

# **Europa and Titan: Oceans in the Outer Solar System?**

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Biologists believe that life requires the presence of some sort of liquid to serve as a medium for the chemical reactions needed to sustain life. On Earth, liquid water plays this role. Water has some chemical properties that make it particularly favorable as a medium for life, although we probably should not rule out the possibility that other types of liquid, such as organic liquids, might play this role in other types of biology. If liquids truly are necessary for life, then the potential abodes for life in the outer Solar System are quite limited. Europa and Titan both have been proposed to have oceans and are therefore the best possible candidate locations for life in the outer Solar System.

## **Europa**

Among its many moons, Jupiter has four large moons that are known collectively as the Galilean satellites. Of these four, Europa is the smallest and the second closest to Jupiter. With a radius of 1560 kilometers, it is slightly smaller than Earth's Moon. Objects of this size are expected to lose their internal heat in a relatively short period of time. For comparison, most volcanic activity on the Moon ended more than 3 billion years ago and the last gasps of lunar volcanism occurred roughly 1 billion years ago. Naively, we might therefore expect Europa to be geologically dead.

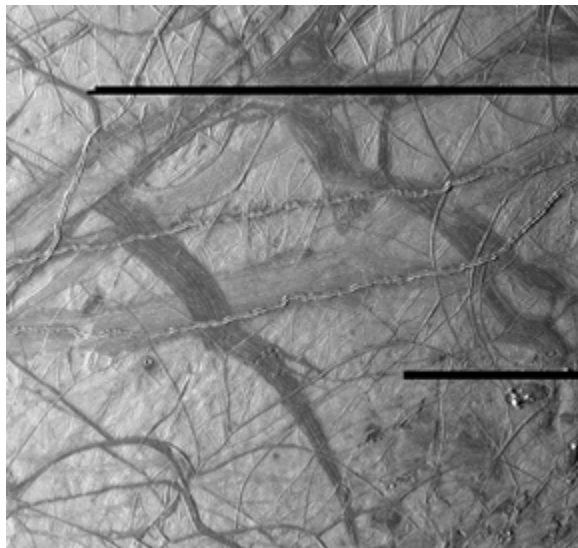
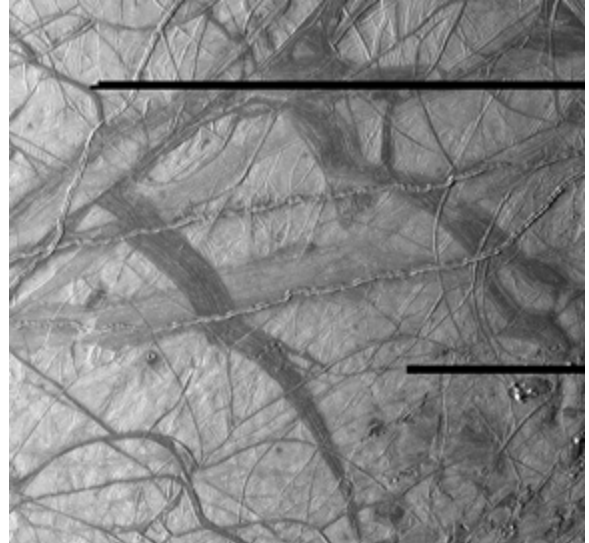
It turns out, however, that there is an energy source that has kept Europa geologically active to the present day. Three of Jupiter's moons, Io, Europa, and Ganymede, orbit in a condition known as a resonance. Every time Io orbits Jupiter twice, Europa completes one orbit. Similarly, every time Europa orbits Jupiter twice, Ganymede completes one orbit. The gravity of each moon tugs slightly on the other moons, and because of the orbital resonance, the tugs occur repeatedly in the same part of each moon's orbit. The consequence is that Io and Europa have orbits that are slightly elliptical.

