Moons of Jupiter

Galilean Moons

Galileo discovered the four large moons in 1610 on the first night he observed Jupiter. From nearest to farthest, these moons are Io, Europa, Ganymede, and Callisto.

(I Eat Green Carrots.)

Jupiter has numerous small moons, which are believed to be captured asteroids. Some of these moons have regular prograde orbits, but most have irregular, highly elliptical and/or retrograde orbits.

Pre-Voyager Questions

Will there be extensive cratering?

NO: These distance worlds are composed of **substantial amounts of ice**, which, being more like plastic, may not preserve the crater basins as long as rock does. Also, these worlds are past the asteroid belt, so there may not have been as many projectiles to hit these worlds as there were to hit the terrestrial planets.

YES: On the other hand, the Galilean moons orbit about an extremely **strong gravitational** source, that is, Jupiter. It should attract many meteoroids, and the closer the moon is to Jupiter, the higher the expected impact rate.

Pre-Voyager Questions

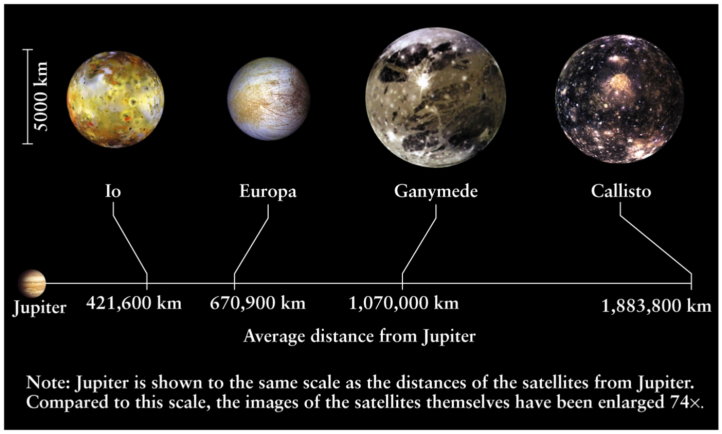
Will there be extensive tectonic activity?

NO: These worlds are about the size of the Moon and Mercury, so they should have cooled quickly, not allowing tectonic (global) activity to occur.

YES: The strong gravitational influence of Jupiter and orbital resonances could have an effect.

Galilean Moons

Distances

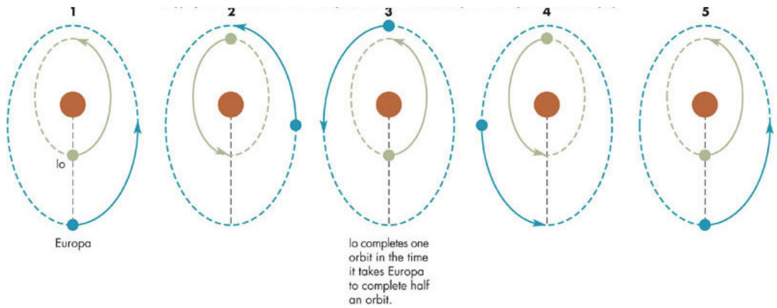


Earth-Moon distance = 385,000 km

Characteristics

Moon	Period (days)	Resonance	Size	Mass (lunar)	Density (g/cm^3)
Io	1.8	4	Moon	1.2	3.5
Europa	3.6	2	Moon	0.7	3.0
Ganymede	7.2	1	Mercury	2.0	1.9
Callisto	16.7	-	Mercury	1.5	1.8

Orbital Resonance

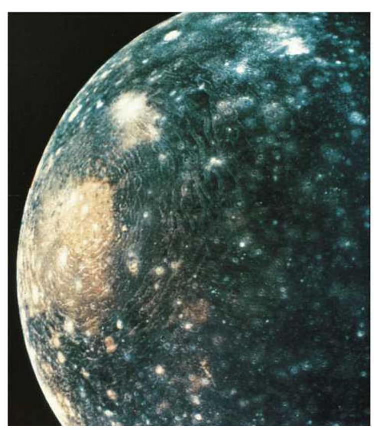


Callisto

Callisto is 2% larger in diameter than Mercury. It may contain a 1000 km layer of ice. **It is completely covered with impact craters**, like the lunar highlands.

