

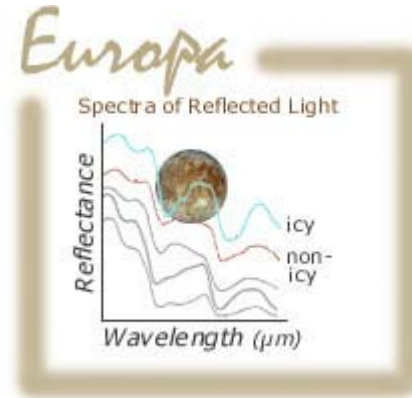
Hot Idea

posted September 24, 1998

Europa's Salty Surface

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Pictures of Jupiter's moon Europa taken by the [Galileo](#) spacecraft during the past couple of years have suggested to scientists that there is now, or was in the past, an ocean beneath the satellite's frozen crust. Now a team from the University of Hawai'i, the Jet Propulsion Laboratory, the U.S. Geological Survey, and STI Inc. may have given us our first glimpse at the chemical composition of that ocean. Using data obtained by the Near-Infrared Mapping Spectrometer ([NIMS](#)) carried by Galileo, Thomas McCord (U. Hawai'i) and his colleagues examined darker regions on the surface and compared the spacecraft data to numerous chemical compounds. Their analysis indicates that the darker areas are most likely composed of deposits of salty minerals such as sulfates and carbonates. McCord and his associates believe that the minerals formed when ocean water erupted onto the surface and then evaporated, leaving behind salty deposits. They hope that further research will allow them to determine the chemical composition of Europa's hidden ocean and assess the likelihood that life could have formed in it.

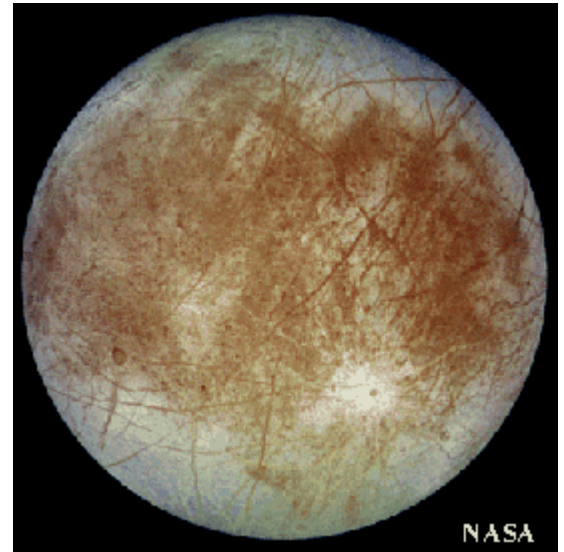
Reference:

McCord, T. B. and others, 1998, Salts on Europa's surface detected by Galileo's Near Infrared Mapping Spectrometer. *Science*, v. 280, p. 1242-1245.