If these orbits were perfectly circular, the gravitational force of Jupiter on the moons would be the same everywhere in the orbit. However, because the orbits are not circular, the gravitational force is not the same everywhere in the orbit. As a result, both Io and Europa are slightly deformed by tides as they orbit Jupiter. As the outer portions of these moons flex up and down in response to these tides, the friction of rock and ice grains sliding across each other releases heat. This heat is very important to understanding the geologic history of these objects.

On Io, this heating produces volcanic activity that is far more active and intense than volcanism on Earth. On Europa, the tidal heating may have heated its interior enough to melt ice and produce a subsurface ocean. The Earth and Moon also experience tidal deformation as the Moon orbits Earth, but the heat released is not significant for either object.

## 1. Global View

As this global view shows, much of Europa's surface is covered by a series of dark bands. When studied by NASA's Voyager spacecraft in 1979, the nature of these bands was enigmatic, but was presumed to reflect some sort of faulting or other type of surface deformation. The virtual absence of impact craters indicates that the surface of Europa is quite young.



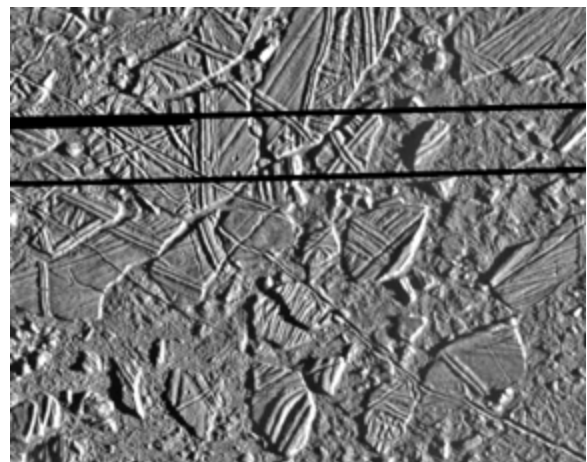
## 2. Wedges Region

Observations by NASA's Galileo spacecraft since 1996 have provided a much clearer view of Europa. This Galileo image is 230 kilometers across and shows some of the dark bands in greater detail. In some cases, these structures can be seen to be low ridges or pairs of ridges. (You can tell whether a feature is high or low by the nature of the shadow it casts. In this image, the illumination is from the left.) The dark band that originates at the bottom center of the image and runs to the left center is wedge-shaped. This wedge-shaped band probably formed by the gradual spreading of Europa's surface - think for

example of the spreading as a door opens on a hinge. As in image 1, there is a noticeable absence of impact craters.

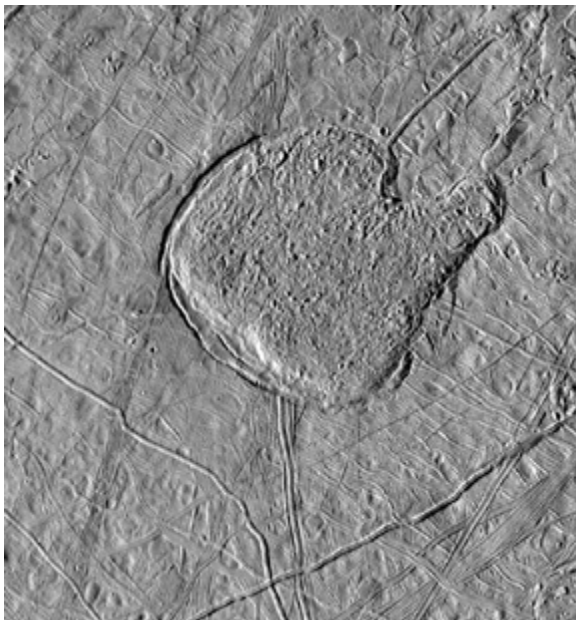
## 3. Ice Rafts

This Galileo image is 42 kilometers across and is illuminated from the right. It shows a series of "ice rafts" that have been disrupted and jostled about. Although we saw indications of surface motions in image 2, this image is by far the clearest evidence for large motions of blocks of material across the surface of Europa. When NASA scientists reported in the spring of 1997 that they had evidence of an ocean below the surface of Europa, this image was their "smoking



gun". The ocean interpretation rests on the belief that the existence of so much lateral motion across the surface requires the presence of some sort of layer to lubricate the flow at depth. These scientists assume that this lubrication requires a liquid, and hence favor the existence of an ocean.

