The Near-Earth Asteroid Rendezvous (NEAR) spacecraft, the first launch of the Discovery program in February 1996, will be the first to achieve orbit around an asteroid. The objective of NEAR will be the unusually large near-Earth asteroid 433 Eros, a member of the S group of asteroids that dominates the inner solar system. NEAR will make the first comprehensive scientific studies of a small body.

During the last decade scientists have gained a new appreciation of how important bombardment by so-called “small bodies”—comets and asteroids—has been in shaping the major planets. One need only look at the pockmarked, cratered faces of the Moon, Mars, and Mercury to recognize that impacts are a major geologic process. However, the impact of comet Shoemaker-Levy 9 with Jupiter in 1994, and recognition of the Chicxulub structure in the Yucatan peninsula as the impact that triggered a mass extinction including the dinosaurs 65 million years ago, have reemphasized that the impact process continues and will inevitably have major effects on Earth again.

SEARCHING FOR ASTEROID-METEORITE CONNECTIONS

The most tangible evidence for bombardment of Earth by small bodies is meteorites, fragments of asteroids or possibly comets that survive passage through the atmosphere to reach the surface. Their chemistry and mineralogy provide direct evidence for processes that occurred in the earliest history of the solar system.

Ordinary chondrites, which make up some 80% of the meteorites in museum collections, are primitive assemblages of iron-
nickel metal and silicate minerals that have changed little since they formed from the solar nebula some 4.6 billion years ago. Basaltic and stony-iron meteorites, which make up about 10% of the collections, bespeak instead active geology in which melting and volcanism occurred in the first hundred million years of the lives of their source bodies, presumably some of the larger asteroids.

Despite what meteoriticists have learned about the early solar system, the asteroids themselves remain precious little more than points of light in the sky to telescopic observers. It is generally agreed that the more than 5000 known asteroids are mostly shattered remnants of a much smaller number of larger "parent" bodies. Spectroscopic surveys of the several hundred brightest asteroids show that their compositions differ, and that different asteroid compositions dominate different regions of the solar system. The dominant type in the outer solar system is C asteroids, low albedo bodies thought to be rich in carbon compounds. S asteroids, made of metal and silicate minerals like those of most meteorites, dominate the inner solar system.

However, spectroscopists have not been able to determine whether S asteroids are primitive mineral assemblages, little changed since they first formed like the ordinary chondrites, or material like basaltic and stony-iron meteorites that have undergone extensive melting and evolution. A composition of ordinary chondrite-like material would imply that parent bodies of S asteroids have had quiescent histories except for impacts, but a stony-iron composition would imply early histories during which they were geologically active. Even less is known about asteroids' large-scale structure; for example, it is not clear whether the small asteroids are coherent chunks, loosely bound rubble, or some combination of both.

The Galileo flybys of the S type asteroids 951 Gaspra and 243 Ida (each asteroid is numbered in order of its discovery) opened our eyes to what an asteroid looks like up close: both are heavily cratered, with grooves or fractures on the surface and subtle but definite color variations that hint at different rock types. Ida even has a small moon, Dactyl. But neither flyby determined what rock type S asteroids are made of or where they come from. The composition, bulk properties, and provenance of S asteroids are key links in establishing the connection between meteorites and the history of asteroids, and in better quantifying the nature of the impact hazard that the asteroids pose to Earth.

**EROS: LARGEST OF THE NEAs**

Most asteroids reside in a broad belt between Mars and Jupiter, but a substantial number lie in orbits that bring them close to Earth. These are the "near-Earth asteroids," prime candidates for the origins of meteorites. Dynamicists who study the evolution of asteroid orbits believe that the near-Earth asteroids or NEAs are mostly pieces cast out of the main asteroid belt by the gravity of Jupiter, with some fraction of extinct comets.

By far the largest and most important of the near-Earth asteroids is 433 Eros, which accounts for over half the volume of all near-Earth asteroids. Eros orbits the sun at an average distance of 1.46 astronomical units (AU), and approaches to 1.13 AU at perihelion. It rotates once each 5.37 hours. As with Uranus a high axial inclination results in the asteroid lying nearly on its side. Eros is also one of the most elongated asteroids, with estimated dimensions of $35 \times 15 \times 13$ kilometers. It is an S type but is known to be compositionally varied, with opposite sides having slightly different mineralogies.

Eros is the prime objective of the NEAR mission, scheduled for launch on February 16, 1996, aboard a 7925 Delta II from Cape Canaveral, Florida. NEAR is being built by The Johns Hopkins University Applied Physics Laboratory and will be the first launch in NASA's Discovery Program. The spacecraft will swing by Earth for a gravity assist in January 1998, approach Eros in January 1999, and be injected into orbit to analyze Eros for nearly one year.

The most important scientific objectives of NEAR are (1) to characterize Eros' physical and geological properties; (2) to infer its elemental and mineralogical units (AU), and approaches to
functional composition and variations; (3) to clarify the relationships between asteroids, comets, and meteorites; and (4) to further understanding of the formation and early evolution of the solar system.

THE SPACECRAFT AND ITS INSTRUMENTS

As a Discovery mission, NEAR faces the challenge of delivering first-rate science on a limited budget and tight schedule. The programmatic guidelines of the Discovery Program are that the development cost (to launch plus 30 days) can be no more than $150 million, the development time must be less than 36 months, and the mission must use a launch vehicle of capability no greater than the Delta II. The launch-plus-30-day budget for NEAR will be approximately $120 million, and development time will be 27 months.

These constraints are met by thoughtful design of the overall spacecraft, use of modular subsystems, and use of off-the-shelf, proven components. The instruments are supplied with data processors sharing a common design. The propulsion system, central data handling system, and several of the instruments represent heritage from previous civilian and military space missions. Major systems are redundant functionally, to avoid the cost and mass of duplicate hardware. For example, the prime attitude determination will be made using a star camera with on-board processing; the backup is the main imager with processing done onground.