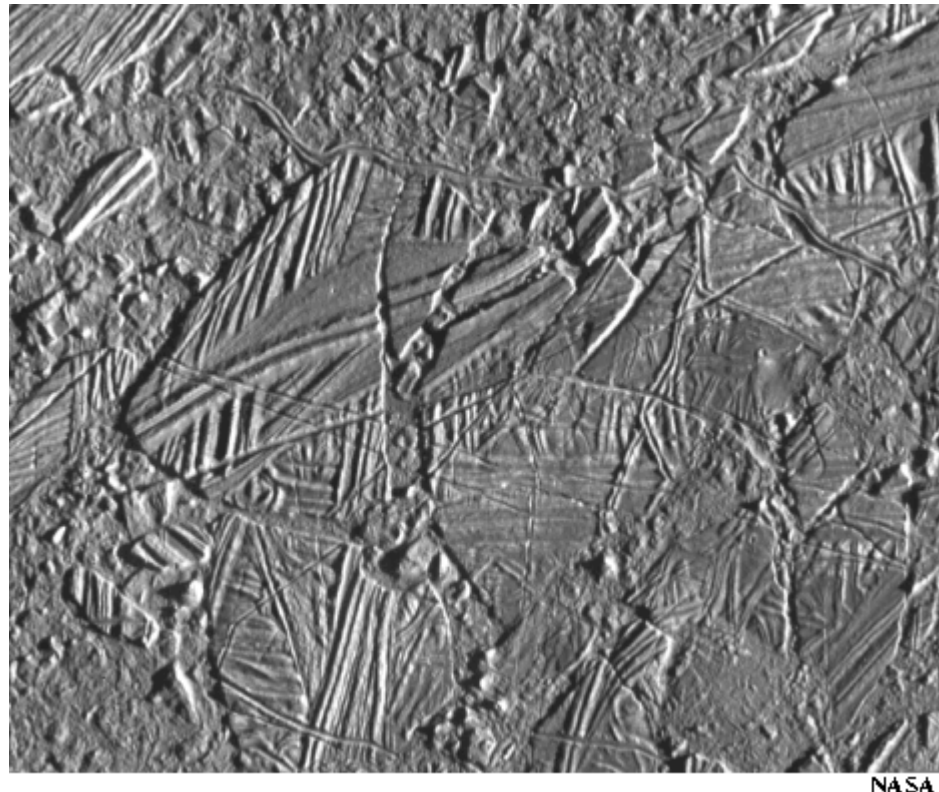
An Ocean Beneath the Ice

Europa has a complicated surface. It has brighter and darker regions, is crisscrossed by ridges and troughs, and large pieces of the crust appear to have rotated. The mottled nature of the surface is seen clearly in images of an entire hemisphere. In spite of these variations, however, the surface is made up mostly of water ice. The brownish areas appear to be mixtures of ice and something else. Tom McCord and his colleagues wanted to find out what that something else is.

This photo was obtained by the Galileo spacecraft in 1996. Note the variation in color across the surface. Some areas are dark and brownish, while others are white to bluish. Europa is 3160 km in diameter, slightly smaller than Earth's moon.



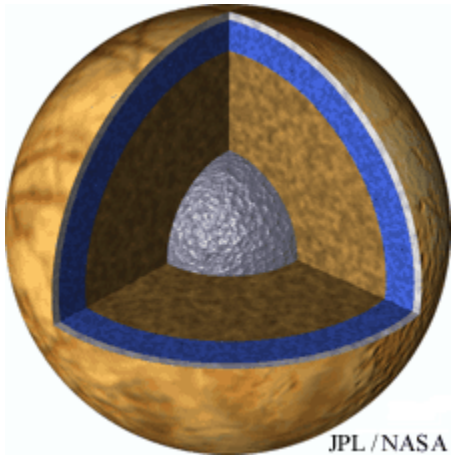
Close-up views of the surface show even more complexity. Some regions are appropriately called "chaotic terrain," such as the Conamara region shown in the image below. Large chunks of the crust have been disrupted, tilted, and rotated. The appearance resembles icebergs somewhat, leading mission scientists to conclude that the thin crust floated on a layer of water or slush, an underground ocean. Movement of the water in the ocean placed stresses on the solid crust, causing huge pieces to break, move, and possibly sink. It is not known if the ocean exists at present or if the surface features reflect conditions billions of years ago.



The image, above, taken by the Galileo spacecraft in 1996 shows a region called Conamara Chaos. The image covers an area about 35 km across. Big blocks of the crust have moved up and down, tilted, and rotated, suggesting that they floated on a layer of liquid water or perhaps slush.

Measurements of the magnetic field and gravity of Europa by the Galileo spacecraft also give clues about the nature of the interior. It has a density of about 3.0 grams per cubic centimeter, indicating that it cannot be made

entirely of ice and water, which have densities of 0.9 and 1.0 grams per cubic centimeter, respectively. Rock (density between 3 and 3.5) and metallic iron (density of 8) must also be present. Putting all the data together, Europa specialists reckon that the satellite has a small metallic iron core, a thick mantle made of rock, a layer of water or water and ice mixed (slush), and a thin (perhaps only ten kilometers thick) crust made mostly of water ice. It is not known how long the layer of water or slush remained liquid: it could still be very fluid, or might have solidified billions of years ago.



Interpretation of spacecraft data suggests that the interior of Europa is composed of a metallic iron core at its center, a large, rocky mantle, a watery layer, and a thin, solid, icy crust. A key outstanding question is whether the watery layer still exists today or whether it has solidified.

Planetary geologists are confident that this general picture of Europa is correct, but it lacks detail. For example, if the ocean is still liquid, what is the chemical composition of the rocky mantle and overlying ocean? Do the ocean and rock react chemically? Does the ocean ever breach the crust and squirt out? Could life have originated in the mysterious subsurface ocean? Those are some of the questions that the NIMS team hopes to answer.

Fingerprints in Reflected Light

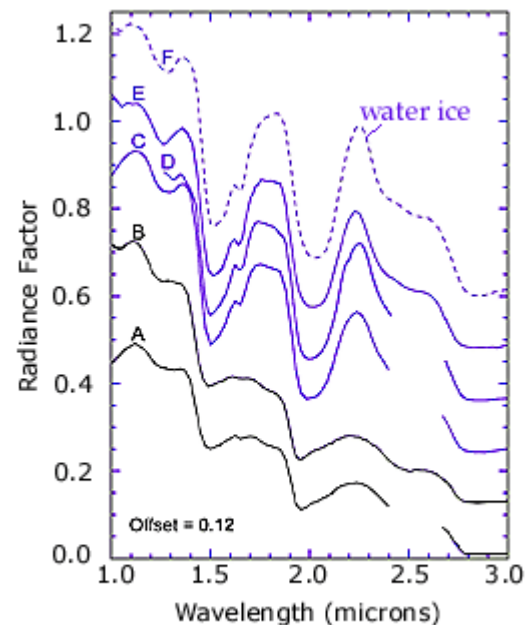
Light reflected off an object contains an enormous amount of information about the object's surface. Our eyes see different colors because an object soaks up more of the light at some wavelengths than at others. Apples are red because its skin absorbs more blue, yellow, and green than it does red, so the light bouncing off is dominated by the wavelengths we identify as red.

