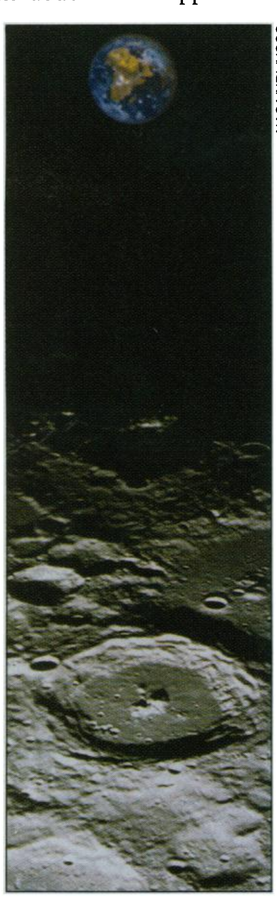
Geophysicists Celebrate Two Satellites, Mourn a Third

Searching for a common theme in a gathering as diverse as the spring meeting of the American Geophysical Union (AGU) in Baltimore last month might seem futile. But satellites, both natural and artificial, provided some of the meeting's high points. Researchers reported on the first science results from the Clementine spacecraft's 2-month sojourn orbiting the moon, the revealing color of the small moon that accompanies the asteroid Ida, and the planned termination of the Magellan spacecraft orbiting Venus.

Clementine Mines Its First Nuggets on the Moon

Clementine, the Department of Defense (DOD) spacecraft billed as the epitome of the "smaller, faster, cheaper" approach to exploring the solar system, had its doubters among planetary scientists. After all, Clementine's ultralight instrumentation was designed to test Star Wars technology, not to study planetary bodies. But the skeptics are in for a double surprise: The probe's 71-day survey of the moon is yielding new insights just a month after it ended, and many of them are coming from a laser ranging instrument that seemed better suited to tracking enemy missiles than the lunar surface.

Even researchers on the project had reservations about an instrument designed, as geophysicist Maria Zuber of Johns Hopkins University recalls the DOD wording, to measure the distance to a "dark metallic object" (presumably a missile), not the lunar surface. As it happened, the laser ranger succeeded in measuring the shape of the moon's surface to an accuracy of about 100 meters, giving investigators their first reliable, nearly global topographic map of the moon. Combined with measurements of lunar gravity, this map is letting investigators peer beneath the moon's surface for clues to its structure and history.


NASA/NRL/USGS

Glimpse of home. The view from Clementine (compressed for artistic purposes).

One clue emerged immediately: the recognition that, as Zuber put it, "the moon is a much lumpier place than we expected it would be." The Apollo missions had reported an elevation range of about 12 kilometers from the deepest to the highest points, but Clementine's laser traced a range of nearly 25 kilometers. It turns out that the moon's most extreme topography, such as the 12-kilometer-deep South Pole–Aitken impact basin, lies at high latitudes on its backside, largely out of view of both Earth-based radars and Apollo altimeters, which orbited near the lunar equator. That the moon has supported such topographic extremes over the 4 billion years since the biggest craters were formed suggests that its rigid outer shell was far stronger (and therefore colder) early in lunar history than had been supposed.

The topographic map also allowed Zuber and her colleagues to probe beneath the surface of the moon by combining topography with variations in gravity. The gravity variations were detected from Earth as Doppler shifts in the frequency of Clementine's radio as the satellite rose and fell in its orbit, and result in part from surface features. The pull of gravity is stronger over the added mass of crater rims, for example, and it decreases where impacts have excavated crater interiors. But once the gravity field is corrected for the effects of surface highs and lows, what remains is a reflection of the density and distribution of subsurface rock.

Among the most striking new features in Clementine's corrected gravity map are the rings of lower gravity around the dark, lava-filled basins on the moon's near side. The basins themselves have long been known to be marked by gravity highs, generated by the masses of volcanic rock, called mascons, that formed within and beneath the craters after the impacts that created them. The rings in turn mark the decreased mass where the moon's outer shell flexes downward under the weight of the mascons. By comparing the extent of the flexing with the amount of mass implied by the gravity highs, Zuber and her colleagues hope to learn the shell's present-day strength.