The spacecraft design also takes advantage of the particular properties of Eros. The asteroid’s elongated shape necessitates use of a near-equatorial orbit in most situations. This combined with the high axial inclination results in the lines of sight to the Sun and Eros typically lying near right angles. This situation is used to advantage by equipping the spacecraft with body-fixed, side-looking instruments that share a common aimpoint. Thus, while the solar panels are aimed at the sun, the instruments can be trained on Eros. Aiming at specific points on the asteroid will be accomplished by small rotations of the spacecraft. The guidance and control software is particularly robust for providing data coverage, and makes use of algorithms like those used in military satellites. Downloaded images from the Multispectral Imager (MSI) will be processed onground to derive a shape model for the asteroid that will be maintained onboard the spacecraft. The instruments can then be pointed at a fixed location in the asteroid interior, so that spacecraft orbital motion builds up mosaicked coverage in a “pushbroom” mode, or custom coverage can be provided by pointing at a sequence of locations on the surface. The spacecraft can even track a specific surface feature to build up stereo imagery.

The basic shape of the spacecraft is defined by fore and aft decks and side panels enclosing the bipropellant propulsion system and the electronics boxes. The high gain antenna dish is fixed to the fore deck, as are the four deployable gallium arsenide solar panels. Attitude is controlled by hydrazine thrusters and reaction wheels. Most of the science instrument complement is body-fixed to the aft deck.

The science instrument complement includes a balance of heritage from previous missions and innovative designs that deliver the data necessary to accomplish the mission objectives. Quality of all the instruments is assured by a combination of careful design, thorough ground testing, and redundant testing of instrument characteristics in flight. MSI is adapted from a military remote sensing system and provides a 2.25° × 2.9° field-of-view, using a CCD with a frame size of 244 × 537 pixels. Brightnesses are encoded to 12 bits instead of the 8 used for Voyager and Galileo, providing 16 times the brightness resolution of imagers on those spacecraft. A filter wheel has 7 color filters covering the wavelength range 0.4–1.1 micrometer, and one clear filter for low-light imaging and optical navigation. The NearInfrared Spectrograph (NIS, also adapted from a military remote sensing instrument) has a 0.38° × 0.76° field-of-view and also reports 12-bit data. Sixty-four spectral channels covering the wavelength range 0.8–2.6 micrometer are measured by germanium and indium-gallium-arsenide detectors. A scan mirror slew the field-of-view over a 140° range; mirror scanning combined with spacecraft motion will be used to build up hyperspectral images.

MSI and NIS will operate synergistically to provide both imaging and determination of mineralogic composition by measuring the spectrum of reflected sunlight. At Eros, MSI will resolve features smaller than 10 meters in size, and NIS will measure spots as small as 300 meters. NIS will measure silicate spectral features.
which are diagnostic of the composition of iron-containing minerals. It features an on-board, solar-illuminated gold calibration target for determination of instrument responsivity on demand. MSI has 70 times the spatial resolution of NIS, and four of its filters are designed to extrapolate the spectral measurements from NIS down to small spatial scales. Instrument performance throughout the mission will be tracked by repeated imaging of bright astronomical objects.

The X-ray Spectrometer and Gamma-ray Spectrometer (XRS-GRS), in contrast to MSI and NIS, will measure and map elemental abundances. These data will remove ambiguity involved in measuring surface composition using reflected sunlight. XRS contains three gas proportional counters, whose field-of-view is restricted to 5° by a honeycomb of beryllium-copper foil, and solar X-ray monitors. Hard X-rays emitted by the sun stimulate different elements in Eros' surface to emit characteristic spectra of soft X-rays. By building up X-ray measurements of the surface throughout the time in low orbit, XRS will be able to map the abundance and abundance variations in magnesium, aluminum, silicon, calcium, iron, and possibly sulfur and titanium down to a 4 kilometer spatial scale. Variations in X-ray emissions from the surface induced by solar activity such as solar flares will be accounted for by the solar monitors. XRS also features an on-board calibration source. This design is updated from that used during the Apollo missions. GRS contains a sodium iodide detector, enveloped by an active bismuth germanate anti-coincidence shield to provide a 45° field-of-view, and is the first instrument of its design to be flown. GRS measures characteristic emission spectra of elements from radioactivity or excitation by cosmic rays. Gamma-ray measurements over the course of the mission will give abundance estimates of silicon, iron, potassium, thorium, and uranium.

The NEAR Laser Rangefinder (NLR), adapted from a similar instrument on Clementine, contains a neodymium-doped yttrium-aluminum-garnet laser and a detector that measures the delay time between firing of a laser pulse and its return reflection from the surface. The instrument typically will fire once per second. While NEAR orbits Eros, NLR will build up numerous range measurements at a spot size of 4–9 m and an accuracy of ±6 meters limited by ephemeris errors, providing detailed topography of the surface. This will complement measurements of gross asteroid shape from MSI by measuring Eros' night side, which MSI cannot, and will provide detailed topographic profiles of major morphologic features including craters and grooves. NLR is the first such spacecraft instrument to have an internal calibration.

The final two elements of NEAR's instrument complement are a magnetometer (MAG) and the radio science experiment (RS). MAG is a 3-axis fluxgate sensor mounted in a bracket off the high gain antenna. It will measure the strength of Eros' magnetic field to within 45 nanoTeslas, and may be capable of detecting variations in the intrinsic field depending on their magnitude and scale. RS will use Doppler tracking to determine acceleration of the spacecraft by Eros' gravity. Tracking, attitude data from the star camera and MSI, and knowledge of Eros' shape from MSI and NLR will allow highly accurate determination of Eros' density and large-scale density variations.

An experienced international science team supports the NEAR mission throughout the prelaunch development, mission operations, and data analysis phases. This team has representatives from universities, government laboratories, and small businesses. It is headed by Drs. Joseph Veverka of Cornell University (MSI-NIS), Jacob Trombka of NASA-GSFC (XRS-GRS), Maria Zuber of Johns Hopkins University (NLR), Mario Acuña of NASA-GSFC (MAG), and Donald Yeomans of JPL (RS).

**THE MISSION PROFILE**

The 14-day launch window for NEAR opens on February 16, 1996. NEAR will follow a "2-minus-ΔVEGA" trajectory that returns to Earth's vicinity for a gravity assist on January 22, 1998. On June 27, 1997, the spacecraft will pass close to the main belt C-type asteroid 253 Mathilde. NEAR will then perform a deep space ΔV maneuver shortly after aphelion to direct it to the Earth swingby. The gravity assist at swingby will bend the trajectory into Eros' orbital plane. This sets up the optimal geometry needed for approach to the asteroid.

