heat generated during its accretion, and also that from radioactive decay processes. However, the other Galilean satellites cause perturbations in Io's orbit so that its distance from Jupiter varies slightly. Jupiter's gravitational field is so strong that even these small changes cause great tidal distortions of Io, and thus produce sufficient heating of the interior to account for all the volcanic activity.

The satellite appears to consist of a molten silicate interior, just possibly with a solid core, overlain by a layer of liquid sulphur several kilometres deep. Above this is a layer consisting of a mixture of solid sulphur and liquid sulphur dioxide ($SO_2$) covered by a solid crust of sulphur and sulphur dioxide.

## Europa

The next satellite out from the planet, Europa, is quite similar in size and density to Io (and the Moon), and again was expected to be covered in craters. However, it also proved to be unique in the Solar System, for a completely different reason. Only a few small impact craters have been found; the rest of the surface is incredibly smooth. A network of straight, curved or irregular dark markings covers the whole surface, and these range from less than 10 km to about 70 km in width. There are also randomly located dark spots, but all these markings appear to have quite negligible vertical height, so that the satellite has been described as 'a billiard ball covered in scribbles from a felt-tipped pen'. Even stranger is yet another network of markings, this time faint and light-coloured, quite independent of the dark ones, and also covering the whole satellite. These are only about 10 km wide, and they do show some vertical relief, although this is less than a few hundred metres. But the most surprising thing about these ridges is that they are not straight: they run across the surface in a regular series of curves or scallops, ranging from about 100 to 300–400 km across.

The first impression that the surface is cracked is quite possibly correct, even though the lack of vertical relief seems surprising. Studies show that parts of the surface are covered with apparently freshwater frost, as well as traces of sulphur (almost certainly derived from Io). However, there is less sulphur than would be expected, which may well indicate that some has been buried beneath fresh frost deposits. These considerations, together with the lack of impact craters, suggest that processes are still acting to smooth out the surface.

Europa, like Io, is subject to tidal forces which could well maintain a certain degree of heating in the interior.

It would seem that a solid rocky core is covered by a thick layer of water and ice (perhaps about 100 km deep). Liquid water could escape to the surface through the cracks and give rise to the frost deposits before the cracks themselves freeze over once again, perhaps after a few years. The low rigidity of the icy crust would account for the lack of impact craters. The darker markings could well have been formed when the underlying water layer contained some mixture of other substances at an earlier period in the body's history.

## Ganymede

Ganymede, the largest satellite in the Solar System, and Callisto both have lower densities than Io and Europa – about 1 900 km per m³. This suggests that they are both comprised of roughly half rock and half ice. Once again they are thought to have rocky cores surrounded by water or icy layers with icy crusts.

The surface of Genymede is very varied. The oldest regions consist of dark plains, one of which, Regio Galileo, is as much as 4 000 km across and preserves signs of a major impact in a series of low ridges (about 100 m high) spaced about 50 km apart. All this old terrain appears to have been fractured into separate blocks, some of which have been displaced, and some completely replaced by younger, lighter-coloured material consisting of long parallel lines of valleys and ridges about 15 km across and 1 km high. This 'grooved terrain' is highly complex in appearance, not only cutting into the old plains, but also intersecting older areas of the same type of surface, suggesting many mountain-building episodes. Still other regions show rough mountainous terrain, and Ganymede's surface seems to be the one place in the Solar System to have undergone geological changes like those produced by plate tectonics on Earth.

Some craters appear relatively fresh, with bright haloes, presumably from ice or water ejected by the impact, but most of the surface is actually very old. Crater counts suggest that the dark plains date back to about $4 \times 10^9$ years, and even the most recent grooved terrain seems to be about $3{\cdot}5 \times 10^9$ years old - roughly the same as the lunar highlands. The low relief probably results from a time when the interior of the satellite was rather warmer and the crust more plastic.

## Callisto

Callisto seems to possess an even thicker icy crust than Ganymede, and it is very heavily cratered. However, all the craters are shallower than similar-sized ones on any of the terrestrial planets, and many of the later ones which might have been expected seem to have disappeared completely. There are remnants of large impacts, but they all have very little vertical relief. One, Valhalla, has a bright central region, about 600 km across, probably representing the original impact crater, and is surrounded by an immense set of 'ripples' which makes its overall diameter nearly 3 000 km – far larger than any feature such as Mare Orientale on the Moon or the Caloris Basin on Mercury. It seems certain that flow has occurred in the icy surface to obliterate many of the very old impact scars, and to reduce the height of the remainder. Apart from this, however, there appears to have been very little true geological activity on Callisto, and certainly not to the extent found on the other Jovian satellites.

## The other satellites

Very little is known about any of the other satellites except for Amalthea, of which Voyager returned images showing it to be an irregular rocky body

Opposite page, top: *Voyager 2 photograph of Jupiter taken on 1979 June 28. One of the dark 'barges' can be seen in the North Equatorial Belt. In the lower half of the picture, south of the Equatorial Zone, a chaotic region of whiter clouds is visible, lying west of the Great Red Spot, which is out of the picture to the right.*

Opposite page, bottom: *A composite picture of a ground-based photograph of Jupiter and a three-hour exposure of Io's sodium cloud. The dark circular area was caused by the occulting disc used to prevent interference by light from Io itself. The size of Io is shown by the white dot.*