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COVER: Computed tomography scan of the brain of a 23-year-old man diagnosed as a chronic schizophrenic reveals enlarged cerebral ventricles, or cavities (shaded areas). This and other types of brain structure abnormalities are being detected in a series of new studies of schizophrenic patients. See story p. 26. (Photo: Daniel R. Weinberger, NIMH)

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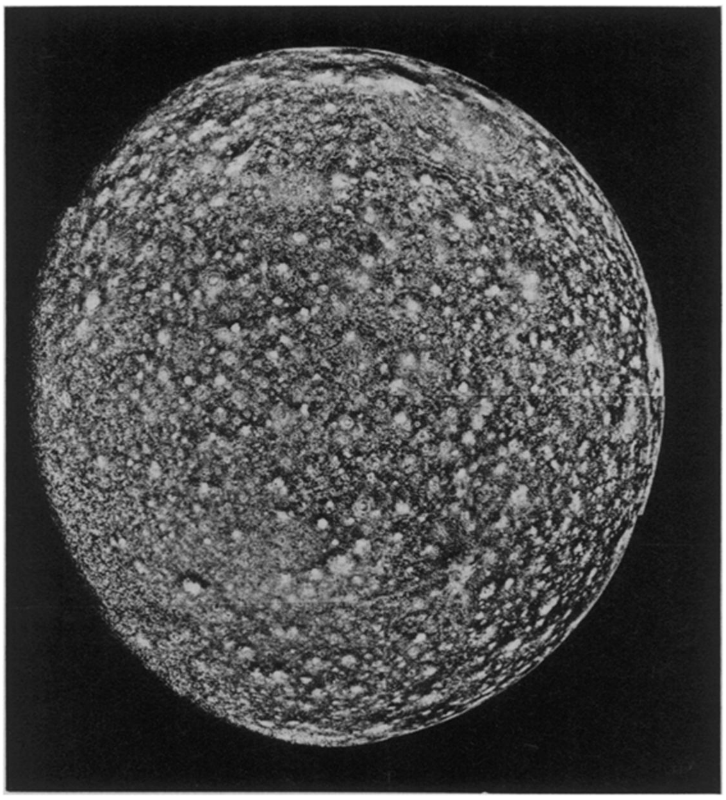
VOYAGER 2: Return to Jupiter & Co.

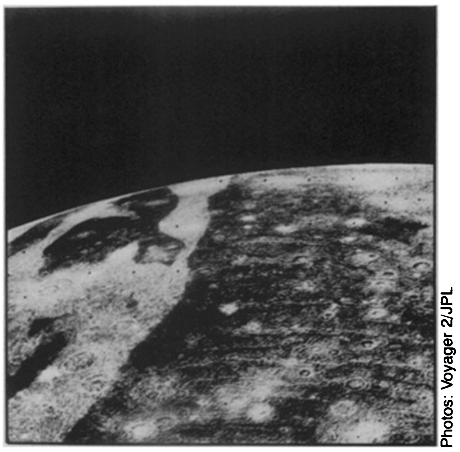

Voyager 2/JPL

The surface of Callisto, called perhaps the most heavily cratered in the solar system, may preserve conditions from its earliest meteorite bombardment, though the ice-rich crust has flattened most of the high rims and peaks typical of impact craters in rocky worlds.

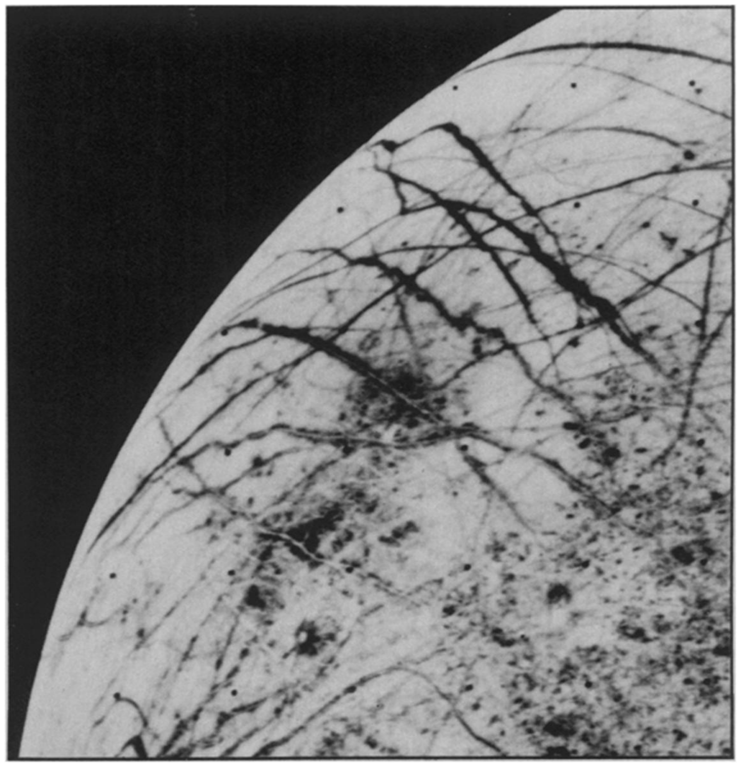
A tour of the "oldest, youngest, darkest, lightest, most active, least active and flattest" worlds in the solar system sounds like a wide-ranging foray that would require the visitor to space-hop back and forth among most of the major planets circling the sun. Yet all, according to Laurence A. Soderblom of the U.S. Geological Survey, are part of a single grouping: the family of Jupiter, whose exotically diverse principal satellites have suddenly found prominent places on the list of the most exciting objects in the sky. The Voyager 1 spacecraft made the point in March of this year, when its instruments revealed cratered Callisto, fractured Ganymede, striped Europa and stunning, volcanically active Io, along with striking new details about their huge host planet. Now Voyager 2 has repeated the feat, following a slightly different path and adding new data that have made its target worlds, if anything, more dramatic still.

