WHAT WE THOUGHT WE "KNEW" ABOUT EUROPA. Steven W. Squyres, Center for Radiophysics and Space Research, Cornell University, Ithaca NY 14853

Europa is perhaps the most enigmatic of the Galilean satellites, and is the one that was most poorly imaged by the two Voyager spacecraft. It is not primarily an icy satellite. The density of Europa is about 3.0 g cm^{-3}, indicating a composition that is dominated by rock. Despite this composition, however, it has an icy surface. The surface of Europa is bright; the satellite's Bond albedo is about 0.6. Moreover, the reflectance spectrum of Europa in the visible and near infrared is, to first order, indistinguishable from that of H_2O frost.

This picture of Europa, with a rocky interior and an icy surface, allows for three endmember models for the satellite's interior. One possibility is that the satellite is largely composed of hydrated silicates with a density near 3.0 g cm^{-3}, with just a thin coating of ice at the surface. A second is that it is composed primarily of dehydrated silicates with a density closer to 3.5 g cm^{-3}, and that these are overlain by a layer of ice; given the density of the satellite, this ice layer would be on the order of 100 km thick. The third possibility is that the interior is dehydrated silicates, overlain by liquid water and, finally, by a thin layer of ice.

Voyager data do not allow a definitive choice among these three models. The first model appears the most unlikely. The combination of radiogenic and tidal heating should have been sufficient to dehydrate most of the silicates in Europa's interior. More convincingly, the lack of substantial topography (including large impact craters) indicates that the rheology of the outer tens of km of Europa is far softer than would be expected for silicates. It is difficult to choose between the second and third models, however. Tidal heating is required to maintain liquid water within Europa. Europa undergoes significant tidal heating, but uncertainties in key model parameters make it unclear whether this heating is sufficient to maintain a liquid layer. A number of lines of evidence have been cited to support the view that liquid exists under Europa's icy crust, but all must be regarded as uncertain. One thing that is certain is that if tidal heating presently maintains a liquid layer within Europa, that heating has persisted throughout Europa's history. This is because an ice layer atop liquid can be maintained only if it is thin enough to resist solid-state convection. If at any point in the satellite's history the ice layer becomes thick enough (perhaps several tens of km) for convective instability to develop, convection will transport heat out through the ice rapidly enough to freeze the water, and will maintain the frozen state indefinitely.

The surface of Europa clearly has undergone substantial resurfacing and tectonic activity. One of the most important observations is that its surface is nearly devoid of impact craters at the highest Voyager resolution ($\sim$ 2 km $pixel^{-1}$). Only a handful of probable craters have been identified, mostly in the range of 10 to 20 km in diameter. The paucity of craters indicates that resurfacing of some parts of Europa has taken place in geologically recent times. The resurfacing mechanism is unclear, however, and could have been as dramatic as eruption of liquid water or as simple as warming of the ice to produce complete topographic relaxation.

The highest resolution Voyager images of Europa show a bewildering array of tectonic features, ranging in dimensions from global-scale lineaments to features near and probably well below the limit of resolution. There are three apparent types of tectonic lineaments on Europa's surface: *dark bands*, *triple bands*, and *bright ridges*. The dark bands may be curving or straight, range in width from a maximum of about 100 km down to the resolution limit, and range in length from tens of km to a few thousand km. No relief is observed to be associated with them. They intersect one another in a complex fashion, dividing the surface into a mosaic of bright polygons separated by dark bands. There is little convincing evidence for purely transcurrent motion along dark bands, but strong evidence for extension, in some cases accompanied by transcurrent or rotational motions. Many dark bands are wedge-shaped, and so have the appearance of propagating fractures. Triple bands are similar in many respects to dark bands, but differ in that they have a bright stripe running down the center. Some triple bands appear to lose their central stripe in places, and there are a few instances where the central stripe appears to be raised. Bright ridges are the most prominent topographic features on Europa. Voyager images suggest that they have very regular widths of about 10 km, heights of at most 100 m, and lengths of hundreds of km. Many, but not all, of the ridges observed by Voyager have a distinctive cuspate pattern. Cuspate dark bands and triple bands are observed as well.

Several attempts have been made to study the orientations of the various types of lineaments, and from the orientations to infer the source or sources of stress responsible for their formation. These attempts have met with limited success, both because of the irregular nature of the lineament patterns, and because of the non-uniqueness of the stress fields produced by several possible sources. Sources that have been considered for stresses near the surface of Europa include (1) volume changes due to silicate dehydration, (2) volume changes due to freezing of ice, (3) solid-state convection, (4) tidal despinning, (5) tidal deformation, (6) secular changes in orbit semimajor axis, (7) non-synchronous rotation, and (8) free rotation of a mobile ice shell over a fixed tidal bulge. Several of these can probably be ruled out as insignificant, most notably (4) because it takes place so early in Europa's history and (6) because of the long timescales and hence low stresses involved. The others, however, all appear credible to various degrees.

Both Voyager and telescopic observations have provided useful information about the surface composition and texture of Europa. All units on the surface are very bright, and H_2O frost is the dominant component. Europa shows a pronounced but very narrow opposition surge, suggesting highly porous (*i.e.*, "fluffy") surface frost. While H_2O dominates, it is clear that other materials are present as well. The material producing the slight darkening of some regions on Europa in the visible is unknown; silicates, radiation-darkened salts, and organics have all been suggested. Observations in the ultraviolet have shown an absorption feature attributable to a sulfur-oxygen bond; implantation of sulfur trapped in the jovian magnetosphere appears to be a likely source for this feature.

If an ocean ever did exist within Europa, it should have been rich in biogenic elements derived from dehydration of chondritic material. Soluble organics should also have been present in ample quantities, including amino acids, purines and pyrimidines. The most viable biologically-useful energy source would probably be geothermal heat that could drive local seafloor hydrothermal systems. On Earth, such systems permit reactions between seawater and hot basalt, producing fluids that sustain the metabolic activity of hyperthermophilic bacteria that form the base of a robust local food chain. Much of the metabolic activity is anaerobic. The origin of Earth's life at such vents has been suggested, though this idea is controversial. Questions of origin aside, familiar organisms could probably be sustained at submarine hydrothermal sites on Europa. Such sites may exist now, and almost surely existed at some point in the past.