As a possible counter-example, consider the physics controlling plate tectonics on Earth. As a general rule, temperature increases with depth inside a planet, and as materials increase in temperature, they tend to become less viscous (less rigid, or more colloquially, softer). The Earth's surface consists of about 12 large tectonic plates, which move about at speeds of up to 10 centimeters per year, producing all of the earthquakes, volcanic activity, and mountain belt formation that occurs on Earth. These plates move over a mantle which is solid virtually everywhere (we know this because of the way seismic waves travel through the mantle). The "lubrication" that allows all of this motion and geologic activity is actually solid rock that is simply hotter and thus less viscous than the rock above it. The Earth's example demonstrates that we should consider the possibility that the motion which we see on Europa is lubricated by warm, soft ice rather than by a liquid ocean.



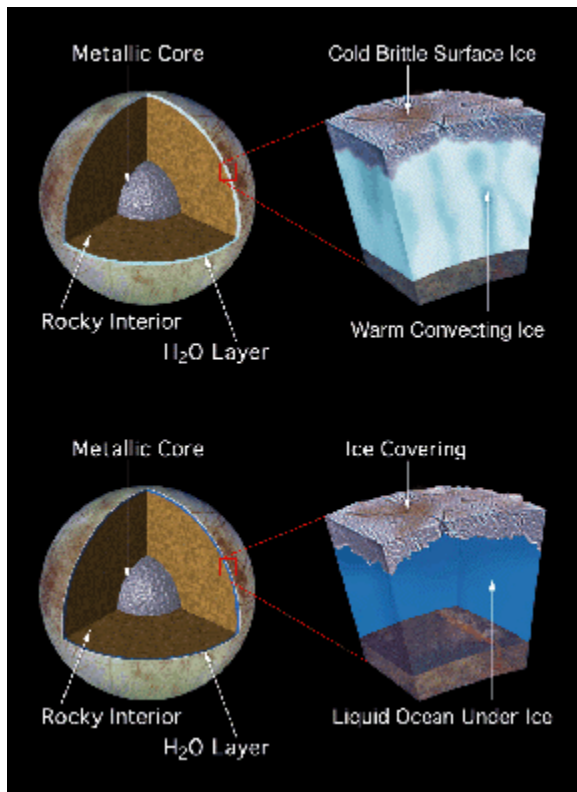
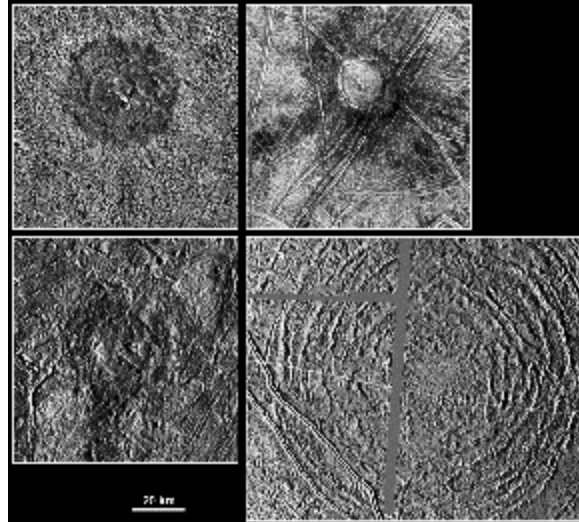
#### **4. Chaos Region**