In January 1999 a series of rendezvous maneuvers will slow NEAR to a velocity relative to Eros of only 5 meters per second. The spacecraft will first fly by the asteroid and then be inserted into a high orbit. Full-color imaging will reveal asteroid shape, morphologic and color features down to 250 meters in size, and NIS will map the surface spectrally at optimal illumination conditions. Imaging and RS will provide a highly accurate mass determination. Then the orbit will be lowered stepwise to 35 kilometers in radius, during which MSI and NIS will observe the surface at progressively higher spatial resolutions. The lowest orbits will be the primary opportunity for NLR and XRS-GRS to conduct detailed mapping of the asteroid's topography and surface elemental abundances, for MAG to measure the magnetic field properties, and for RS to search for variations in interior density.

From the data returned by NEAR, we will have the first comprehensive picture of the physical geology, composition, and geophysics of an asteroid. High resolution imagery can be expected to yield detailed maps of craters, grooves, and other landforms. More detailed analyses will provide insights into the thickness and distribution of regolith and the history of impacts recorded in the crater population. Spectroscopic analysis will provide maps of mineralogy at 300-meter resolution and elemental composition at 4-kilometer resolution. The radio science and magnetometer experiments will yield information on the strength and character of the magnetic field, and on global density and density distribution. All these data will be used to determine which meteorite types may be similar to Eros. This link, if made, will allow the extensive database on meteorites to be associated with a specific, common type of asteroid to help clarify the early solar system history recorded in small bodies.

(The authors are members of the NEAR Mission Science Team and are staff scientists with The Johns Hopkins University Applied Physics Laboratory, Laurel, Maryland.)
HUBBLE IMAGES STORMS ON JUPITER

This Hubble Space Telescope image provides a detailed look at a cluster of three white oval-shaped storms southwest of Jupiter's Great Red Spot. The clouds, as imaged on February 13, 1995, look considerably different from their appearance only seven months earlier. The features are moving closer together as the Great Red Spot is carried westward by prevailing winds and the white ovals are swept eastward. (This change in appearance is not an effect of last July's comet Shoemaker-Levy 9 collisions with Jupiter.)

The outer two of the white storms formed in the late 1930s. They are high pressure systems where the air is rising, carrying ammonia gas upward. White ice crystals form when the upwelling gas freezes as it reaches the cloud top level where temperatures are -200°F (-130°C).

The intervening white storm center, the ropy structure to the left of the ovals, and the small brown spot have formed in low pressure cells. The white icy clouds sit above locations where gas is descending to lower, warmer regions. Melting of the ice exposes varied amounts of Jupiter's underlying brown haze. The stronger the down flow, the less ice, and the browner the region.

A scheduled series of Hubble observations will help target regions of interest for detailed scrutiny by the Galileo spacecraft, which will arrive at Jupiter in early December this year. Galileo will obtain close-up images of the structure of clouds that make up large storm systems such as the Great Red Spot and white ovals seen in this picture.

OXYGEN ATMOSPHERE DETECTED ON EUROPA

Astronomers using the Goddard High Resolution Spectrograph on the Hubble Telescope detected the spectral signature of molecular oxygen on Europa in ultraviolet light during observations made on June 2, 1994. They believe they have identified an extremely tenuous atmosphere of molecular oxygen around Jupiter's moon, Europa. "Europa's oxygen atmosphere is so tenuous that its surface pressure is barely one hundred billionth that of the Earth," said principal investigator Doyle Hall, of Johns Hopkins. "It is truly amazing that the Hubble Space Telescope can detect such a wispy gas so far away."

If all the oxygen on Europa were compressed to the surface pressure of Earth's atmosphere, it would fill only about a dozen Astrodome-sized stadiums. The researchers caution that the detection should not be misinterpreted as evidence for the presence of life on the small, frigid moon. Not only is it too cold (-230°F; -145°C) to support life as we know it on Earth, but the oxygen detected is produced in a completely different way. Unlike Earth, where living organisms generate and maintain a 21% oxygen atmosphere, Europa's oxygen atmosphere is produced by purely nonbiological...
processes. Its icy surface is exposed to sunlight and impacted by dust and charged particles trapped within Jupiter’s intense magnetic field. Combined, these processes cause the frozen water ice on the surface to produce water vapor as well as gaseous fragments of water molecules.

The gas molecules undergo a series of chemical reactions that ultimately form molecular hydrogen and oxygen. The relatively lightweight hydrogen gas escapes into space, while the heavier oxygen molecules accumulate to form an atmosphere which may extend 125 miles (200 kilometers) above the surface. The oxygen gas slowly leaks into space and is replenished continuously.

Europa is approximately the size of Earth’s Moon, but its appearance and composition are markedly different. The satellite has an unusually smooth and nearly craterless surface of solid water ice. Mysterious dark markings crisscross the surface, giving the moon a “cracked eggshell” appearance. Under the fragmented icy crust, tidal heating by Jupiter might heat the icy material enough to maintain a subsurface ocean of liquid water.

LUNAR PROSPECTOR WILL BE THIRD DISCOVERY FLIGHT

A mission to the Moon has been selected for funding as part of NASA’s Discovery Program of frequent, low-cost solar system exploration missions. Missions to study the Sun, Venus, and a comet also have been selected for further detailed study under the Discovery effort.

The mission to the Moon, called Lunar Prospector, was judged mature enough to proceed directly to full development and construction following final technical definition. Scheduled for launch in June 1997, the $59 million orbiter mission will map the chemical composition of the lunar surface and the Moon’s global magnetic and gravity fields. The mission will also look for significant quantities of water ice in permanently shadowed craters near the lunar poles that were imaged for the first time by the Clementine spacecraft in 1994. Such a discovery could be a boon to future human exploration of the Moon.