The topography-corrected gravity data are also leading to a sharper picture of the cataclysms that formed the basins. The impacts must have excavated much of the crust, allowing the underlying mantle to rise. Since mantle is denser than crust, their relative proportions can be determined from the basins' gravity signature. But Apollo-era estimates of just how much the crust had been thinned were uncertain by a factor of two to three, says Zuber, because of the poor topographic control. Clementine's corrected gravity map now makes it clear that the crust thins from its average thickness of 60 or 70 kilometers to as little as 12 kilometers beneath the solar system's largest and deepest basin, the South Pole–Aitken basin. Assessing the damage done by these giant impacts may help researchers grasp how the moon's crust has been reshaped by impacts of all sizes.

The laser ranger wasn't the only star of the Clementine session at AGU, however. The researchers got their deepest look at the moon from the same radio tracking of the spacecraft's orbit that produced the gravity map. The overall shape of the orbit traces the broad tidal bulges raised on the moon by Earth and the sun; the size and timing of the bulges depend on the moon's rigidity. The Clementine data show that somewhere, probably deep in its interior, the moon is not quite as rigid as solid rock would be. Most likely, part of the rock is still molten.

The moon's soft heart might be due to a molten core—a long-debated possibility—or to more dispersed bits of magma. It would take more orbital data to be sure, and Clementine left the moon in early May. But its glimpse of the moon's interior is a fitting legacy for a spacecraft named for a miner's daughter, and its mountains of other data—including more than 2 million images at a variety of wavelengths—will be panned for treasures for years to come.

A Planetary First: Magellan Is Marked for Termination

The news came as a footnote to Stephen Saunders' AGU talk on the Magellan mission that is mapping Venus. "In October, we will do some interesting things that should terminate the spacecraft." A few years back the words "terminate the spacecraft" would have been inconceivable, since planetary probes, worth hundreds of millions of dollars and serving as the wellsprings of innumerable scientific careers, were kept running until some fatal mechanical failure ended their useful lives.

The news about Magellan didn't come as a complete surprise, however. Indeed, the cash-strapped National Aeronautics and Space Administration (NASA) has repeatedly threatened the spacecraft with extinction during its 4 years of radar mapping and gravity surveying. And now that the agency has made a firm decision to cut off Magellan's $6-million-per-year funding, scientists are taking the loss rather well. Even though the craft is still returning useful information, it has already had a relatively long and productive scientific life. But the action highlights the tough decisions awaiting planetary scientists as the NASA budget crunch forces more cost cutting (*Science*, 19 March 1993, p. 1696).

Termination, in Magellan's case, means something more dramatic than shutting down mission control, says Saunders, a Magellan project scientist who is now at NASA headquarters. In Magellan's next-to-last experiment, dubbed Windmill, spacecraft operators will gradually lower its orbit into the upper reaches of the atmosphere with the spacecraft oriented so that its outspread solar panels will tend to catch the "wind" and spin. At the same time, the attitude control jets will fire to counteract the spinning; by monitoring how much power it takes to keep the spacecraft from spinning out of control, controllers hope to learn how the sparse gas molecules of the upper atmosphere interact with the panels.

Engineers are eager for the data from Windmill, notes Saunders, because "aerobraking" by dipping into a planet's upper atmosphere is expected to become a common strategy for changing a spacecraft's orbit. Magellan's next—and final—act, meanwhile, might also reveal something about how a space plane entering Earth's atmosphere would behave. After the controlled Windmill experiment, engineers will drop Magellan deeper into the atmosphere for one last test of its reactions. This termination experiment will probably end when the craft runs out of fuel and loses attitude control, which will break radio contact. Then, within a day or two, the atmosphere will drag Magellan down beyond hope and incinerate it.

Saunders is philosophical about the imminent loss of a spacecraft he has worked on for almost 20 years. "We're on the downhill slope of scientific return. We got the science we wanted. Why should we keep a beautiful old spacecraft going when we've gotten 99% of the information [we had hoped for] out of it?" An extension of the mission, he estimates, would at most add 20% to the scientific return. It's time, he says, to think about returning to Venus with different spacecraft to focus on questions raised by Magellan and its predecessors.