It is also covered with a blanket of dark, dusty material. Where this material came from, and how it came to be distributed across the surface is not understood.

Several multi-ring impacts are seen.

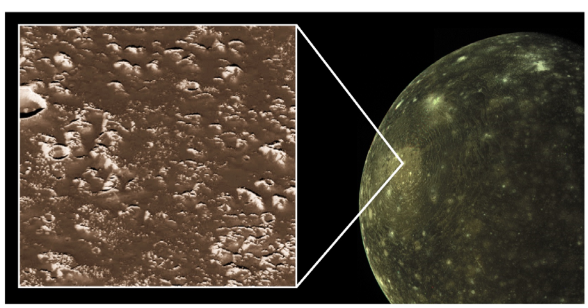


Callisto

The existence of this heavily cratered surface tells us three important things not known before Voyager:

1. An icy planet retains impact craters in its surface if its temperature is low enough,
2. There was a heavy bombardment by debris in the outer Solar System as well as nearer the Sun, and
3. Callisto has experienced little, if any, geological activity other than impacts for a long time.

Callisto



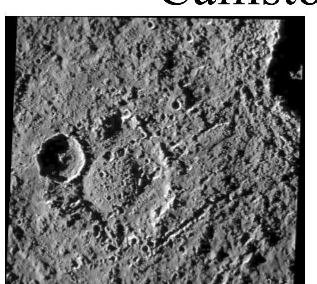
There are very few craters with diameters less than 1 km. These sized craters are found on Ganymede, so the impact rates should have been the same. Somehow most of Callisto's small craters have been eroded away.

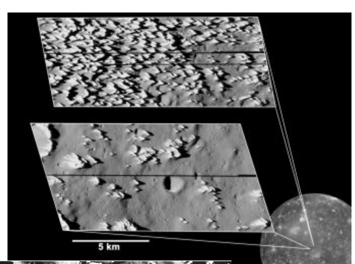
Callisto

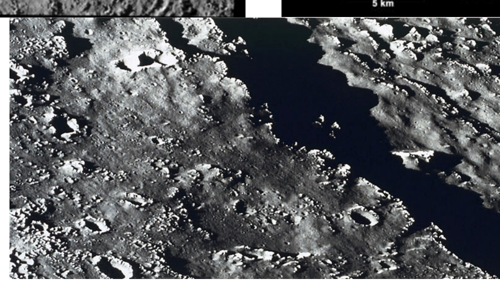
The craters do not look like their counterparts in the inner Solar System. They tend to be much flatter, as if the surface did not have the strength to support much vertical relief.

Such subdued topography is to be expected for an ice crust at the temperatures of 140 K measured near local noon on Callisto, since ice loses some of its strength as it is warmed.

Callisto Terrain



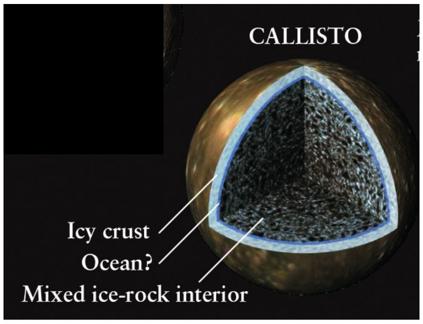




Interior Structure

The Galileo spacecraft measurements indicate the interior is not differentiated, that it is cold, and that there could be a liquid layer beneath the surface.

This is difficult to understand. Even with antifreeze, the layer cannot be too cold or it would solidify – that would suggest a warm interior.

