Europa: distant

Europa may hold an ocea

By Michael Carroll

n ocean is the womb of a planet," says University of Washington oceanographer John R. Delaney. "It is the place where life can begin. It moderates the environment. It is a planetwide solvent." Many scientists join Delaney in their belief that life on Earth began in the ocean. And as we ponder the possibilities of life elsewhere in the universe, we seek evidence of waters past and present, the host seas of habitation. Although lately our scrutiny has been squarely on Mars (July issue, page 42), there may be a better site to explore — a place that may well have an ocean of its own: Jupiter's frigid satellite Europa. This world is the smoothest body yet seen in the solar system, and its surface looks superficially like sea ice found near Earth's poles. Images and other data from NASA's Galileo spacecraft reinforce this hypothesis.

The circumstantial evidence that Europa harbors a deep ocean under its icy crust has brought together a strange mix at recent conferences. Communities of planetary scientists and marine researchers are combining forces. "It is an interesting cultural experiment where we have brought a group of oceanographers and planetologists together to trade sea stories," Delaney observed at one such meeting in November 1996. What excites

Above: **A bloated Jupiter, glowing from the residual heat of gravitational collapse, hangs in the sky of primordial Europa. The giant planet's warmth may have been enough to keep Europa's surface liquid, perhaps long enough for life to develop. Eventually temperatures dropped and the surface froze. Did life retreat under the surface, where it was sustained not by sunlight but from thermal vents induced by tidal flexing of the moon?**

ocean, hidden life?

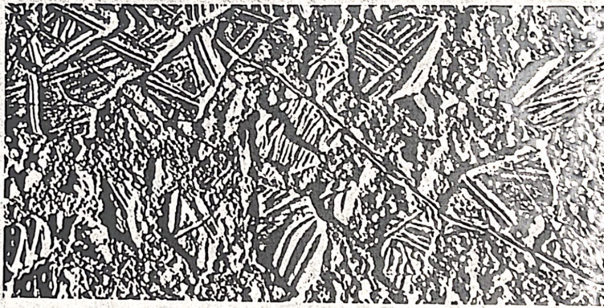
beneath its icy surface, but is something alive down there too

many scientists is not only that Europa may harbor an ocean, but that it may also be the dwelling place for new kingdoms of flora and fauna.

Jupiter's Water World?

Europa is fairly large as moons go. With a diameter of 3,138 kilometers, it is slightly smaller than Earth's Moon and is the sixth-largest satellite in our planetary system. The moon was among the four Jovian companions spied by Galileo Galilei as he explored the capabilities of his new telescope in 1610. Today, Jupiter's largest satellites — Io, Europa, Ganymede, and Callisto — are often referred to as the Galilean satellites.

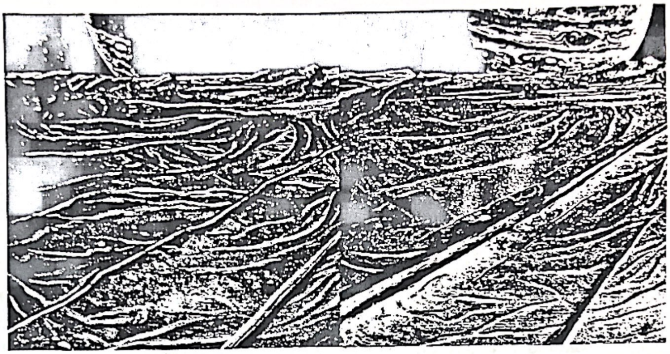
For more than 300 years, not much was known about Europa and its siblings. Then, in 1979 Voyagers 1 and 2 flew through Jupiter's family, transmit-



As captured by the Galileo spacecraft, regions of Europa's surface appear shattered where giant blocks have been broken and then "floated" away. Such ice rafts bolster the view that the satellite harbors a subsurface ocean.

ting thousands of images and other data back to Earth. Virtually overnight those encounters introduced us to the workings of planetary geology at cryogenic temperatures.

The innermost Galilean satellite, Io, was found to be remarkably active, with nine volcanoes erupting during the two encounters. Suffering from the same one-side-always-facing-the-planet — or synchronous — rotation as our Moon, Io is also locked in a gravitational resonance with other large satellites. For every orbit Ganymede makes around Jupiter, Europa goes around twice and Io four times. The combination of forces induces 50-meter tides in Io's crust. This flexing produces tremendous internal heat, which escapes as violent volcanic outpourings.



