Frigid Oceans for Triton and Titan

Oceans are being found in the most unexpected places. At the Natural Satellites meeting in early July,* researchers resurrected the idea of a globe-encircling sea on Saturn's satellite Titan, with liquid ethane substituted for the previously proposed but impractical methane. A group of astronomers also presented evidence of a liquid nitrogen ocean on Triton, the major moon of Neptune.

Once the Voyager 1 spacecraft had confirmed the presence of a dense, methane-containing atmosphere on Titan, speculation ran wild about the possibility of a methane ocean, methane clouds, and methane rain, an entire hydrologic system supplied by what earthlings would view as a vast pool of liquefied natural gas. Recent analyses of the Voyager data by Von Eshleman and Leonard Tyler of Stanford University and Gunnar Lindal of the Jet Propulsion Laboratory and by Michael Flasar of the Goddard Space Flight Center appeared to eliminate the possibility of a global methane ocean and cast doubt on the existence of any body of liquid on Titan large enough to be called an ocean.

Methane may be out, but Jonathan Lunine, David Stevenson, and Yuk Yung of the California Institute of Technology pointed out at the meeting that sunlight has had more than 4 billion years to convert methane to ethane above an altitude of about 50 kilometers. The ethane would steadily condense and fall to the surface to mix with the methane ocean that presumably covered the surface after Titan formed. After eons of photochemical conversion, Lunine and Stevenson calculate, the global ocean would be about 75 percent ethane and only about 20 percent methane. Dissolved atmospheric nitrogen would account for the remaining 5 percent. The dilution of the methane avoids the restrictions imposed by the Voyager data, which showed that the atmospheric temperature gradient is not reduced by the condensation of methane gas overlying pure methane liquid.

At the unearthly surface temperature of −184°C an ethane ocean would still produce an ethane-rich mist below an altitude of 10 kilometers and a methane-rich haze above that. A photochemically produced snow of acetylene would drift through the hazes and settle to the bottom of the 1-kilometer-deep ocean to form a few hundred meters of sediment. Traces of photochemically produced organic compounds would tint sky and sea a reddish-orange. Boating on Titan would be a bit monotonous. Because of the expected low relief, few islands would break the surface. Continents are unlikely, as Carl Sagan and Stanley Dermott of Cornell have pointed out; large landmasses would dissipate ocean tidal energy and eliminate any eccentricity of Titan's orbit, which has not happened. Hardly a breeze would ripple the surface. Not even an occasional water iceberg would drift by—water ice sinks in ethane.

Oceanographic conditions are more uncertain on Triton, whose surface temperature of 62 K freezes even methane. Dale Cruikshank, Robert Brown, and Roger Clark of the University of Hawaii reported the detection of a feature at a wavelength of 2.15 micrometers in the infrared spectrum of Triton that they attribute to absorption by molecular nitrogen. This particular absorption is characteristic of densely packed nitrogen molecules, which at Triton's temperature could be either liquid or solid. The Hawaii group favors a liquid because infrared radiation probably could not penetrate the meter or so of solid nitrogen required to produce the strength of the absorption.

If the Hawaiian astronomers' interpretation is correct, the surface of Triton is probably more varied than Titan's. Methane has already been detected on Triton, apparently as a solid distributed unevenly around the globe. The Hawaiian group can improve the match of their spectrum with known compounds by including fine-grained water ice. These compounds are probably mixed with each other and some are soluble to varying degrees in each other, but one could imagine methane icebergs floating in a placid sea of liquid nitrogen between water-ice continents covered with methane snow. Or perhaps shallow swamps cover much of Triton. A cruise would be interesting but terribly chilly.

*Natural Satellites Colloquium, held 5 to 9 July at Cornell University; cochairmen were Joseph Burns, Cornell University, and David Morrison, University of Hawaii.

Chaotic Rotation Predicted for Hyperion

Throw a rock into the air, and it will tumble over and over until it hits the ground. Blast the same rock into orbit around a planet, and the gravity of the planet will slow the rock's spinning until the rock rotates synchronously, once for each time it revolves around the planet, as our moon does. The rotation of Hyperion, an odd-shaped moon of Saturn, may be like neither of these.

Jack Wisdom and Stanton Peale of the University of California at Santa Barbara and François Mignard of the Research Center for the Study of Geodynamics and Astronomy (CERGA) in Grasse, France, predicted that Hyperion will be found to be tumbling chaotically—not just end over end, but first one way and then another, slowing down and then speeding up, turning and twisting like a demented gyroscope. According to their theoretical calculations, Hyperion could be rotating synchronously at one point, keeping the same face toward Saturn as its better-behaved neighbors Rhea and Iapetus do, but during the next revolution about Saturn it could be rotating as much as twice as fast.

These theorists believe that Saturn's gravity would synchronize Hyperion's rotation if it were not for the satellite's odd shape—it measures 115 by 145 by 190 kilometers—and its elongated, eccentric orbit. As Hyperion follows its eccentric orbit, Saturn tugs on different parts of the satellite with differing effects, sending it into chaotic tumbling. It cannot stabilize itself because Titan, orbiting just inside the smaller Hyperion, keeps Hyperion's orbital eccentricity high through periodic gravitational tugs of its own.