The relative amount of light at each wavelength can be measured accurately with a high-tech gizmo called a spectroscope. Such devices split the light into all the colors of the spectrum, including wavelengths outside the range visible to humans. This allows us to plot the intensity of reflected light against the wavelength of light, producing a spectral plot. Most materials have unique spectral signatures, allowing us to identify what compounds are present, without even touching the sample.

The Galileo spacecraft has an especially fancy spectroscope that not only measures the reflected light at numerous wavelengths, but also takes a picture at the same time. Each picture element contains a spectrum, allowing planetary scientists to make maps that show differences in the mineral make-up of the surface of one of Jupiter's satellites. Galileo's high-tech spectral gadget is called the Near-Infrared Mapping Spectrometer or NIMS for short.

A good example of the important information that NIMS can obtain is the basic identification of water ice on Europa. The diagram, on the right, shows several spectra of areas on Europa, along with a laboratory spectrum of ice. Note that spectra C and E are very similar to F, which is a laboratory spectrum of water ice. This is the type of data that led scientists to conclude from telescopic observations that Europa has an icy surface. Spectrum E is from Jupiter's satellite Ganymede, showing that it, too, has ice on its surface. On the other hand, spectra A and B look different from the ice spectrum, as if they have been distorted. McCord and his colleagues focused their research on those areas. They wanted to determine the abundances of ice and non-ice, and to figure out what the non-ice was. An important hint came from the basic shape of the spectra of those areas. Though not as smooth as ice spectra, they had some of the same dips, especially at 1.5 and 2.0 micrometers. This suggests that the material also contains water, but bound in another chemical compound. Logical possibilities are hydrated (i.e., containing water) silicate minerals, such as clays, and hydrated salts.

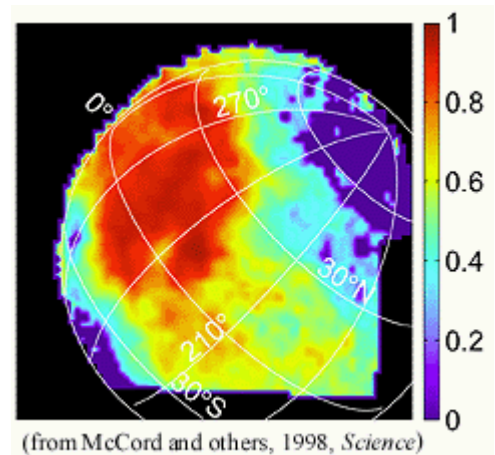
Caption: This diagram shows the amount of light reflected at different wavelengths between 1 and 3 microns for some areas on Europa (A-D) and Ganymede (E), compared to a laboratory spectrum of water ice (F). Spectra C, D, and E are strikingly similar to the spectrum of ice (F), showing that those regions are dominated by ice. Spectra A and B, however, are different.



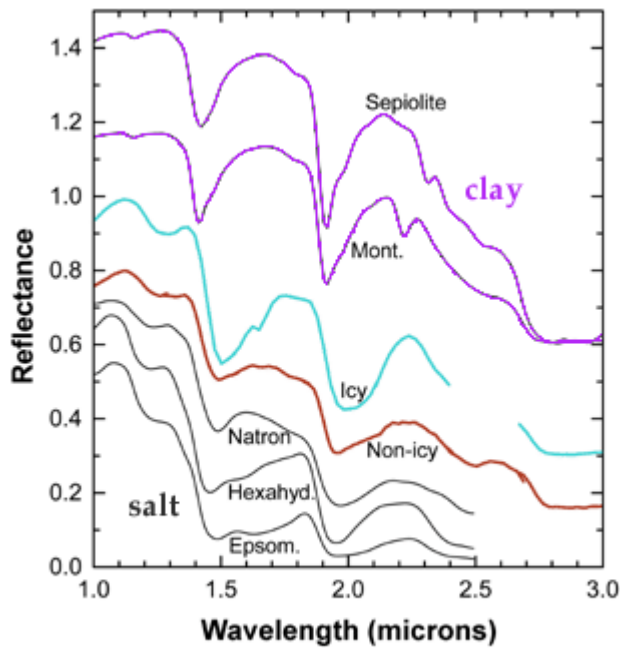
(from McCord and others, 1998, *Science*)

The Salty Surface

Using spectra of pure ice and of the non-ice areas (spectra A and B in the diagram above), McCord and coworkers devised a scale of the abundance of ice on the surface of Europa. It turned out that the less ice there is, the darker the surface is. The map below shows the distribution of almost pure ice (dark blue), pure non-ice (red), and mixtures of the two (colors in between) on the surface of Europa.