This Galileo image is 175 kilometers across and is illuminated from the left. The major feature is a mitten-shaped region of chaotically disrupted terrain in the center of the image. This chaos region is superimposed on the surrounding plains and ridges, so it must be the youngest feature in this region. Based on the pattern of sunlight and shadows around the edge of the chaos region, the chaos region is slightly elevated compared with the surrounding plains. On the west (left) side of the structure, there is a narrow trough separating the plains from the uplifted chaos terrain. Similar chaos units are found in many parts of Europa. Some scientists believe that these regions form when the subsurface ocean melts through a relatively thin outer ice shell. Other scientists

believe that the chaos regions are uplifted and disrupted where a diapir ("blob") of relatively warm ice rose through the surrounding crust of colder ice. Numerous ridges also cross this image. The relative ages of these ridges can be determined by observing the intersections between ridges (the younger ridge will appear to cut the older ridge).

## 5. Impact Craters

This image shows four of the largest impact craters found on Europa. Because impact craters excavate into the crust of a planet, they serve as natural core samples into the structure of the upper crust. Generally, the excavation depth of a crater increases as the size of the crater increases. In other words, small craters make shallow holes and larger craters make deeper holes. If an impacting object penetrated all the way through the solid ice shell on Europa to an underlying ocean, the sudden loss of material strength in the crust would cause the crater to collapse (think about the "hole" that is made when you throw a rock into a pond!). Based on the known depths of the largest craters on Europa, it appears that the ice shell of Europa remains solid to a depth of at least 19 to 25 kilometers. The pattern of crater depths as a function of crater diameter suggests that either an ocean or a layer of warm (and thus soft and weak) ice occurs below this depth.



## 6. Internal Structure

This image shows cross sectional views of Europa's internal structure. Our current knowledge of the interior of Europa comes from observations of its gravitational and magnetic fields. Europa's relatively high density of 3.04 grams per cubic centimeter implies that it is composed mostly of rock and metal, with relatively little water ice. This material has probably separated into a metal-rich core and a rock-rich mantle, with the core having a radius of 500 to 1000 kilometers. The surface of Europa is known to be predominantly water ice, probably with some rock mixed in, based on spectroscopy studies. This outer shell of water ice is 100 to 200 kilometers thick.

The right side of the image highlights two fundamentally different views about the nature of the ice shell on Europa. The available gravity observations do not indicate whether this layer is entirely solid or if there is a subsurface ocean on Europa. However, magnetic field observations do indicate the presence of an ocean: the salts that would likely be dissolved in such an ocean would be good electrical conductors and hence modify Jupiter's magnetic field in the vicinity of Europa. This effect has been observed by Galileo and is the strongest present evidence for a

subsurface ocean inside Europa. This ocean must be globally distributed. Solid ice and rock can not explain the observed magnetic signature.

The magnetic evidence requires that the ocean be at least 10 kilometers thick, but does not tightly constrain the depth at which this ocean begins. As noted in the captions for other images, geological arguments have been made for both a thin ice layer and a thick ice layer. In the thin ice shell model, the ice shell might be just 1-2 kilometers thick. In this model, the ocean might frequently break through to the surface, and the various ridges and faults are assumed to be related to tidal forces in the ocean. In the thick ice shell model, the ocean occurs at much greater depths, at least 20 kilometers beneath the surface. There are scientists who argue with great passion for each model. In my personal view, the cratering evidence (image 5) is a strong constraint favoring a relatively thick ice shell. It is possible that heat pulses do occasionally produce regions with a thin ice shell (for example, the chaos regions shown in image 3 and 4). However, such regions of thin ice are probably restricted to geographically limited regions and to short intervals of time.