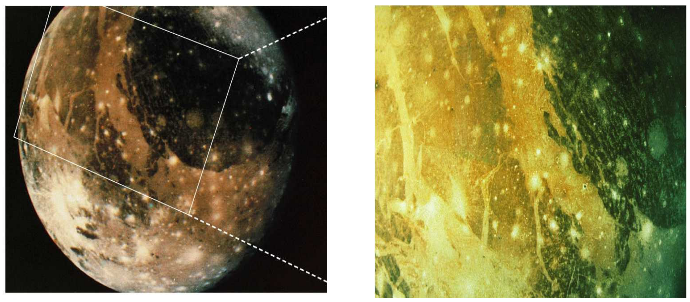


Ganymede

Ganymede is the largest moon in the Solar System (8% greater than the diameter of Mercury).

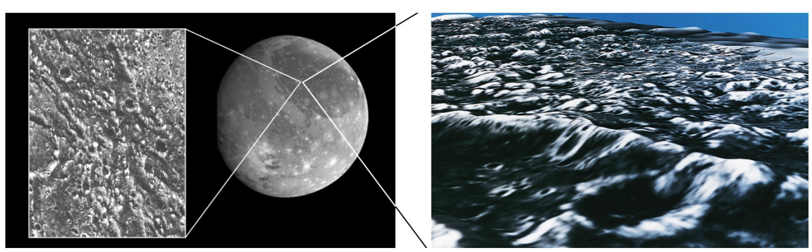
It is also cratered, but less so than Callisto. About one-third of its surface (the dark regions) seems to be ancient and contemporary with Callisto, whereas the rest formed later, after the heavy bombardment period. This younger terrain is probably about as old as the lunar maria or the Martian volcanic plains.

Galileo Regio



The large dark area, named **Galileo Regio**, covers one-third of the surface. It is believed to be billions of years old because of the numerous craters.

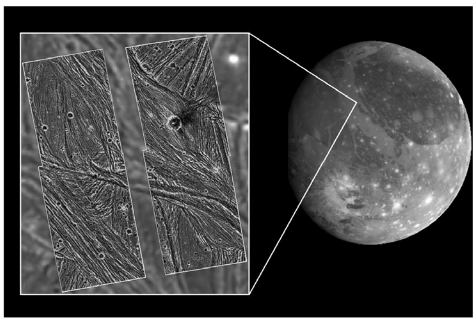
Old, Dark Terrain



Small craters dot the landscape (about the size of Rhode Island), and long, deep furrows extend from the upper left to the lower right. These furrows are deformations of Ganymede's crust that have partially erased some of the oldest craters (since craters lie on top). The stresses that created the furrows must have occurred long ago.

Bright, Young Terrain

Linear features are seen in the bright terrain. These are long grooves, some of which extend for hundreds of kilometers and are as much as a kilometer deep.



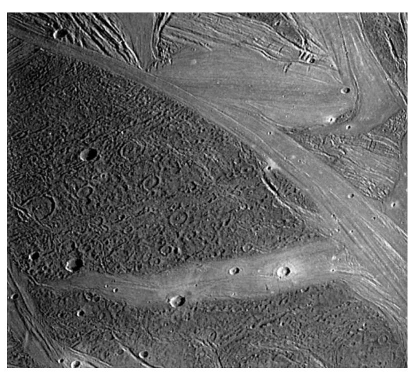
The bright terrain has been subjected to a variety of tectonic stresses. The density of craters indicates these regions are old, but not as old as the dark regions.

[Resolution differences between Voyager and Galileo images are clearly seen.]

Young Ganymede Terrain

The younger terrain was badly fractured by the stresses that produced the grooves.

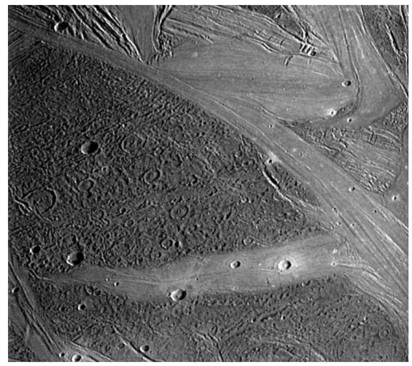
Fracturing makes it more reflective. The furrows in the dark terrain and the grooves in its bright terrain suggests that Ganymede was once geologically active.