Three additional Discovery missions will continue detailed study development until fall 1995, when one will be chosen for flight. The Stardust Mission would fly through the extended coma of the active comet P/Wild 2, taking images and returning a sample of its cometary dust to Earth. The Venus Multiprobe Mission would drop 16 small probes into the thick venusian atmosphere to study its unusual atmospheric circulation and model it in three-dimensions. The Suess-Urey mission would collect samples of solar wind streaming outward from the Sun and return it to Earth for laboratory study.

“I am absolutely thrilled with the potential of these missions, and with the universally high quality of the 28 proposals submitted to us,” said NASA Administrator Daniel S. Goldin. “The university and aerospace industry communities should be proud of their efforts, which represent a model of how to pursue scientifically first-rate space exploration using small, advanced spacecraft.”

The Lunar Prospector will be built and launched on a Lockheed Launch Vehicle by Lockheed Missiles and Space Company under the direction of Principal Investigator Dr. Alan Binder of Lockheed. NASA’s Ames Research Center will be responsible for one of the spacecraft’s instruments and technical support.

The Suess-Urey team is led by Principal Investigator Dr. Donald Burnett of the California Institute of Technology Pasadena with Martin Marietta Astronautics as the contractor. The Venus Multiprobe Mission team is led by Principal Investigator
Dr. Richard Goody of Harvard University with Hughes Space and Communications Group as the industry contractor. The Stardust team is led by Principal Investigator Dr. Donald Brownlee of the University of Washington with Martin Marietta as the contractor. NASA’s Jet Propulsion Laboratory will provide project management for these three missions.

Stardust would be launched on a Med-Lite in February 1999 for a total cost to NASA of $208 million. The Venus Multiprobe Mission would be launched on a Delta II launch vehicle in June 1999 for a total cost to NASA of $202 million. Suess-Urey would be launched on a NASA Med-Lite launch vehicle in August 1999 for a total mission cost to NASA of $214 million.

NASA officials hope to release Announcements of Opportunity for new Discovery investigations on the average of every 18 months. The actual release dates depend on future approved NASA budgets and the size of previously selected missions.

HUBBLE DISCOVERS NEW DARK SPOT ON NEPTUNE

The distant, blue-green planet Neptune has developed a new great dark spot in the cloudy planet’s northern hemisphere, revealed in recent images from the Hubble Space Telescope. Only last June, Hubble images revealed that a great dark spot in the southern hemisphere, discovered by Voyager 2 in 1989, had mysteriously disappeared.

The new dark spot is a near mirror image of the previous feature mapped by Voyager 2. The new, northern dark spot is accompanied by bright, high-altitude clouds. As atmospheric gases flow up over the spot, they cool to form these methane-ice crystal clouds. “Hubble is showing us that Neptune has changed radically since 1989,” said Heidi Hammel of the Massachusetts Institute of Technology. “New features like this indicate that with Neptune’s extraordinary dynamics, the planet can look completely different in just a few weeks.”

Like its predecessor, the new spot might be a hole in Neptune’s methane cloud tops that gives a peek to lower levels of the atmosphere. “We weren’t surprised the other spot disappeared,” said Hammel. “It was kind of ‘floppy’ because it changed shape as atmospheric circulation carried it around the planet.” (By contrast, Jupiter’s Great Red Spot, which is similar to Neptune’s original spot in relative size and position, has remained stable in appearance for at least 300 years.)

Hammel points out that studying the dynamics of Neptune’s immense atmosphere might lead to a better understanding of Earth’s atmosphere. “Neptune’s unusual behavior is showing us that though we can make great models of planetary atmospheric circulation, there may be key pieces missing.”

Energy from the Sun drives Earth’s weather system. However, the mechanism must be very different on Neptune, because the planet radiates two times more energy than it receives from the distant Sun. The dynamics of Neptune’s atmosphere may be caused by a strong internal heat source that warms the cloud layers from below. A slight change in the temperature differential from cloud bottom to top might trigger rapid, large-scale changes in atmospheric circulation. Astronomers don’t know how long the new feature will last, but Hubble will allow them to track Neptune’s atmospheric changes over at least a decade.
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<td>One Technical Report/Contrib.</td>
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<td>Each Abstract Set</td>
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- [ ] MasterCard

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TESTING A "LUNAR" MARSOKHOD

— by Graham Ryder

THE MISSION & THE TEAMS

For three days in February 1995 teams of scientists tested an unmanned robotic rover in making geological observations. The Marsokhod is a six-wheel drive, Russian-built vehicle. McDonnell Douglas and NASA Ames Research Center are mainly responsible for its development and operation as it now exists.

Marsokhod was at Kilauea in Hawaii making traverses assisted by volcanologist Laszlo Keszthelyi (University of Hawaii) and his team. The team at Ames included engineers and controllers, led by Butler Hines (NASA Ames), and the geology group I belonged to.

We were trying to find out how reasonable our remote observations and interpretations of the geological features are, as well as figure out how a team can organize itself, make decisions, and produce strategies for obtaining information. At bottom it was a geologically-based training run for a potential mission to send a rover to the Moon and try to understand its volcanic features. (Immediately prior to our study, another group of geologists had gone through a similar exercise for a rover mission to Mars, which included the time-delay that would be involved in communications over the Earth-to-Mars distance.)

Kilauea has varied volcanic characteristics. Its topography is rugged, with rifts and gullies. The ground surfaces include ashy materials and other wind-blown fragmental debris. On the Moon there would be more regolith and less bedrock. But for this test, we weren't trying to precisely simulate lunar terrain; we were assessing our ability to observe and successfully interpret volcanic features in general—and whatever else we might see—through the eyes of a rover.

Our geology team started out as Cass Coombs (College of Charleston), Larry Crumpler (Brown University), and me, all with experience in field geology, volcanology, and planetary studies. Jeff Taylor (University of Hawaii) had planned the traverses. We used aerial photos to simulate orbital and descent images. One of us was in charge of decision-making while the others provided advice and geological input from images. We rotated the functions daily.