Among the evidence for Europa's subsurface ocean are the crisscrossing dark lines, or linea, on its surface. One theory holds that these bands begin as thin cracks in the surface. Liquid water seeps — or explosively escapes — to the surface and flows outward, building up linear ridges on either side of the fracture. As a ridge becomes more massive, the ice crust cannot support its weight, and more parallel fractures form. These cracks, in turn, go through the same process until several parallel ridges rise from the surface. Analysis of shadows indicates that these ridges grow no higher than 300 meters, at which point they may sink back into the surface due to their own weight, ultimately leaving a smooth "triple band." The fact that Europa's surface cannot support mountainous formations gives credence to the argument that an ocean lurks beneath.

Next out from Jupiter is Europa, which most scientists had predicted to be a cratered ball of ice. But astronomer Fraser P. Fanale (University of Hawaii) suspected otherwise. In 1977 he published the first hypothesis pertaining to how an ocean might form and remain stable even in the chilling temperatures at Jupiter. "This was before we knew about tidal heating," Fanale says. "I said that if you have a crust [of ice] deeper than 30 km you could have melting at the base."

Just two years later, the Voyagers revealed Europa to have smooth, icy plains crossed by dark stripes. Surprisingly, there were virtually no craters, which meant that something was keeping the surface fresh. Fanale's suspicions were confirmed; Europa was not a dead world. Either it was erupting water from "ice volcanoes" akin to neighboring Io's, or Fanale was right: an ocean beneath the crust was keeping the surface pliant. Either way, the implication of subsurface liquid water was inescapable. And on the floor of that ocean some researchers postulated volcanic vents fired by tidal flexing with Europa's rocky interior.

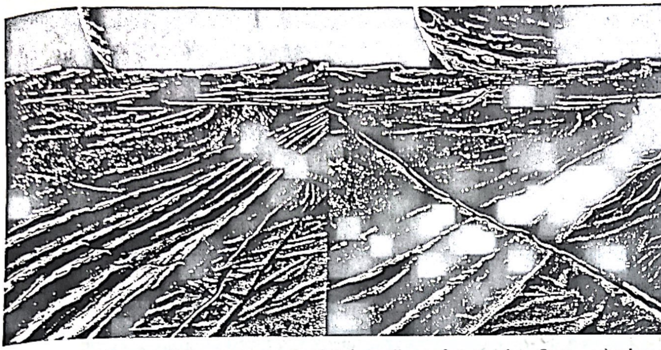
Other ideas were born after the Voyager flybys. In the January 1980 issue of the now-defunct *Star & Sky* magazine Richard C. Hoagland outlined why he believed Europa was the solar system's best chance for a second cradle of life. When the Sun and planets were young, he reasoned Jupiter would have been like a second Sun — glowing from the residual heat of gravitational collapse. The warmth may have been great enough to keep Europa's water liquid and to support an atmosphere. Eventually, Jupiter cooled, and the moon iced over. Nevertheless, was there enough time for some form of life to develop near the surface? Could it have survived deep in the subsurface oceans kept warm by the moon's flexing?

At about the same time, a seemingly unrelated discovery was made on Earth's ocean floor. Undersea explorers found billowing volcanic vents surrounded by colonies of living organisms, some of which had never been documented. Amazingly, here life flourished *without* sunlight.

Oceans, Volcanoes, and Life on Earth

Up until the last few years most biologists assumed that all terrestrial life was dependent on the Sun for energy. Even saprophytic life forms such as mushrooms which thrive in dampness and shadows derive nourishment from dead material that ultimately derived its sustenance from

Crisscrossing fractures on Europa's surface are the scars of internal activity. But do the dark stains contain organic matter? Further studies by Galileo may provide an answer.



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solar energy. Creatures living at great depths in the ocean depend on biological materials that fall from waters where sunlight is present. But when explorers ventured to chart the Mid-Atlantic Ridge, our concept of life changed. Divers witnessed active volcanic vents spewing black, smoky fluid — rich in minerals — into the water. Fish, albino crabs, and 10-foot-long tube worms huddled around the volcanic openings like moths around a flame.

At first researchers assumed that the booming colonies near the vents were feeding off the nutrients in the water. But later studies revealed microorganisms living *within* the hot fluid. These organisms were thermophylic bacteria, or bacteria that thrive in temperatures around 55° Celsius (130° Fahrenheit). Since the surrounding water temperature hovered around 2° to 4° C, scientists realized that these organisms came from beneath the sea floor, rather than trickling down through cracks and being recycled. "I used to think of the ocean floor as a desert with oases around volcanic sites," says Delaney. "But these vents may, in fact, be tips of a huge biomass iceberg."

