated Mariner 10 data tapes into a modern, usable format, Robinson came to a startling conclusion. Even after the infamous heater had stopped working, the –10°C temperature was warm enough to allow at least one of the cameras to function normally.

Over the next several years, Robinson and University of Hawaii colleague Paul G. Lucey worked to establish the proper calibration of separate far-side images taken with blue and orange filters. One factor complicated his labors: The sensitivity of the cameras' electronic light detectors, or picture elements, does not increase in direct proportion to exposure time or light intensity.

As a final check, Robinson applied his calibration to photographs Mariner 10 had taken of known features on the near side of the moon. In both hue and intensity, the images matched previous snapshots of these familiar regions. The calibration had worked.

Collaborating with Lucey and University of Hawaii co-workers B. Ray Hawke and Gregory A. Smith, Robinson recently completed a preliminary analysis of the Mariner images of the eastern edge of the lunar far side. The team found that this region contains far lower concentrations of titanium oxide than do many maria on the moon's near side. (Galileo revealed a similarly low concentration on the western part of the far side.)

Since the lunar maria appear to contain relatively large deposits of titanium – a valuable resource that people might one day mine – it would behoove NASA to know what regions harbor most of the oxide. In addition, says Robinson, the distribution of titanium oxide found by both Mariner 10 and Galileo dovetails with a key feature scientists already knew about the moon.

Several lines of evidence, including analysis of moonquakes and human-generated disturbances on the moon, have revealed that the lunar far side has a much thicker crust than the near side. Exactly why remains a matter of debate. But it seems clear, Robinson says, that a dense lava, such as one containing high levels of titanium oxide, would have a much harder time rising to the surface if it had to plow through a thicker crust. Thus, the lower concentration of the oxide on the far side matches with previous observations.

In examining the Mariner images, Robinson and his colleagues found that one far-side highland region had an unusually bluish cast, indicating an abundance of titanium oxide, typically associated with maria. The team says the finding provides supporting evidence that one of the moon's maria lies half-buried on the eastern edge of the far side.

Far-side regions that Galileo will view when it returns for its fleeting lunar visit in December should overlap with portions of the surface imaged by Mariner 10 in 1973, Robinson notes. Thus, Galileo's one-day photo session may help bolster some of the tentative findings suggested by Robinson and his co-workers.

As for Head, he looks forward to future missions that together will provide a portrait of the lunar surface over many wavelengths, ranging from gamma rays, at the shortest end of the electromagnetic spectrum, to the infrared. Indeed, instruments capable of capturing this broad range of radiation may fly aboard lunar explorer missions as soon as 1995.

By the end of this decade, says Head, the secrets of the lunar far side, already partially revealed by the Galileo and Mariner 10 spacecraft, may be fully exposed. □