For Saunders' colleagues on other missions, such a decision might not be so easy to face. But in today's fiscally strained climate for space science, those researchers may soon have to start asking themselves when they can accept pulling the plug on aging but still productive spacecraft.

A Shade of Difference Separates Ida and Its Satellite

The hypothesis seemed plausible enough: The most common meteorites falling to Earth—stony lumps called ordinary chondrites—are chips off of the most common kind of asteroids, the S type. And to at least some astronomers, the color of some S types did seem to link them to ordinary chondrites. But lately the link has been strained as more spectroscopic data pared the list of possible chondritic asteroids. New results from the Galileo spacecraft presented at the AGU meeting have now weakened it further, if not ruptured it.


NASA/JPL

A moon of a different color. A false-color image showing the asteroid Ida and its moon is based on recent Galileo data hinting at slightly different compositions for the two bodies.

Last August, on its way to Jupiter, Galileo got a close-up look at Ida, an S-type asteroid that some researchers hoped might rescue the S type–chondrite link. Its color wasn't a bad match, but then a tiny satellite of Ida turned up last March in the images still trickling back from Galileo. Analysis of those images now shows that Ida and its satellite have different colors—a hint that the two bodies can't be made of the same homogeneous material as the chondrites. If that's the case, says Galileo team member Clark Chapman of the Planetary Science Institute in Tucson, Arizona, "it's not looking so good" for Ida—and by inference most of the other S types—as a chondrite source.

Not everyone agrees with Chapman, but there's no dispute about the color difference between Ida and her satellite. Kenneth Klaasen of the Jet Propulsion Laboratory (JPL) reported on spectra of Ida and its moon taken in visible light, Robert Carlson of JPL reported on near-infrared spectra, and James Granahan of the University of Hawaii considered both sets of data together. All three researchers agreed at the AGU meeting that the two bodies have different colors, with Ida absorbing less light—and therefore appearing brighter—at red and near-infrared wavelengths.

One way to interpret the color difference is to attribute it to different compositions. In that case, said Carlson, Ida would be composed mostly of the mineral olivine with a small amount of orthopyroxene, while its satellite would consist of olivine with larger proportions of orthopyroxene and clinopyroxene. And that difference in makeup would imply that the two bodies could be nothing like ordinary chondrites.

The reason is that Ida and its satellite must have originated in the same body. Either the satellite was chipped off Ida itself by the impact of a tiny asteroid or, more likely, they are both fragments of a much larger asteroid destroyed by a catastrophic impact. Either way, the original larger body must have had a varied composition, the result of heating and melting early in its history. The primordial, homogeneous rock of an ordinary chondrite, however, shows no signs of such differentiation.

Not everyone agrees with that interpretation of the color difference, however. Carlé Pieters of Brown University in Providence, Rhode Island, argues that under the skin, Ida and its moon might have an identical, chondritic composition; the colors might be due to differences in the sizes of the rock particles on the surfaces of the two bodies or in the amount of weathering by impacts and radiation in space. But Pieters is in a small minority. Galileo project scientist Torrence Johnson, a one-time asteroid specialist himself, thinks particle size and space weathering probably can't account for the difference. "I think the weight of the evidence—the nature of the [color] variations and the internal consistency of the [spectral] trends—is on the side of the difference being compositional."

If Ida and similar S-type asteroids no longer look promising as chondrite sources, where can astronomers turn next? Among the S types, Michael Gaffey of Rensselaer Polytechnic Institute in Troy, New York, has a short list of candidates that still look like ordinary chondrites—providing he assumes they are heavily camouflaged by weathered rubble. But many asteroid specialists now say the best bet may be to search for more asteroids like the single small body, discovered last year, whose color was a dead ringer for a chondrite (*Science*, 23 July 1993, p. 427). They're hoping this new kind of candidate will prove easier to pin down.

–Richard A. Kerr