The peaks and valleys in the spectra suggested that the unknown dark materials were minerals that contain water. To determine which mineral or minerals, McCord and associates compared the Europa non-ice spectra to a large database of spectra compiled by the U.S. Geological Survey. This search ruled out clay minerals, which some scientists had hypothesized to be present on Europa, because clay minerals have extra dips in their spectra, especially between 2.2 and 2.4 micrometers, features not seen in the Europa spectra (see diagram below). The best matches were obtained for hydrated salts, including sulfates, carbonates, and borates. The investigators eliminated borates because boron has a very low abundance in planetary materials. The best bets seem to be natron ($\text{Na}_2\text{CO}_3(10\text{H}_2\text{O})$), epsomite ($\text{MgSO}_4(7\text{H}_2\text{O})$), and hexahydrate ($\text{MgSO}_4(6\text{H}_2\text{O})$), although there are a few small differences between them and the Europa spectra.



(from McCord and others, 1998, *Science*)

Spectra of reflected light of possibilities for minerals making up the dark regions of Europa, compared to spectra of icy and non-icy portions of Europa. Clay minerals such as sepiolite and montmorillonite do not match the non-icy regions, but carbonates like natron and sulfates like hexahydrate and epsomite are similar to the non-icy regions.

The identification of carbonates and sulfates on Europa still needs to be verified by further measurements, which will be done by the Galileo spacecraft, and by additional laboratory measurements. One uncertainty is the cold temperatures on the surface of Europa, which is less than $-150\text{ }^{\circ}\text{C}$. In contrast, the laboratory spectra of minerals were usually made at room temperature. Another factor is the size of the particles on the surface, which may affect how distinct the spectral features are. McCord and associates are looking into all possibilities, but do not think their interpretation will change drastically.

Assuming the identification of hydrated salts is correct, how did they get onto the surface? On Earth, salts are formed by evaporation of salt water, which leaves behind a deposit of salt crystals. Perhaps some salty water from the ocean beneath Europa's crust erupted onto the surface, evaporated in the vacuum of space, and formed salt deposits. Over geologic time, this process could have affected vast areas of the surface.

Why would the ocean have sodium, magnesium, sulfur, and so on dissolved in it? The most likely answer is that the ocean reacts chemically with the rocky mantle, and quite possibly, warm water circulates throughout the mantle, dissolving some of it, and transporting the elements into the ocean. Once they know more about the nature of the deposits on Europa, planetary geologists will be able to learn more about the chemical composition of its rocky mantle. Gases such as carbon dioxide could also be released from the mantle, rising to the base of the crust. There they would accumulate until the pressure built up enough for the gas to fracture the crust, causing an eruption of gas and salty water, leading to the formation of a salt deposit by evaporation. Ocean water may also be driven to the surface by other forces, such as flexing of the crust by the interaction of gravitational tugs from Jupiter and Europa's neighboring moons.

Life in the Ocean?

If Europa has an ocean, it has lots of elements dissolved in it. Its rocky mantle continually adds material to it, and Jupiter's gravitational tugs keeps the satellite warm enough for liquid water to exist. These conditions may have existed for billions of years. Water, chemical compounds, time—these are the ingredients that may be essential for life to originate. Exposure to direct sunlight is not necessary. On Earth, whole ecosystems flourish deep in the ocean at hydrothermal vents, where the water is warm, there is an abundance of chemical compounds, and chemical reactions provide the energy needed by each organism. That is why Europa is so attractive to scientists searching for life elsewhere in the Solar System. The Galileo results are the first step in that quest.

Additional Resources

Anderson, J. D., E. L. Lau, W. L. Sjogren, G. Schubert, W. B. Moore, 1998, Europa's Differentiated Internal Structure: Inferences from Two Galileo Encounters, *Science*, v. 276, p.1236-1239.

McCord, T. B., G. B. Hansen, F. P. Fanale, R. W. Carlson, D. L. Matson, T. V. Johnson, W. D. Smythe, J. K. Crowley, P. D. Martin, A. Ocampo, C. A. Hibbitts, J. C. Granahan, and the NIMS Team, 1998, Salts on Europa's Surface Detected by Galileo's Near Infrared Mapping Spectrometer, *Science*, v. 280, p. 1242-1245.

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