The first of the mission's close encounters was with the outermost of Jupiter's so-called Galilean satellites, Callisto, which may turn out to be a special kind of prize indeed. Since the early days of planetary research by spacecraft, scientists have hoped to find examples of "pristine surfaces"—areas of planetscape whose appearance preserves a record of the heavy meteorite bombardment in the early days of the solar system. A few patches exist on earth's moon (and fewer on Mercury), but much has been covered up by more recent episodes of lava flooding and other processes. Callisto, however, says Torrence Johnson of Jet Propulsion Laboratory, "doesn't look like anything has happened to it since the end of the final stages of accretion," when the object was still in its infancy. In fact, Johnson says, "Callisto may well turn out to be the most heavily cratered body in the solar system," with its cratering record seemingly free of broad lunar-style maria or intercrater plains. If so, it would be a virtual museum on the past of 4 billion years ago and more. Only in the area covered by a few huge, concentric-ringed basins (one seen by Voyager 2 is about 1,500 km across) do the numerous craters diminish.

What is missing, however, or at least greatly reduced, is the craggy topography left by such intense bombardment. Virtually absent are the kilometers-high crater walls and towering central peaks typical of rocky worlds — for Callisto may be as much as half ice, whose



Ganymede: Arcs may be ancient basin.



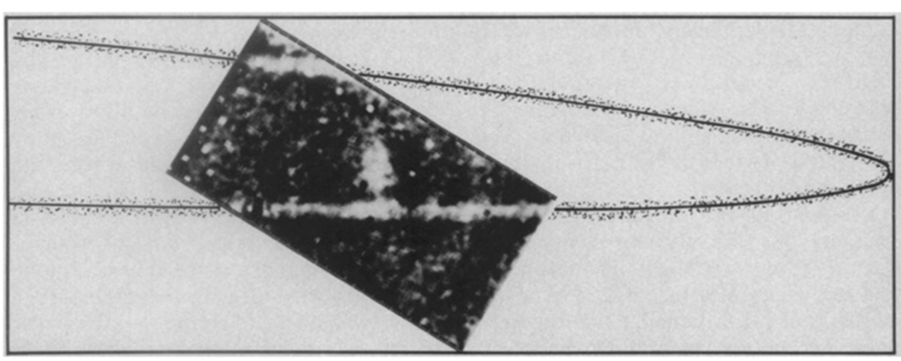
Twisted streaks criss-cross Europa, some of them long and wide yet apparently flush with the surface. Only a few light streaks — possibly low-density material extruded up from beneath — together with a few pits and localized depressions seem to provide vertical relief amid the prevailing smoothness.

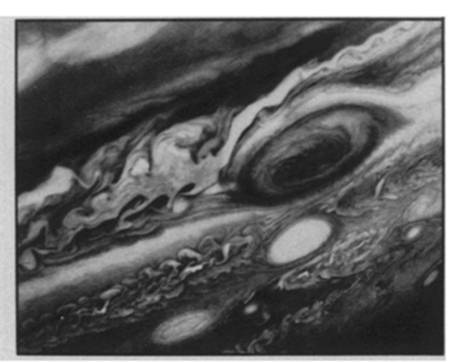
gradual flowing, Soderblom says, could erase most of such vertical relief in "a tiny fraction of Callisto's lifetime," possibly less than 1,000 years. Even to experienced moon- and Mercury-watchers, the cratering is strikingly uniform — but the surface may still not be everywhere the same. Special, false-color processing of some of the new photos suggests larger-scale (though subtle) variations, implying, according to imaging team leader Bradford Smith of the University of Arizona, that Callisto's surface "is not of uniform composition." Just what the differences are, however, will take lengthy analyses of Voyager's infrared and other data, and probably help from the multiple mid-1980s flybys by the Jupiter-orbiting Galileo spacecraft, now struggling to meet a late 1982 launch date.

