PLANETARY SCIENCE

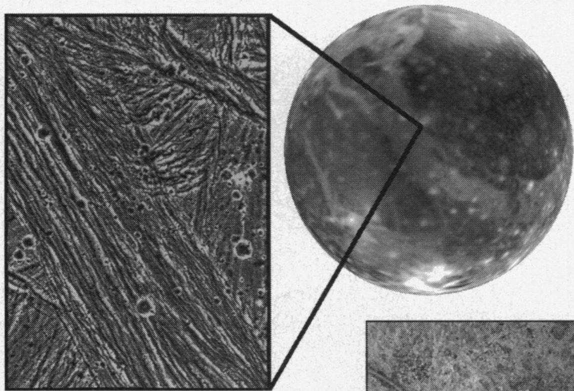
Galileo Turns Geology Upside Down on Jupiter's Icy Moons

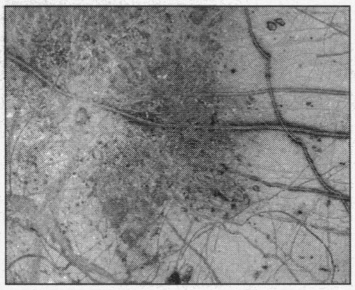
When Galileo Galilei turned his rudimentary telescope on Jupiter almost 4 centuries ago, he saw four points of light hugging the immense disc of the planet. That first glimpse of Jupiter's moons was amplified over the years, as later astronomers distinguished at least 16 satellites orbiting the planet. But it wasn't until 1979, when two Voyager spacecraft whizzed by Jupiter, that those four bright dots were transformed into individual worlds that a geologist could try to understand. Now, that exploration has taken another big step forward, as the spacecraft Galileo offers a longer, more intimate look at the Jovian system—including closeup images that are overturning scientists' ideas about the geology of these icy moons.

In this issue of *Science* (beginning on p. 377), Galileo team members report their latest interpretations of data returned by the spacecraft as it circles Jupiter. The findings range from the probable identification of the satellite Io as the source of some interplanetary dust to the discovery of thunderstorm-like clouds in Jupiter's Great Red Spot. But the most startling news comes from the moons Ganymede and Europa. What seemed to be relatively young ice volcanism on Ganymede now looks like older, tectonic deformation of the crust, and what looked to be stretched crust on Europa now appears to be the remains of volcanic eruptions. These new images will help geologists understand the nature and timing of the turmoil that shaped the moons' wrinkled visages. "It's what exploration is all about," says Galileo team member James Head of Brown University. "Turning your thinking upside down, pushing the reset button, that's what you need to do."

Astronomers' view of the enigmatic Ganymede has been revolutionized before. The 17th-century Galileo's pointlike view of this 5262-kilometer moon—and that of the ground-based astronomers who followed him—was transformed when Voyager gathered images that could resolve features as small as 1 kilometer. Now the Galileo spacecraft has swept within 835 kilometers of Ganymede, carrying a more sophisticated camera that yielded images with resolution as precise as 11 meters. "When you talk about two orders of magnitude improvement," says planetary geologist Steven Squyres of Cornell University, "you're in a different realm."

As an example of that new realm, consider two images of the same area of parallel ridges on Ganymede—one a Voyager image with a resolution of 1100 meters and the other Galileo's version at 74 meters (see figure 12, p. 383). "Each ridge or furrow seen at the Voyager resolution turns out to have five or six additional ones parallel to it," says Head. The ridges must have been pulled apart by crustal extension early in Ganymede's history, and the spacing between them reflects the thickness of the crust. So the multiplication of ridges implies a thinner crust—and therefore greater heating of the moon—than planetary scientists had supposed.





PHOTOS BY JPL/NASA

Second sight. Galileo improved Voyager's view, revealing finely spaced ridges on Ganymede *(above)* and fuzzy edges *(dark material)* on Europa's triple bands *(right)*.

And that may have implications for a hot topic among planetary scientists: just how and when Ganymede was heated. All newly formed planetary bodies experience some heating, but Galileo's recent discovery of a magnetic field around Ganymede has suggested a relatively young source of heat as well, something capable of churning a conducting liquid to form a geodynamo (*Science*, 19 July, p. 311). But this younger heat source is still theoretical, and which of these heating episodes created the narrow ridges—and when—awaits a more detailed examination of Ganymede's terrains and their relative ages.

For now, the Galileo spacecraft's higher resolution is helping to straighten out the sequence of events in one type of terrain on Ganymede. Voyager researchers had identified some areas that they thought represented surface flooding by "volcanic lavas" of water and ice. Such cryovolcanic resurfacing would presumably flood older, rougher terrain with fresh ice lavas. In that case, brighter and smoother terrains—that had less time to accumulate the scars of tectonic deformation and meteorite impacts—would be younger. But Galileo images show that this common presumption can be a trap. "Some of the bright terrain that looks smooth at Voyager resolution turns out to be not younger [than adjacent terrain] but older," says Head. On closer inspection, this older terrain has more impact craters and more varied styles of deformation, he says, which tend to break up the pattern of surface roughness and so smooth out its appearance at lower resolution.

Ice volcanism may be harder to find on Ganymede, but Galileo's sharper images have now found evidence for it on Europa. A prominent type of feature on this 3138-kilometer moon is a triple band—a 10- to 20-kilometer–wide dark zone with a central bright stripe—that had been attributed largely to tectonic forces. According to a leading theory, as the crust was pulled apart, a long block dropped downward between two faults. Dirty, icy slush then flooded the resulting trough. Such a mechanism would produce sharp fault lines along the edges of the block where the crust broke, notes Galileo team member Ronald Greeley of Arizona State University. But Galileo images reveal that the outer edges of triple bands are diffuse over distances of 10 kilometers.

"That rules out a faulting mechanism for the outer edge of the triple bands," says Greeley. And so he and others are turning to volcanic alternatives: The dark banding could be debris lofted from an eruption along a narrow fracture, says Greeley. Once the dark material was cleared from the throat of the fracture, clean ice from lower depths would mark the central stripe. Such volcanism implies considerable internal heat, which is consistent with the notion of a water ocean beneath Europa's icy shell—a possibility that sparked excitement a few months ago because water is considered a prerequisite for life (*Science*, 23 August, p. 1048). But the new images can offer no solid evidence of such an ocean.

Ideas about the moons are evolving constantly as researchers scramble to keep up with the surprises revealed by ever-increasing resolution. "You pose questions given Voyager's resolution and then target specific areas to clarify things," says Head. Then the Galileo spacecraft "solves that problem, but of course the resolution opens up things you hadn't expected—the serendipity aspect. It sounds like job security, but it's just the nature of exploration."

–Richard A. Kerr