Three people were not enough to keep pace, so we enlisted the help of Jayne Aubele (Brown University) and Carol Stoker (NASA Ames). On a real mission we would need far more. But we were here to learn, not simulate. We made decisions about where and when we would use instruments for chemical and mineralogical analyses on a mission, but this test had no such instruments.
TEST DAY 1. NASA Ames Research Center, California — Through the stereo cameras of the Marsokhod rover, we can see an exposure of the far wall of a gully. We think we are looking at dark basalt flows towards the bottom, with paler ash layers on the top. But can we be sure? Can we see what we need with these images? We ask for some high quality monochrome stereo television images and an even higher quality color image with a different camera. Because the color camera is fixed, unlike the stereo cameras, which can pan to see in any direction, it is difficult to point the Marsokhod here so that the camera has the appropriate tilt; the slope we are on is too steep. So we have to back off that request.

TEST DAY 3. NASA Ames Research Center, California — By the start of the third day, we have become a field commander, a chief analyst communicating with the commander, and two analysts. We spend some time finding where we are (the field team has told us roughly where we "landed"). Nobody mentions the surface materials, as we are too busy panning for identifiable landmarks. Then we recognize lava with "dirt" that is probably a wind-drifted fragmental material (later we are told that the "dirt" is indeed windblown tephra—fragmental deposits).

We start to traverse even though we don’t know exactly where we are. At first we take no detailed images for scientific analyses, but use one taken for navigation. We approach an outcrop and examine it. Shiny surfaces look like glassy surfaces on lava. We can tell it is solid and hard. We argue (or discuss?) alternatives. Is it glass reflecting sunlight? If we look from another direction what does it look like? A human field geologist would move rapidly and answer some of these simple questions very quickly; with the rover each movement is a carefully considered option. We decide that a (time-consuming) chemical analysis would be required here. We interpret holes as vesicles in the lava. And so we make our inferences, collect images, imagine that we would have made the chemical analysis, and discuss where we are off to next. . . .

RUMINATIONS & RESULTS

The idea of unmanned vehicles roving over planetary surfaces, operated from Earth, is hardly a new one. However, over recent years the concept has received tremendous stimulus. Funding for planetary exploration using humans will not be easily forthcoming (it is now more than twenty years since any living creature went further than low earth-orbit), whatever the balance of virtues and capabilities of robots and humans is. The tremendous advance in robotics and telepresence that the computer and miniaturization has enabled makes the capabilities of robots and their instruments potentially much greater than they were even a decade ago.

These advances have prompted some to state that all our major objectives in planetary exploration can be met using robots. But we have not yet really tried out such exploration. Attention has focused on the mechanics and operation of a robot rover and not on the quality of the observations and inferences. Little attention has been paid to the real-time cognitive aspects of knowledge production (i.e., humans thinking) in geological field
For the nineteenth season, the LPI Summer Intern Program offers selected undergraduate students an opportunity to participate in lunar and planetary science research at the Institute and the NASA Johnson Space Center. The 1995 program begins on June 13 and ends August 19. For more information or to apply for internship next year, contact LPI Summer Intern Program, 3600 Bay Area Boulevard, Houston TX 77058-1113. Participants in this summer's program will work on the following projects under the guidance of their advisors at LPI and JSC.

CHRISTOPHER D. ADKINS, Virginia State University
Advisor: Paul Spudis, Lunar and Planetary Institute

The intern will use laser altimetry and a global topographic map produced by the Clementine lunar mission to study processes in the formation of lunar basins. Basin volumes and the topographic relief of the rim crest and ring segments of multi-ring basins are constraints on the volumes of material excavated and the amounts of structural uplift in basin formation. The quantities are difficult to determine because many basins are flooded with basalt, and, until now, we have not had the data necessary to measure basin volumes and ring and rim relief accurately. The Clementine laser altimeter has provided topographic profiles with 50-meter vertical precision along longitude and the data has been gridded into a global topographic map of 100-kilometer resolution. We will use this data for relatively fresh, unflooded basins, such as Orientale and Humboldtianum, to determine basin volume and ring relief. Measured values will be compared to predicted values to test models of basin formation and evolution. The work will involve computer image manipulation, photogeology, and the creation of digital image models.

BRIAN E. BREWINGTON, California Institute of Technology
Advisor: Stephen Clifford, Lunar and Planetary Institute

A critical feature of most attempts to model the diffusive transport and storage of H$_2$O within the martian regolith is the assumption that its diffusive properties can be reasonably approximated by a soil of uniform pore size. However, this simplification is only valid when the diffusing species is a noncondensable gas. When the gas can condense and obstruct the pore network, the effect of pore structure cannot be ignored, because the condensation of ice preferentially occurs in the smallest (and most numerous) pores, which will impede the rate and extent of diffusive transport and choke off much of the pore network well before the larger pores are filled with ice. The net effect is that, when compared against soils that have geologically reasonable pore size distributions, calculations based on the assumption of a uniform pore size can over-predict vapor transport and the rate of ice accumulation by as much as several orders of magnitude. To calculate the diffusive flux of a condensable gas through a geologically reasonable soil, an accurate model of both the pore-size distribution and pore structure must be used. Unfortunately, even some of the best models for describing diffusion through soils with broad pore-size distributions fail miserably when applied to diffusion problems that involve condensation. Because of the important constraint that pore structure and ice condensation place on diffusion in soil—and because of the implications that such transport has for regolith/atmosphere exchange, the stability of ground ice, and the evolution of the martian climate—our efforts will focus on developing a computer model of pore structure and diffusive transport that more accurately reflects the complexity of this process. We will attempt to test the model against "ground truth" by comparing its predictions with the results of various experimental studies that have been reported in the terrestrial soils literature.

CATHERINE M. CORRIGAN, Michigan State University
Advisor: Mike Zolensky, NASA Johnson Space Center

By exploring the nature of interplanetary dust particles (IDPs) and carbonaceous and ordinary chondrites, we hope to learn a great deal about the original state of the solar system.
nebula, as well as the subsequent processes that have shaped it. One particular area of interest is aqueous alteration of materials, which has played a large role in the development of some asteroids and possibly comets as well. Determining the porosity of a sample is important in studying aqueous alteration. There are already a number of time-proven methods for determining porosity in a bulk sample, and actual, physical liquid/gas flow measurements work quite well in samples large enough to test in this manner. However, these methods are not applicable to small samples of IDPs and most meteorites. By utilizing scanning electron microscope (SEM) images and computer image processing (in the VDAS lab), last summer we developed a method for determining sample porosity efficiently and accurately for nanogram-sized samples. Much work remains to be done. Relatively few IDPs have been examined, and there is a paucity of data for carbonaceous chondrites. This summer we will continue our work on IDPs and extend it to carbonaceous and ordinary chondrites on samples now in hand. With the results of this summer’s work in hand, we should be able to proceed with three-dimensional numerical modeling of the fluid flow and attendant alteration within hydrous asteroids.