The proposition that a hidden biome exists beneath the rocks of the sea floor is bolstered by the fact that microbes have been found 2.8 km underground in rock core samples. These creatures thrive in microbial ecosystems within the pores between mineral grains of igneous rocks. They derive nutrients from inorganic chemicals around them. Similar microbes have been discovered within rocks in the dry valleys of Antarctica. Over 9,000 distinct species have been cataloged from subsurface ecosystems. "It's a new paradigm," Delaney says. "We think a significant fraction of the planet's biomass resides in its crust."

This revelation has great implications in the search for life on Europa. If life on Earth is not dependent on sunlight, and if life can be sustained solely by hydrothermal sources, then the possibility of life locked under the ice crust of Europa increases. The late planetary geologist Eugene M. Shoemaker (Lowell Observatory) said, "If we want to get at the fundamental questions of life, and if there is an ocean out there, my bet is that Europa has a better chance than Mars for life today."

Even if Europa has an ocean and undersea volcanic activity, its environment is quite hostile. Daytime surface temperatures reach highs of about –130° C, and radiation from Jupiter falls upon Europa at levels that would be deadly to humans in a very short time. Could life exist in such a treacherous place?

Simple organisms live in many diverse conditions on Earth. Bacteria have been found growing within the radiated waters of nuclear generators. Other creatures tolerate wide ranges of temperature, living in the throats of volcanoes and in the ice of glaciers. Oceanographer James H. Morison (University of Washington) points out that "the bulk of the biomass in the arctic is actually attached to the underside of the ice."

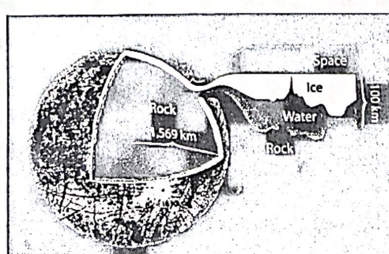
The combined discoveries of life in the dark ocean depths and volcanoes in the outer solar system improve the odds of life existing in a Europan ocean. More data were needed, but that would have to wait for further exploration of both Jupiter and the Earth's oceans. "The idea of a Europan ocean was a hot topic from about 1980 to 1986," says Torrence V. Johnson (Jet Propulsion Laboratory), who was a member of Voyager's imaging team and now heads the science teams for Galileo. "But with no new spacecraft going out there, eventually we ran out of data. I put it on the shelf as interesting but unproven." Researchers realize that finding any proposed Europan biology will be challenging, both technologically as well as economically and politically.

The Case for an Alien Sea

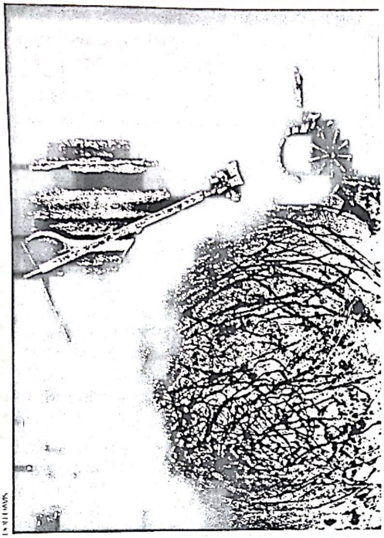
Apart from the conjecture about life within Europa, planetary scientists are still debating whether or not Europa actually has a liquid ocean. A steady stream of data from the Galileo spacecraft is adding fuel to the debate, bringing models and estimates into sharper focus.

Galileo began its 23-month survey of Jupiter and its moons in December 1995 (*S&T:* April 1996, page 20). The orbiter's powerful cameras have returned images far more detailed than those captured by the Voyagers 17 years earlier. Features as small as 12 meters have been discerned.

Scrutinizing Europa, Galileo's robotic eyes have shown Earth observers a frozen landscape fractured by forces as yet not well understood. Walls of ice extend



What lies beneath Europa's icy crust? Data from the Galileo spacecraft suggest that the rigid exterior covers a layer of liquid water. While the exact proportions of frozen and liquid water are not known, researchers believe that the combined layers are at least 100 kilometers thick.