Young Ganymede Terrain

There is even evidence that blocks of the older, heavily cratered terrain may have rotated or slipped at the time the younger crust was forming, providing a surprising analog of Earth's plate tectonics.

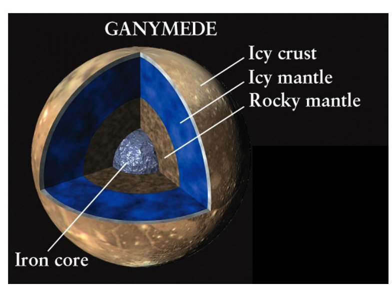
Ganymede experienced expansion and consequent resurfacing during the first billion years after its formation, while Callisto did not. Apparently the small difference in size between the two led to this difference in their evolution.



Interior Structure

The presence of a magnetic field shows that electrically conducting material must be in motion, which means it must still have substantial internal heat.

Having a warm interior would cause **differentiation**. It has a metallic core, surrounded by a rocky mantle and by an outer shell of ice.



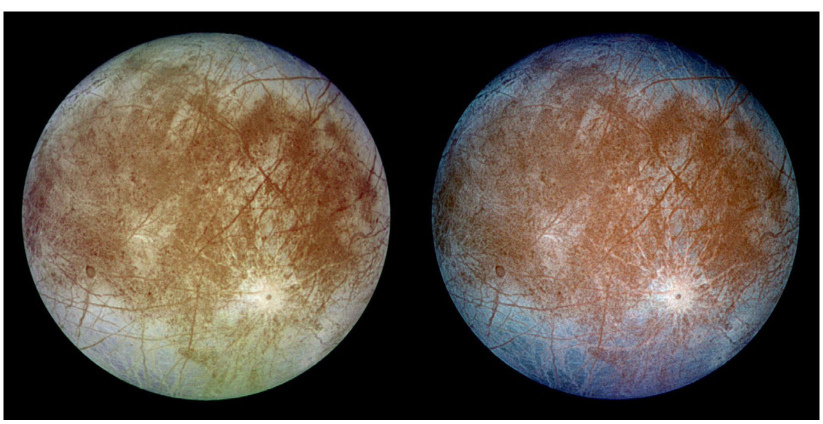
Europa and Io

The two inner Galilean moons are not icy worlds like most of the moons of the outer planets. Similar to our Moon in density and size, they appear to be predominately **rocky** objects.

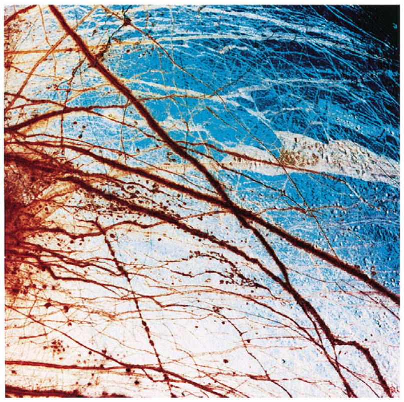
The most probable reason that they failed to acquire ice is due to Jupiter, which became hot and radiated a great deal of infrared energy during the first few million years after its formation.

Temperatures therefore rose in the disk of material near the planet, and ice evaporated, leaving Europa and Io with compositions more appropriate to bodies in the inner Solar System.

Europa



Europa



In spite of its mainly rocky composition, Europa has an water and ice-covered surface, about 100 km thick.

It is like the Earth, which also has global oceans of water, except most of Europa's ocean may be frozen.