Ganymede, next satellite in toward Jupiter and larger than Mercury, received Voyager 2's closest scrutiny of the mission, as the craft swept past at a distance of barely 60,000 km. Voyager 1 (which saw the object's other face, and from no closer than 112,000 km) had already riveted the scientists' attention by revealing numerous examples of apparent classic, parallel faults, some aligned side by side in swaths more than 100 km wide. In places, the swaths are broken — laterally offset — by what look like textbook cases of transverse faulting, which suggest that Ganymede may be the most conspicuous known extraterrestrial example of earth-style tectonics. "Plate motions, linear motions, lateral motions, some rotational motions," says Smith of Ganymede's fault-line implications, and some arrays seem to meet in patterns of surprisingly regular right angles. But there's more. Bounded by the fault paths are cratered areas including one vast, circular region so heavily pounded that it looks, according to Soderblom, "like a piece of Callisto." With certain fundamental differences: Far from resembling a pristine surface, says Harold Masursky of the USGS, the craters in Voyager 2's close-ups suggest a wide range of ages, and one large, smooth basin reminds him of "Mercury, or the highlands on Mars." Some of the cratered terrain seems to overlie the remains of multi-ringed basins, ancient events on a titanic scale. "Ganymede geology," says Masursky with a smile implying understatement, "is more complicated than we thought."

Io: Formerly heart-shaped ejecta blanket (lower left) around vent now looks oval.

Next inward of the Galilean satellites is Europa, paradoxically the blandest, yet one of the strangest, of the lot. Showing few craters, it is marked most conspicuously by a confusion of straight and rambling linear features, dark against the light, icy surface in Voyager's (contrast-enhanced) photos and extending for hundreds to thousands of kilometers, looking "remarkably," says Smith, "like the Orwellian drawings of Mars." But unlike the distinctly grooved striations of Ganymede,





Jupiter's twisted cloud patterns (right) and ring system, which may extend all the way into the planet itself.

most of Europa's dark markings are so flat, says Smith, that they could have been "drawn with a felt-tip pen." They are believed to be filled-in faults—cracks—in the crust, but, again unlike Ganymede's, they do not appear to have been created under pressure, as by plates moving relative to each other. An alternative, offers Soderblom, is that they might have grown to their sometimes considerable width (tens of kilometers) simply by progressive erosion along the facing edges of the initial fissures.

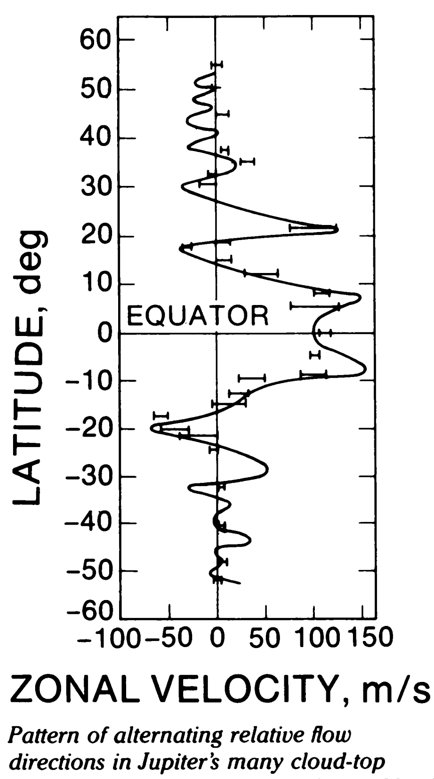
But what created the presumed breaks in the first place? The surface appears cracked on a variety of size scales, much like pack ice on a frozen-over sea, and a number of Voyager's scientists think the analogy may be an apt one. One suggestion, for example, is that the tidal-dissipation mechanism proposed by some researchers to account for the recently discovered active volcanoes on Io (the remaining Galilean satellite) may also affect Europa (though only perhaps a tenth as much). This might stress the ice-crust either directly or from beneath, in the latter case by flexure of the rocky layer below the ice.

Europa is not totally flat, however—just close to it. Voyager 2's close-ups, about 10 times sharper than its predecessor's, show occasional signs of apparent "sagging" of the ice, says Masursky, as though localized heat sources (tidal flexions? radionuclides?) may exist beneath. There are also a few seemingly pitted regions, as though the ice, which would normally erase such features, is supported more firmly in some spots than in others. Finally, in addition to the flat, relatively dark streaks, there are some conspicuously light-colored ones, which appear to rise a few tens of meters above the surrounding terrain. Perhaps, says Soderblom, these could be places at which comparatively "clean" (and thus low-density) ice has risen through the adjacent ice that contains traces of heavier, rocky material.