JAMES T. DAVENPORT, South Dakota School of Mines and Technology
Advisor: Paul Schenk, Lunar and Planetary Institute

Io is the most volcanically active object in the solar system, yet we know little about even the gross composition of the lavas that cover the vast majority of its surface. Numerous volcanic pits, or calderas, dot the surface. Geologic mapping and dimensional analysis of volcanic calderas will allow us to constrain the physical strength of Io’s tortured crust and may ultimately provide clues to the nature and evolution of magma beneath the crust. The intern will learn stereo (not previously used for Io) and multispectral imaging techniques as well as develop geologic mapping techniques using remote sensing data.

MICHELE C. DODGE, University of Hawai at Hilo
Advisor: Walter S. Kiefer, Lunar and Planetary Institute

Lunar mascon basins are regions of above-average gravitational acceleration, implying the presence of excess mass. This situation is unexpected for topographic lowlands. The Clementine spacecraft recently made near-global gravity and topography observations of the Moon, with higher spatial resolution and more uniform coverage than previous datasets. The intern will analyze data for one or two mascon basins to develop improved models for the mass distributions and compensation mechanisms responsible for these gravity anomalies.

DAVID W. GWYNN, Rutgers University
Advisor: Fredrich Hörz, NASA Johnson Space Center

We are participating in the development of flight instruments to collect hypervelocity cosmic dust particles in space and return them to Earth for compositional analysis. Such instruments use thin foils that will be penetrated by most particles. A substantial fraction of particles will fragment at these impact conditions. The size-frequency distribution and radial dispersion of these fragments determines how much material per unit surface area can be collected on the collector-substrate to the rear of the penetrated foil. This spatial density of impactor residue in turn dictates which analysis methods may be suitable (or unsuitable) for studying composition. We study this fragmentation process using powder propellant and light-gas guns that launch small glass spheres from 1 to 7 kilometers per second against aluminum foils of variable thickness. A massive witness plate behind the penetrated foil simulates the collector substrate and intercepts the debris cloud exiting the target foil. This cloud, however, consists of both
projectile fragments and debris dislodged from the target foil itself. There are no reliable morphologic criteria to distinguish among the secondary craters on the witness plate those that were produced by projectile fragments from those caused by target debris. Scanning Electron Microscope (SEM) methods, combined with Energy Dispersive X-Ray Spectroscopy (EDS), are necessary to reveal the actual fragment composition responsible for each witness plate crater. The intern will analyze three or four representative witness plates and determine the spatial distribution of projectile fragments (silicate) vs. foil debris (aluminum) using SEM-EDS methods in the elemental mapping mode. These element maps will then be used to deduce the spatial distribution of both projectile and target-derived debris and associated size distributions, the latter extracted from a crater diameter measurement.

**BETH N. HARTMAN, Smith College**  
**Advisor:** Deborah Domingue, Lunar and Planetary Institute

Hapke's photometric model is used to describe textures of different planetary surfaces and compare their reflective properties to one another by using a mathematical description of how individual particles scatter light. Understanding how the particles or grains of a planet's regolith scatter light is important in interpreting planetary images and in understanding geologic processes that have formed and modified planetary surfaces. Currently, the best method or mathematical expression to use for describing the particle-scattering behavior is controversial. Helfenstein et al. (1994) have submitted a paper to *Icarus* that examines albedo dependence on particle phase functions. In this project we will examine three different expressions for particle phase function to see which best describes the laboratory work of McGuire and Hapke (1994). The selected function will then be applied to snow reflectance data, supplied by Anne Verbiscer, to help interpret results of Hapke modeling of icy outer planet satellite surfaces.

**KEVIN C. A. PETERSON, Acadia University**  
**Advisor:** Arch Reid, Lunar and Planetary Institute, and University of Houston, Department of Geosciences

Sample DOM85505 is an LL5 chondrite from the 1993 Antarctic meteorite collection. The meteorite is unusual in that it contains an achondritic clast that cannot readily be matched with the common achondrites. One objective of this study is to study the main meteorite, which is a highly shocked LL chondrite, and to compare DOM85505 with other known chondrites. A more important objective is to provide a description of the achondritic clast and to compare that clast with other achondrite meteorites. Rare achondrite-chondrite mixtures are most likely a consequence of impact of an achondrite onto the chondritic parent. We hope to establish the type of achondrite involved, specifically, whether it represents a new type of achondrite, or a more familiar type subjected to unusual conditions. Furthermore, we wish to explore the significance of this unusual association for aggregation histories of chondrites and achondrites.

**KATHERINE RAWLINS, Yale University**  
**Advisor:** Julianne I. Moses, Lunar and Planetary Institute

Groundbased radar observations of Mercury have revealed surprisingly strong depolarized echoes from Mercury's north and south poles. These radar signatures are consistent with the presence of water ice in polar crater floors and other permanently shaded regions at high latitudes on the otherwise extremely hot planet. Recent thermal models show that ice in permanently shaded polar regions on Mercury should be stable over long timescales. However, these studies do not consider all the possible loss mechanisms for polar ice and do not examine the details of how the water might have arrived at Mercury in the first place. We will examine the possible sources and sinks of water on Mercury and explore the stability of water ice in Mercury's polar regions.
KAREN SPIKER, New Mexico Institute of Mining and Technology
Advisor: Allan Treiman, Lunar and Planetary Institute

The walls of the Valles Marineris canyons on Mars are steep scarps up to 8 kilometers tall, and provide a unique view of Mars subsurface geology. The plateau above the canyons is cut by many small normal faults that form shallow grabens. Some of these fault lines appear to continue onto the canyon’s walls as ridges, more resistant to weathering than the surrounding material. Fault lines usually do not form ridges, as the crushed rock in fault zones weathers more easily than the surrounding solid rock. These ridges in Valles Marineris are almost unstudied. In this research project, the intern will learn the geology and setting of the Valles Marineris, map selected areas of the Valles Marineris in detail, and model the three-dimensional shapes of the fault/ridge surfaces. These data and analogies from the Earth will be used to examine how the ridges may have formed and their implications for the volcanology, tectonics, and hydrology of Mars.