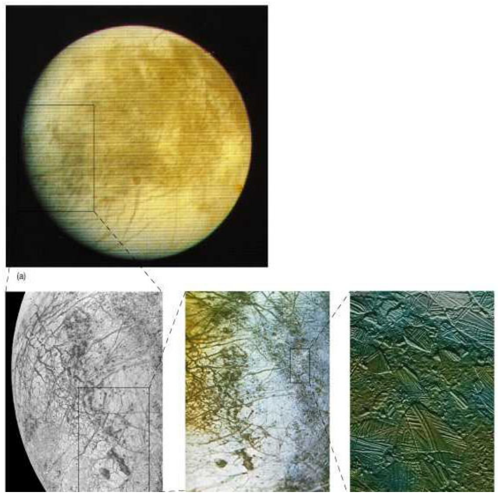
There are very few craters, indicating that the surface has been capable of some degree of self-renewal.

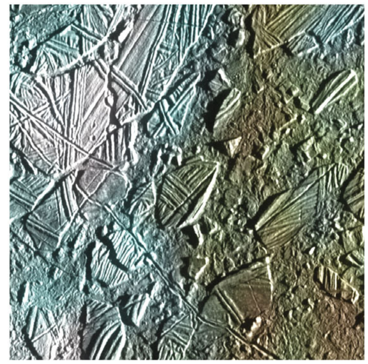
Additional indications of internal activity are provided by an extensive network of cracks in its icy crust.

Surface Detail

Galileo images show "pulled apart" terrain that suggests upwelling material filling in the gaps between separating surface ice sheets, and a region where liquid water appears to have flooded a portion of the surface.

Europa

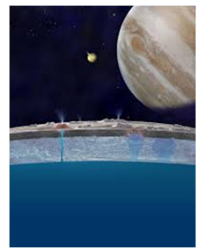




Ice Rafts

Arctic Ice Rafts

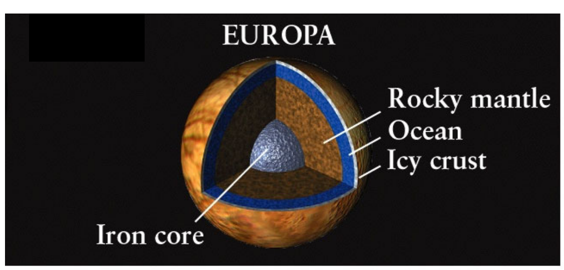
Europa’s Lenticulae



This Galileo image shows a region of Europa about 100 km across. The dark spots are *lenticulae*, which are 100-m high ice mounds that may have formed when relatively warm blobs of ice rose through the colder surrounding ice. The warm ice in the mounds may contain chemicals from the ocean beneath.

Interior Structure

By combining measurements of Europa’s induced magnetic field, gravitational pull, and oblateness, scientists conclude that Europa’s outermost 100 to 200 km are ice and water. Within this outer shell is a rocky mantle surrounding a metallic core.



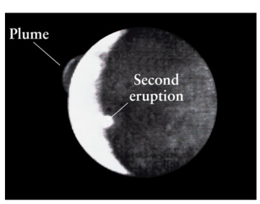
Io

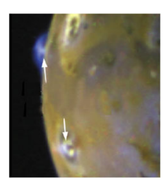
Io displays a high level of volcanic activity. **The discovery of active volcanism on Io was the most dramatic event of the Voyager flybys of Jupiter.**

Eight volcanoes were seen erupting when Voyager 1 passed in March 1979, and six of these were still active four months later when Voyager 2 passed.

Volcanic Plumes

Io's volcanic eruptions were first discovered on this Voyager 1 image. The Pele volcanic plume at upper left rises to 260 km. A second plume can be seen on the boundary between the day and night hemispheres.