Galileo is scheduled to make some bonus flybys of Europa in 1998–99 — ir cluding sailing only 200 km from the surface. The additional data will hel constrain the thickness of the moon's crust of ice and give scientists som good targets for future exploration.

across the surface. Even more intriguing are brownish stains that accompany the fractures. These stripes are diffuse, suggesting that material has erupted from the fractures, painting the landscape in "triple-band" patterns reminiscent of multilane highways. Some dark regions are associated with lobate ice flows appearing like terrestrial lava flows. Other experiments aboard the craft indicate that much of Europa's surface is porous, suggesting powdery ice or frost. Frost must be continuously replenished in the vacuum of space, so something is resurfacing the moon even today. As one mission scientist put it, "Fresh ice means activity."

Will Galileo be able to determine whether Europa has a hidden ocean? The answer depends on many variables, including how thick the crust is, whether some type of water volcanoes can be caught in the act, and how many observations can be made of the moon. Galileo team member Adriana C. Ocampo (JPL) laments, "We have great circumstantial evidence pointing to a fluid down there," but no smoking gun.

Some of that circumstantial evidence has come from Galileo's sixth orbit, says Ronald Greeley (Arizona State University). On earlier orbits it was apparent that there was fracturing of the surface, faulting, and shifting of features. But with data obtained in February, Greeley explains, "The evidence is pretty clear that surface and near-surface [liquid] water existed in the geologically recent past. Judging from the lack of craters, we're probably looking at the very recent past."

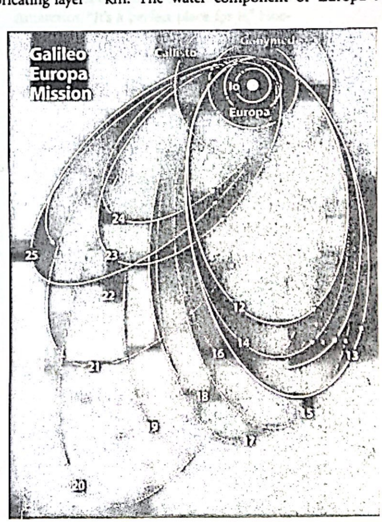
Galileo has relayed high-resolution images of ice "rafts." Europa's scored and ridged crust has broken off into sections that have spun or tipped into new positions before refreezing. These areas superficially resemble the disruption of pack ice atop Earth's polar seas during spring thaws. Alternatively, the displacement could have been caused by a layer of soft ice or a thin, lubricating layer of water under the surface. Greeley hopes data from additional flybys will constrain the geologic models and let one explanation rise to the top. So does Fanale, who has a slightly different perspective: "I'm a firm believer in a dichotomous Europa where some of the ice is locked to the surface rock and some is supported by fluid water, causing this rafting we're seeing."

Europan Extreme Close-Up

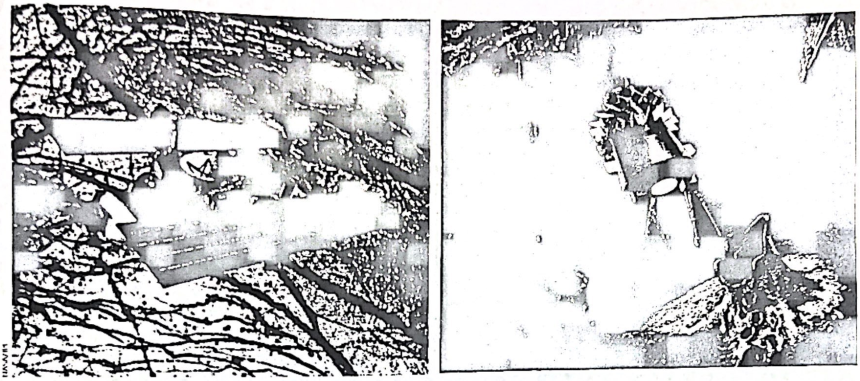
Initial plans called for the Galileo mission to end in December 1997 after 11 orbits around Jupiter. But instead it will continue on a program encore called the Galileo Europa Mission (GEM). Thi two-year extension will make eight clos passes by Europa, then four flybys of Ca listo, and then dive past Io to make up fc the missed observations when Galile first arrived (March issue, page 34).

The flybys on this extended missio will return the best images yet. "We' have some fantastic Europa data on th 12th orbit [December 16th]," says Ocam po, science coordinator for Galileo's Nea Infrared Mapping Spectrometer (NIMS "We'll see down to resolutions in th meter range, and 100-meter for NIMS She believes that some Europan mysterie may well be solved by the later encoun ters. "We really hope to see clean, fu spectra from the triple bands. If there ar organics down there, NIMS will fin them." The instrument's coverage in cludes key bands for organic molecules.