Observers have confirmed part of this theoretical prediction. Both a group headed by Peter Thomas of Cornell, working from Voyager 2 images, and Jay Goguen of the University of Hawaii, observing with the 224-centimeter telescope on Mauna Kea, found that the most likely rotation period for Hyperion is 13 days, not the 21 days expected for synchronous rotation. Peale notes that this period is within the predicted realm of chaotic rotation. The catch is that 18 months separated the two sets of observations, during which Hyperion was presumably changing its spin rate. Theorists are calling for more thorough, nightly observations. Observers wonder how they can justify that much telescope time.

Could Saturn's Rings Have Melted Enceladus?

A group of theorists has suggested a solution to a problem in satellite geology that would also solve half of a major problem in planetary ring dynamics. The geologic problem is the melting of Saturn's satellite Enceladus. It appears to have partially melted too much to have drawn on heat left from its formation or generated by Saturn's periodic tidal distortion of its shape. The problem in ring dynamics is the presence of small satellites near the edge of the broad outer ring A—the satellites and the ring should have repelled each other, collapsing the ring inward and driving the moonlets outward.

The solution and a half offered by Jack Lissauer and Jeffery Cuzzi of the Ames Research Center in Mountain View, California, and Stanton Peale of the University of California at Santa Barbara, is that the tiny moon Janus was able until recently to transfer some of the orbital energy of ring particles out to Enceladus, which melted its interior, while maintaining Janus' position near the rings. The first leg of the outward transfer of momentum and energy is evident today in the spiral density waves in the A ring that are generated by Janus and its companion ring moons.

The second leg, from Janus to Enceladus, is missing now, but Lissauer and his colleagues have traced Janus's outward drift under the influence of the rings back 15 to 20 million years to a place where Enceladus could have locked it in a stable orbit through a gravitational resonance. This 2:1 resonance, in which Janus feels a periodic tug from Enceladus after every second revolution about Saturn, would both anchor Janus against the repulsion of the rings and extend the transfer of ring orbital energy to Enceladus. That would increase the eccentricity of Enceladus's orbit, allowing Saturn to tidally squeeze the satellite repeatedly and generate the heat needed to melt it. Because Janus is drifting freely now, Lissauer and his colleagues presume that a catastrophic collision, which could have formed Janus's present co-orbital companion, or the formation of the Enceladus-Dione 2:1 resonance cut Janus free of its anchor and allowed a final cooling of Enceladus that may continue today.

Problems remain, these theorists point out. Other near-ring moons must be anchored, and this hypothesis accounts only for the loss of ring energy. Either the rings are relatively young, or a still unimagined source of orbital energy is resupplying the rings.

Volcanism at 100° Below

Where could lavas flow at 100°C below zero? Where might glaciers emerge from the very ground beneath your feet? On the icy satellites of the outer solar system. The Voyager images of smooth, uncratered plains, bright wispy markings, and crisscrossing bands of fresh, uncratered terrain on these satellites startled planetary scientists, who presumed that most of the icy satellites were too cold to be geologically active. Obviously, forces within some satellites had reshaped their surfaces since the meteorite cratering episode early in the history of the solar system.

Given a modest source of heat energy in a satellite, whether left from the formation of the satellite or produced by radioactive decay in its rocky core, the question becomes, Why should anything in the interior ever reach the surface? On Earth, molten rock rises to form volcanoes because it left denser minerals behind when it melted deep in the mantle. The magma is lighter, so it rises.

Volcanism cannot work quite that way on the icy satellites, noted David Stevenson of the California Institute of Technology. On Jupiter's Ganymede, for example, a young water ocean would have been sealed by increasingly thick surface ice. Stevenson sees no way of driving water through the less dense ice, but Randolph Kirk of Caltech and he have proposed a way to cover the surface with fresh ice despite the barrier to rising water. Their resurfacing process depends on the formation of ice III, a high-pressure form of ice, at the bottom of the iced-over ocean.

As the two ice layers grow toward each other at the expense of the water between them, the deep, relatively warm ice III layer becomes unstable and susceptible to external disturbance. A meteorite impact could plow through the upper ice and ocean and create rising, elongated blobs of ice III. Within a few years, one of these plumes would cross the water boundary, begin forcing its way through the upper ice layer, and eventually spill onto the surface where it would flow like a glacier. Such an ice plume would bear a strong resemblance to the terrestrial mantle plumes thought to feed volcanic hot spots, such as the island of Hawaii.

On the intermediate-sized satellites of Saturn and Uranus, where Stevenson expects frozen ammonia would be found as well as water ice, he envisions liquid, water-ammonia magmas flowing to the surface, driven by their inherent buoyancy. The ammonia is crucial because it lowers the melting point of the ice to the attainable temperature of −100°C. On Saturn's Enceladus, such water-ammonia lava flows might have smoothed some of the cratered surface and formed the plains seen by Voyager. Resurfacing may continue today (see preceding briefing). If so, says Stevenson, ammonia gas expanding away from fresh lava flows could form icy, 2.5-micrometer spherules of the kind thought to form the nearby faint E ring of Saturn.

The addition of methane to water-ammonia magmas could have created explosive volcanism akin to that of Earth's Mount St. Helens, says Stevenson. If "hot" water-ammonia magma encountered methane clathrate, which is water ice that has trapped methane in its crystal structure, the heat would explosively decompose the clathrate. That could possibly account for the bright material that has been strewed across Saturn's Dione, Rhea, and Tethys. On Pluto and on Neptune's satellite Triton, where at least some of the methane is not in clathrate form, magmas might have taken up methane and released it near the surface, driving geysers and forming temporary lakes. A major unknown, says Stevenson, is when and for how long any satellite was warm enough to drive icy volcanism.

—RICHARD A. KERR