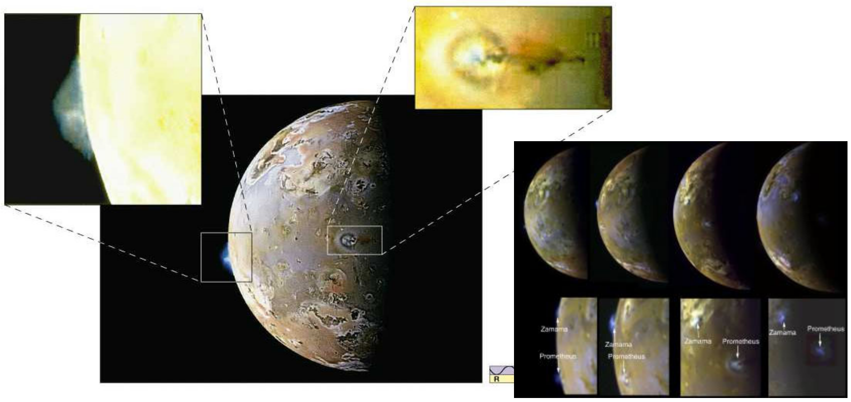




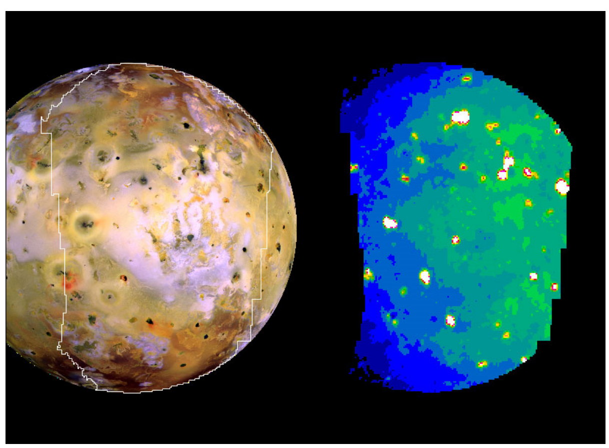
The second photo, taken by Galileo, shows plumes from two other volcanoes. Particles in the plumes scatter sunlight, which makes a bluish color.

Volcanic Plumes

These eruptions consisted of graceful plumes
that extended hundreds of km into space.



Volcanoes



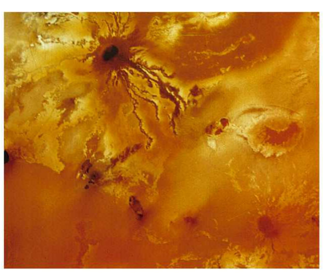
Io's Lava

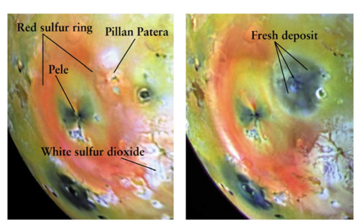
The material erupted is not lava or steam or carbon dioxide, all of which are vented by terrestrial volcanoes, but sulfur and sulfur oxides. Both of these can build up to high pressure in the crust of Io and then be ejected to tremendous heights.

As the plume cools, the sulfur and SO_2 re-condense as solid particles, which fall back to the surface in gentle "snowfalls" that extend as much as a 1000 km from the vent. The SO_2 snow is white, while sulfur forms red and orange deposits. Another sulfur compound detected is H_2S.

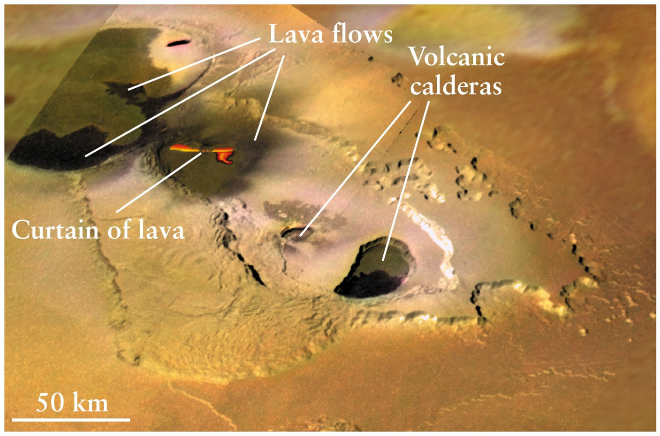
Lava Flows

Also seen are shield volcanoes and twisting lava flows, thought to be made of sulfur, hundreds of km long. Further activity includes hot spots. The largest hot spot is a type of "lava lake" 200 km in diameter near Loki.