Galileo is tugged by Europa each time flies past, resulting in slight trajectory devi ations that can be used back on Earth t create detailed gravity maps. GEM promis es to provide an estimate of the crus thickness with an uncertainty of 0.1 per cent or better, which translates to within 2 km. The water component of Europa i



After Galileo finishes with its primary mission at the end of this year, planetary scientists hope to extend the program two more years so that the spacecraft can fly by Europa eight more times before diving closer to Jupiter for a look at Io.



Planetary scientists at the Jet Propulsion Laboratory are devising follow-up missions to Europa to help fill in the blanks left by Galileo. Among the concepts are an Ice Clipper *(left)*, which would send a projectile slamming into the surface, then swoop overhead to collect the lofted debris. A more ambitious program *(right)* would send a probe down through the ice with the intent of exploring the subsurface ocean firsthand.

known to be at least 100 km thick, so this determination would yield valuable conclusions as to how thick Europa's crust is, and how much liquid might be under it.

Nevertheless, GEM is not without risk. While the spacecraft's electronics have been "hardened" to resist damage from radiation, it is by no means immune. Each passage through Jupiter's deadly inner magnetosphere jeopardizes software, data, and even equipment. Johnson warns, "There's an increasing probability of increasing failures in the spacecraft as we go through this period of time. Some things simply might not work. This is a risky thing. But we should get quite a number of Europa encounters before we start taking on a lot of risk."

Next-Generation Explorers

An important goal of Galileo's observations of Europa is to arm scientists with a list of sites for advanced missions. Concepts for future flights are already under development. Scientists are now outlining what kinds of probes will be needed for these explorations, and the debate on how best to explore is just heating up. Shoemaker said, "We need to figure out clever ways of doing this. Do we bring a snowmobile? Ice skates? Submarines?"

One such clever mission — dubbed Ice Clipper — is being studied at JPL. The flyby mission would send a 10-kilogram sphere careening into Europa's surface while the main spacecraft swoops to within 50 km overhead. The impact of the sphere would blow a cloud of debris high into the moon's airless sky, where the passing spacecraft would sample it and transmit data to waiting scientists in real time. Some of the material would be captured, stored cryogenically, and returned to the Earth. This simple, inexpensive mission would investigate upper layers of the moon in situ, without the risk of landing. Although NASA managers recently opted not to fund Ice Clipper as part of the Discovery series, designers are hopeful that something like it will be approved in time.

To determine what's going on beneath the crust will require more complex probes. Orbiters could return detailed gravity maps, take radar data, and launch penetrators into the surface. Seismic instruments in the penetrators would measure the internal structure of the ice, especially as the other instrument packages impact the surface. JPL's Henry M. Harris, who is working on a Europa orbiter-lander design, explains, "A seismometer tells a lot about the interior. We may be able to detect ice fracturing and shifting, and even wave action."

Assuming these early missions can certify that liquid water exists, more sophisticated landers would be dispatched. As Canadian oceanographer Richard Thompson (Institute for Ocean Studies) puts it, "You've got to get your finger in it!" These advanced probes might include miniature submarines that melt their way through the crust into the ocean below.

JPL's Joan C. Horvath has been working on such a concept for several years. Her "cryobot" would melt its way through kilometers of ice to reach Europa's supposed ocean. As it does so, it unreels a cable attached to a communications station up on the surface. Once through the ice crust, a small "hydrobot" would wander off, relaying its data via the cryobot. Horvath's team hopes to test the concept on Lake Vostok in Antarctica. "It's a perfect place for it," Horvath explains. "There's a 4-km-thick crust of ice over a deep lake." Tests may commence on this bit of Europa-on-Earth within two to three years.

Alas, these missions are a long way off. Despite the tremendous advances brought by Galileo, a lot of questions will remain at mission's end. If the existence of liquid water is established, what is the nature of the ocean beneath the ice? How globally is it distributed, and what current systems and heat exchange are at work to cause the remarkable features evident on the surface? "We can't predict or adequately model much of what goes on in Earth's oceans," Fanale reminds us. "Imagine trying to do it with an object 500 million miles away that we know next to nothing about!" For now, scientists wait — and wonder — whether a frozen moon of Jupiter will finally enable us to say, "We are not alone."

When not rubbing elbows with planetary and marine scientists, Michael Carroll *paints his visions of space in his Colorado studio.*