CATHERINE THIBAULT, Denison University
Advisor: Faith Vilas, NASA Johnson Space Center

C-class asteroids probably underwent aqueous alteration during their history in the solar system. Spectral reflectance studies in the visible and near-infrared have identified absorption features similar to those seen in laboratory reflectance spectra of phyllosilicates. This project will involve study of a large number of telescopic narrowband reflectance spectra of asteroids that contain the dominant 0.7-micrometers Fe²⁺-Fe³⁺ absorption feature, quantifying the characteristics of these absorption features, and studying any trends found in the context of solar system compositional formation.

JOHN M. WOODELL, North Carolina State University
ADVISORS: Carlton C. Allen, NASA Johnson Space Center and David S. McKay, NASA Johnson Space Center

Violent volcanic eruptions on the Moon have produced large deposits of microscopic glass beads. These glasses have been found in many lunar soil samples, including some composed almost completely of glass. Several of the glasses have been shown to be outstanding "ores" for oxygen production at a future lunar base. We have conducted experiments to obtain oxygen from a wide range of lunar soils, and are now studying the release of oxygen specifically from the volcanic glass beads in these samples. The intern will use optical and electron microscopes to identify the volcanic glass particles in each soil sample and correlate the glass compositions with evidence of oxygen release. In addition, the intern will use remote sensing data from the Clementine lunar mission to identify the compositions of pyroclastic deposits on the lunar surface.

ABSTRACT DEADLINE FOR 27th LPSC ANNOUNCED

The LPI Publications and Program Services Department has set 5 p.m. CST, January 10, 1996 as the deadline for receipt of abstracts for the 27th Lunar and Planetary Science Conference. In a departure from tradition, the due date falls on a Wednesday, rather than Friday. Announcements and instructions for abstract preparation will be mailed to the community as usual during the fall of 1995 and will be accessible from the LPI Home Page (http://cass.jsc.nasa.gov/lpi.html) as they are published. LPSC itself will be March 18–22, 1996.
### JUNE

**1–4**

**4–7**

**5–7**
35th U.S. Symposium on Rock Mechanics, Lake Tahoe, Nevada/California. (Includes session on Planetary Rock Mechanics.) Contact: Richard Schultz, Co-Chair, Mackay School of Mines/172, University of Nevada, Reno NV 89557. Phone: 702-784-4318; fax: 702-784-1833. Internet: schultz@mines.unr.edu

**6–8**
Twentieth Symposium on Antarctic Meteorites, Tokyo, Japan. Contact: Keizo Yanai, Secretary of the Symposium, Department of Antarctic Meteorites, National Institute of Polar Research, 9-10, Kaga 1-chome, Itabashi-ku, Tokyo 173, Japan. Phone: 03-3962-2938; fax: 03-3962-5711.

**14–15**
Workshop on Discovery Lessons-Learned, Washington D.C. Contact: Publications and Program Services Department, LPI, 3600 Bay Area Boulevard, Houston TX 77058-1113. Phone: 713-486-2166; fax: 713-486-2160. Internet: cangelosi@lpi.jsc.nasa.gov

**19–23**
Gordon Research Conference on Origins of Solar Systems, New Hampton, New Hampshire. Contact: Anneila Sargent, Caltech 105-24, Pasadena CA 91107. Internet: afs@mmstar.caltech.edu

**22–28**

### JUNE (CONTINUED)

**Directions:** 6/26-28: Scientific Symposium: Clusters, Lensing and the Future of the Universe. Contact: ASP Annual Meeting, ASP, 390 Ashton Avenue, San Francisco CA 94112. Phone: 415-337-1100; fax: 415-337-5205. Internet: lbaker@stars.sfsu.edu

**25–30**
Cataclysmic Variables and Related Objects, Keele University, England. Contact: F. Ringwald, Department of Physics, Keele University, Staffordshire, ST5 5BG, United Kingdom. Phone: 44-782-583319; fax: 44-782-711093. Internet: cvconf@astro.keele.ac.uk

### JULY

**2–14**

**3–8**

**20–23**
Ecological Consequences of Earth Collisions with Small Bodies of the Solar System, Tomsk, Russia. Contact: Gennadij Andreev, Astronomical Observatory of the Tomsk State University, Box 1106, 634010 Tomsk, Russia. Phone: 7-3822-909721; fax: 7-3822-230450. Internet: ok@siberia-ltd.tomsk.su or niipmm@urania.tomsk.su

**24–31**
Fifth International Tunguska Expedition, Tunguska Meteoritic Park, Evenkiya, Russia. Contact: Gennadij Andreev, Astronomical Observatory of the Tomsk State University, Box 1106, 634010 Tomsk, Russia. Phone: 7-3822-909721; fax: 7-3822-230450.

**31–Aug 3**
Workshop on Chaos in Gravitational N-Body Systems, La Plata, Argentina. Contact: J. C. Muzzio, Observatorio Astronómico, Paseo del Bosque, 1900 La Plata, Argentina. Fax: 54-21-21-1761 or 54-21-25-8985. Internet: chaos@fcaglp.edu.ar
### CALENDAR 1995