### **Future Exploration of Europa**

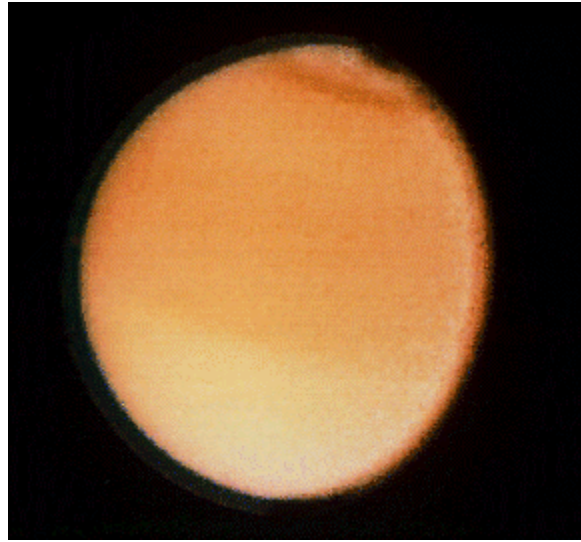
NASA has considered a Europa Orbiter mission that might provide clearer evidence about the nature of Europa's subsurface ocean. The orbiter would use very long-wavelength radar to attempt to see through the ice to an underlying ocean. A radar flown on the Space Shuttle in 1981 was able to "look" below the Sahara Desert and detect ancient river channels that are now buried under 1 to 2 meters of sand. On Apollo 17, a radar system was able to look through the upper kilometer of rock and image buried lava flows on the Moon. Similar radars are planned for launch to Mars in 2003 and 2005 to image the subsurface distribution of water and ice.

The Europa Orbiter would also carry an altimeter to accurately measure Europa's shape. The shape changes over the course of an orbit about Jupiter because of tidal deformation. The amount of tidal deformation depends on whether there is an ocean just below the surface or if Europa is solid throughout. Thus, precise measurements of the shape of Europa may provide details about the structure of the subsurface ocean. The Europa Orbiter would also collect additional high resolution images and gravity observations of Europa. Jupiter is surrounded by very strong radiation belts that are dangerous to spacecraft. The Galileo spacecraft dipped deep into the radiation belts for only a few days every few months. In contrast, the Europa Orbiter would be exposed to strong radiation for a much longer period of time. Because of the high cost of designing a spacecraft to endure such radiation (perhaps one billion dollars), the proposed mission is currently on hold.

## Titan

### 7. Voyager Image of Titan

Titan is the largest of Saturn's moons. With a radius of 2575 kilometers, it is the second largest moon in the entire Solar System and is larger than the planets Mercury and Pluto. Titan is the only satellite in the Solar System to have a significant atmosphere. At the surface, the atmospheric pressure is 1.6 bars (60% higher than on Earth) and the temperature is a frigid 94 Kelvin. The atmosphere is composed primarily of nitrogen, as on Earth, and also includes some methane and possibly argon. Trace amounts of hydrogen and many organic molecules are also present. Some of these compounds form a thick haze layer in the upper atmosphere of Titan. At visible wavelengths, this haze makes it impossible to see down to the surface of Titan. Ultraviolet radiation from the Sun can break up methane molecules, and the resulting hydrogen atoms can be lost to space. The remnants of the methane can form heavier organic compounds, such as ethane and acetylene. Even at Titan's cold temperature, ethane is a liquid and might form an ocean on Titan's surface. Over the age of the Solar System, an ocean of ethane several hundred meters thick might have formed, probably with some methane dissolved in it. The actual distribution of ethane, whether in a surface ocean or in subsurface cavities, is not known at present. Infrared images of Titan obtained by the Hubble Space Telescope show a pattern of bright and dark regions that some scientists think might be related to oceans and continents. Radar observations of Titan also hint at the possibility of oceans and continents.



### 8. Cassini Probe at Titan

The Cassini spacecraft was launched in October 1997 and will arrive at Saturn in July 2004. In early 2005, a probe will study the composition and physical properties of Titan's atmosphere and surface. In the event that the probe lands in an ethane ocean, it is able to float. Cassini will also use radar to map parts of Titan's surface and will also study Saturn's atmosphere, rings, magnetic field, and other satellites between 2004 and 2008.