With three of the four Galilean satellites behind it, Voyager 2 finally encountered Jupiter itself, although the huge planet had actually been in the cameras' view for months. The diverse and spectacular features of the Jovian cloud tops are known to change on time scales of centuries, years, months, days and even hours, and Voyager 2 further proved the point. Smooth areas have become turbulent, active features quiescent. The broad white band that contained the famous Great Red Spot a few years ago had become a narrow stripe in Voyager 1's images in March, and is now narrower still, though there are signs east of the Spot that the band may be widening again. There are countless other examples, and as one Voyager researcher points out, "You could re-map the planet once a week forever and always see a different version." But mere spot-plotting and stripe-typing are no longer the point. The Voyager team is looking for explanations, seeking method behind the Jovian madness. Given the overall banded appearance of Jupiter, says Andrew Ingersoll of the California Institute of Technology, "It's hard to understand how turbulent fluids can be so orderly on a large scale." The planet's rapid rotation (its day is barely 10 hours long) is certainly a factor, but is that enough? The Red Spot, for example, has been known almost as long as Jupiter itself, yet it is not always found at the same longitude — it drifts.

One hint at an overall pattern has come, says Ingersoll, from studies of Voyager photos showing the relative velocities of the planet's many axial stripes. The result, partially reinforced by a similar compilation from five years of earth-based observations, is a chart showing a remarkably regular alternation of eastward and westward relative movement, with near-mirror-image patterns in the northern and southern hemispheres. But what causes the patterns? Past diagrams of Jovian cloud behavior have concentrated on the behavior of the upper clouds. Perhaps, however, speculates Ingersoll, the so-far inaccessible depths of the atmosphere will have to be taken into account, since most of Jupiter's heat comes from within. "We're sort of in the position of oceanographers," he says, though on earth the driving energy supply comes from the sun above.

Voyager 2 also rephotographed in spectacular fashion the thin ring system of particles surrounding the planet, discovered in a single photo by Voyager 1. Seen precisely edge-on at that time, it was purposely shaped a few degrees out-of-plane by Voyager 2, revealing a structure whose



Voyager data: G. Hunt, A. Ingersoll, et al./earth-based data: R. Beebe, et al.

Pattern of alternating relative flow directions in Jupiter's many cloud-top bands, based on Voyager data (curved line) and earth-based observations (bars).

brightest rotation spans about 6,500 km radially, but which, judging from early impressions, may also contain lesser concentrations of material inside the main ring element. It may be, says Smith, that "that material goes all the way down to the surface of Jupiter." Matched images of the Jovian ring system taken through colored filters will give Voyager scientists a chance to attempt some conclusions about the rings' particle size and perhaps composition. (Auroras, magnetic-field effects and other phenomena were all part of the mission. More next week.)

The last of the spacecraft's close encounters was with Io, where the discovery by Voyager 1 of still-erupting volcanoes (SN: 3/17/79, p. 165) has been hailed as one of the major findings in the history of planetary exploration by spacecraft. Of the eight active vents identified in the earlier photos, Voyager 2 reexamined seven — and found some differences. Although the tidal-heating theory had been interpreted by some as implying that the eruptions would be virtually continuous, one vent — the largest — has now shut off completely, though not before spewing forth enough material to modify its heart-shaped ejecta blanket into a smooth ellipse.

Competing theories have already arisen to explain the eruptions and their contributions to Io's sulfur-rich surface. In the simpler proposal, liquid silicate rock (possibly kept molten by the tidal effect) like earthly magma rises through an overlying crust of solid silicate laced with sulfur; the magma might either leak through to the surface, forming "basaltic-type" flows, or first penetrate and vaporize a trapped layer of sulfur dioxide — Io's equivalent of the water in a terrestrial aquifer — to produce the observed explosive eruptions. Smith suggests an alternative in which the underlying solid silicates contain pockets of molten sulfur that extend up and out into a veritable "sulfur ocean" beneath a solid sulfur crust. Unlike water, sulfur is lighter in liquid than solid form, and any crack in the surface would let the liquid rise to the surface, again either slowly or, with the help of suddenly vaporizing SO_2, with a bang. Proponents of the different models disagree on the dominant process, though Masursky asserts that both — and others — may operate in different places. Near Io's South Pole, for example, stand some several kilometer-high mountains that, he says, might well be too heavy to be supported by the supposed sulfur ocean, even with a solid crust. In the lower latitudes where most of the active vents seem to exist, however, a variety of eruptive styles suggest that anything is possible. (Indeed, with Io almost anything *is* possible; again, more next week.)

Both Voyagers are now on their way to Saturn, which will get a first closeup look from the Pioneer 11 spacecraft this September. □