#### AUGUST

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<td>13-17</td>
<td>Microscopy &amp; Microanalysis—Annual Meeting of the Microscopy Society of America and the Histochemical Society</td>
<td>Kansas City, Missouri</td>
<td>MSA Meeting Office P.O. Box EM, Woods Hole MA 02543. Phone: 800-538-3672; fax: 508-548-9053. Internet: <a href="mailto:mmaser@mbl.edu">mmaser@mbl.edu</a></td>
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<tr>
<td>14-15</td>
<td>Mars Telescopic Observations Workshop</td>
<td>Ithaca, New York</td>
<td>Contact: MTO, Publications and Program Services Department, LPI, 3600 Bay Area Boulevard, Houston TX 77058-1113. Phone: 713-486-2166; fax: 713-486-2160. Internet: <a href="mailto:cangelosi@lpi.jsc.nasa.gov">cangelosi@lpi.jsc.nasa.gov</a></td>
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<td>14-18</td>
<td>IAU Colloquium 150: Physics, Chemistry &amp; Dynamics of Interplanetary Dust</td>
<td>Gainesville, Florida</td>
<td>Contact: M. S. Hanner. Internet: <a href="mailto:msh@iplsc8.dnet.nasa.gov">msh@iplsc8.dnet.nasa.gov</a></td>
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<td>24-30</td>
<td>Mars Pathfinder Landing Site Workshop II: Characteristics of Ares Vallis Region</td>
<td>Spokane, Washington</td>
<td>Field Trip I: Channeled Seablands (9/24-27); Field Trip II: Missoula Lake breakout (9/30), Moses Lake area, Washington. Contact: Publications and Program Services Department, LPI, 3600 Bay Area Boulevard, Houston TX 77058-1113. Phone: 713-486-2166; fax: 713-486-2160. Internet: <a href="mailto:simmons@lpi.jsc.nasa.gov">simmons@lpi.jsc.nasa.gov</a></td>
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<tr>
<td>8-13</td>
<td>27th Annual Meeting of the Division for Planetary Sciences of the American Astronomical Society</td>
<td>Kona, Hawaii</td>
<td>Contact: Karen Meech, University of Hawaii, Institute of Astronomy, 2680 Woodlawn Drive, Honolulu HI 96822. Internet: <a href="mailto:meech@pavo.ifa.hawaii.edu">meech@pavo.ifa.hawaii.edu</a></td>
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<td>10-12</td>
<td>Artificial Intelligence &amp; Knowledge Based Systems for Space: 5th Workshop</td>
<td>Noordwijk, The Netherlands</td>
<td>Contact: ESTEC Conference Bureau, P.O. Box 299, 220 AG Noordwijk, The Netherlands. Phone: 31 1719 85005; fax: 31 1719 85658. Internet: <a href="mailto:confburo@estec.esa.nl">confburo@estec.esa.nl</a> WWW: <a href="http://www.estec.esa.nl/aikbs.html">http://www.estec.esa.nl/aikbs.html</a></td>
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<tr>
<td>11-14</td>
<td>The Role of Dust in the Formation of Stars</td>
<td>Garching, Germany</td>
<td>Contact: Hans Ulrich Kaufl, European Southern Observatory. WWW: <a href="http://http.hq.eso.org/stardust.html">http://http.hq.eso.org/stardust.html</a></td>
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#### NOVEMBER

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<tr>
<td>26-Dec 1</td>
<td>International Symposium on Spectral Sensing Research (ISSSR) 1995</td>
<td>Melbourne, Australia</td>
<td>Contact: Judy Cole, Science and Technology Corporation, 101 Research Drive, Hampton VA 23666-1340. Phone: 804-865-7604; fax: 804-865-8721. Internet: <a href="mailto:cole@stcnet.com">cole@stcnet.com</a></td>
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#### JANUARY 1996

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<td>7-11</td>
<td>Space Technology and Applications International Forum (STAIF-96)</td>
<td>Albuquerque, New Mexico</td>
<td>Includes: 1st Conference on Commercial Development of Space; 1st Conference on Next Generation</td>
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Launch Systems; 1st Conference on Remote Sensing for Commercial, Civil, and Science Applications; 2nd Spacecraft Thermal Control Symposium; 13th Symposium on Space Nuclear Power and Propulsion. Contact: Mary Bragg, ISNPS, University of New Mexico, School of Engineering, Albuquerque NM 87131-1341. Phone: 505-277-4950; fax: 505-277-2814. Internet: mjbragg@unm.edu

22–26
New Extragalactic Perspectives in the New South Africa: Changing Perceptions of the Morphology, Dust Content, and Dust-Gas Ratios in Galaxies, Johannesburg, South Africa. Contact: David L. Block, Department of Computational & Applied Mathematics, Witwatersrand University, P.O. Box 60, WITS 2050, South Africa. Phone: 27-11-339-7965; fax: 27-11-716-3761.

MARCH

18–22

continued from page 12
work. Unlike a static vehicle such as Viking, a rover continuously and rapidly requires many decisions about what to look at, with what instruments, and when.

At Kilaeua, we did quite well on many observations, according to the debriefing when it was all over. We were able to identify flow fronts, vesicles in basalts, tension cracks in the ground, and stratigraphic relationships among basalts, and not just because of prior knowledge. We were able to define different types of surfaces. The pace of movement was sometimes frustrating (a human can scan and select very rapidly) and the optical limits sometimes equally so. The test emphasized the basic reality that learning has as much to do with forgetting as remembering: eliminating the irrelevant from the synthesis.

The team had varied opinions on how close this all came to actually being in the field; I never lost the feeling that I was encumbered by the limited vision and was never able to feel that I was actually there, but others came close. We still have a lot to do to define team structure, team strategies, and decision-making, but this test gave us a lot of confidence that we can use such a rover to make excellent observations on other planets.

It is inevitable that planetary exploration will include robotic roving, such as Mars Pathfinder. We need to know how to do it well. For our next tests we would want some improvements: better real-time imaging, continuous knowledge of the heading and tilt of the rover, and faster image-processing and informed feedback. We would make more panoramic sweeps as we drive.

We have to accustom ourselves to the difference between rover vision and our own vision: the much lower viewpoint and much wider instantaneous field of view of the rover tricked us into thinking objects only a few meters away were a hundred meters away. And we have to learn how to question our observations, make sure we complete our observations, and learn how to communicate rapidly with each other. But everyone needs more than one class when they take Drivers-Ed! We are excited at the prospects of another next lesson! ☺

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The Lunar and Planetary Information Bulletin is published quarterly by the Lunar and Planetary Institute, 3600 Bay Area Boulevard, Houston TX 77058-1113.

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Editorial and production support are provided by the LPI Publications and Program Services Department. Copy deadline for the summer issue of the LPIB is July 21, 1995.

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