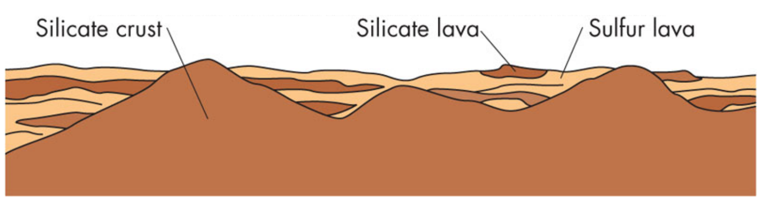




Lava Lakes

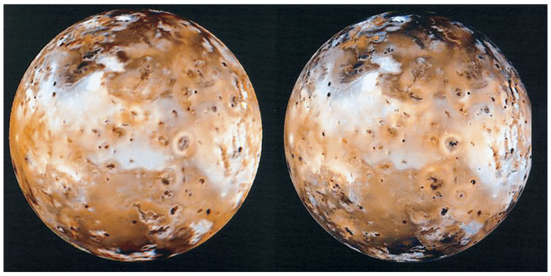


Io’s Volcanism



The surface of Io is slowly buried in these deposits, which accumulate at an average rate of a millimeter or so per year. Over millions of years, this is sufficient to cover any impacts, so it is no surprise that no such craters have been seen on Io’s surface.

Io's Volcanism



The Voyager image (left) and Galileo image (right) show the same region of Io. Note the many changes during the 17 years between the two. One of the most conspicuous changes is a dark lava flow from the volcano Prometheus, the bright ringed feature just to the right of the center.

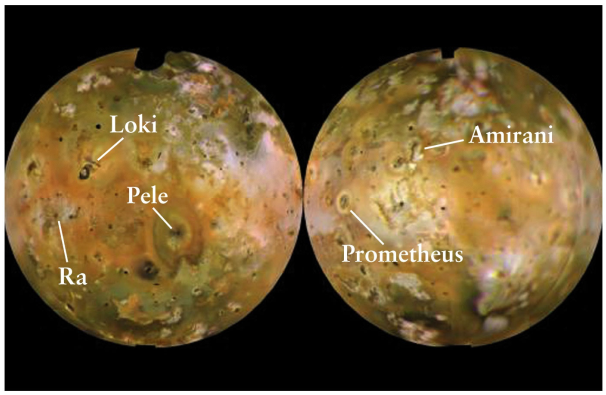
Io's Volcanism

Io maintains this level of volcanism because of **tidal heating** by Jupiter. It is about the same distance from Jupiter as the Moon is from the Earth, yet Jupiter is 300 times more massive than Earth, causing tremendous tides on Io. These tides pull the satellite into an elongated shape, with a bulge several km high extending toward Jupiter.

If Io always kept this bulge toward Jupiter, there would be no heat generated. However, Io's orbit is not quite circular, because of the **resonances** (e.g., gravitational forces) by Europa and Ganymede. Io twists back and forth, at the same time moving nearer and farther from Jupiter on each revolution. The flexing of the bulge heats Io, melting its interior and providing power to drive the volcanoes.

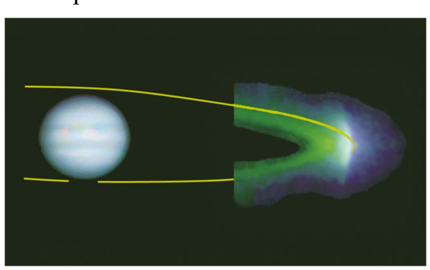
Io's Volcanism

After billions of years, this tidal heating has taken its toll on Io, driving away H_2O and CO_2 and other gases, until now **sulfur** compounds are the most volatile materials remaining. The inside is entirely melted, and the crust itself is constantly recycled by volcanic activity.

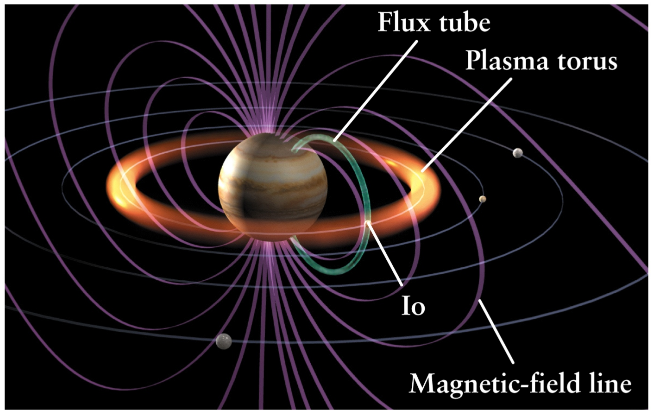


Plasma Torus

The SO_2 and other gases ejected out by Io's volcanoes form a tenuous atmosphere. However, Io orbits deep within the Jovian magnetosphere, and its surface is subjected to a tremendous bombardment by energetic ions of sulfur and oxygen. The molecules in Io's thin atmosphere are dissociated and ionized by these charged particles. Once ionized, they are swept up in Jupiter's magnetic field to form the Io **plasma torus**. Thus Io's volcanic eruptions have a major influence on the huge magnetosphere of Jupiter.

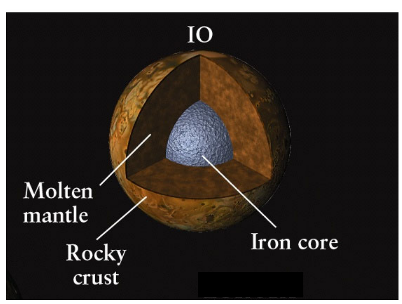


Plasma Torus

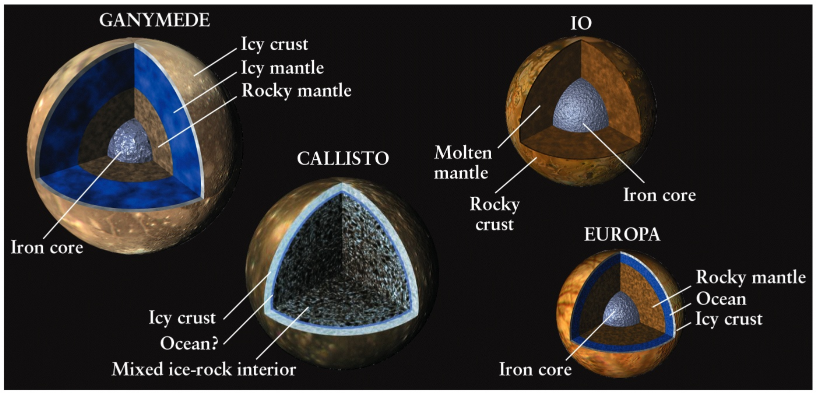


Interior Structure

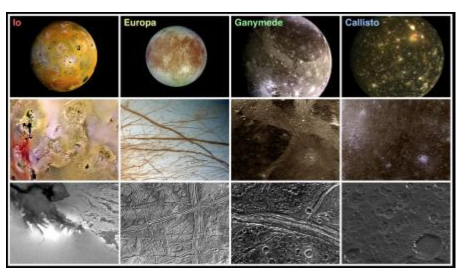
If Io has undergone enough tidal heating to melt its interior, chemical differentiation must have taken place and it should have a dense core. Galileo observations suggest that Io has a dense core composed of iron and iron sulfide, with a radius about half of its overall radius. Surrounding the core is a mantle of partially molten rock.



Interior Structures of 4 Moons



Surface Comparisons



Other Moons

Pre-Voyager

The other 12 Jovian satellites are much smaller. They divide themselves into three groups of four each. The inner four all circle the planet inside the orbit of Io. The outer satellites consist of four in direct but highly inclined orbits and four farther out in retrograde orbits. These eight are believed to be captured objects.

Post-Galileo

The list is up to 50 confirmed moons and 16-17 provisional ones.

Other Moons