8 The Search for Extraterrestrial Life

Looking at the nature, origin, and evolution of life on Earth is one way of assessing whether extraterrestrial life exists on Earth-like planets elsewhere (see Chaps. 6 and 7). A more direct approach is to search for favorable conditions and traces of life on other celestial bodies, both in the solar system and beyond. Clearly, there is little chance of encountering nonhuman intelligent beings in the solar system. But there could well be primitive life on Mars, particularly as in the early history of the solar system the conditions on Mars were quite similar to those on Earth. In addition, surprisingly favorable conditions for life once existed on the moons of Jupiter. Yet even if extraterrestrial life is not encountered in forthcoming space missions, it would be of utmost importance to recover fossils of past organisms as such traces would greatly contribute to our basic understanding of the formation of life. In addition to the planned missions to Mars and Europa, there are extensive efforts to search for life outside the solar system. Rapid advances in the detection of extrasolar planets, outlined in Chap. 4, are expected to lead to the discovery of Earth-like planets in the near future. But how can we detect life on these distant bodies?

8.1 Life in the Solar System

If life exists outside Earth in the solar system, where would we look for it? Are there places that have the required conditions for life (discussed in Chap. 5), such as a suitable temperature, an aquatic environment, and sufficient energy? Because neither Mercury nor our Moon have atmospheres or oceans, there is little chance of finding life there. For the same reason, asteroids, comets, and small moons can also be discounted. Venus is an inferno with surface temperatures of 480°C. Shrouded under dense aerosol clouds of sulfuric acid, it has an atmosphere consisting of 96.5% CO_2, 3.5% N_2, and traces of SO_2, H_2S, and H_2O. However, because of its solid rock surface, Venus is another unlikely place for life. The same can be said of the giant planets Jupiter, Saturn, Uranus, and Neptune, which are completely covered by cold (-100°C to -190°C) and deep oceans, consisting of liquid H_2 and He. As every inorganic or organic molecule is heavier than these elements, it will sediment down to the bottom of these oceans.

Remaining possible locations for extraterrestrial life in the solar system are therefore Mars, the large moons of Jupiter (Io, Europa, Ganymede, and Callisto) and maybe Saturn's moon Titan. Although the moons of the giant planets are far outside the habitable zone, it is the nearby planets that could supply the necessary energy for life by tidal heating. Since these moons have accumulated from planetesimals beyond the ice–formation boundary, it is not surprising that there was plenty of ice at their formation. Gravitational and magnetic field measurements by NASA's *Galileo* spacecraft have enabled the interior structure of these moons to be unraveled. We now know that the three inner moons of Jupiter have iron cores overlaid by a mantle consisting of silicate rocks. Above the mantle, Ganymede, with a radius of 2634 km, has a 1000 km deep surface layer of ice, while Europa (radius 1565 km) has a 350 km ice layer. No ice has been found on Io (radius 1821 km), probably because it was lost from that moon during its evolution, while Callisto consists of a relatively uniform mixture of ice and rock.

The existence of large amounts of ice on the surfaces of Ganymede and Callisto can also be seen from their white craters which, due to underlying fresh ice, are conspicuous by the sharp contrast with the surrounding dark dust-covered regions. However, it is doubtful whether moons such as Callisto and Titan can be seats of life, as the available energy appears to be too small because both moons are too far away for tidal heating.

Closer to Jupiter, however, much more energy is available, as demonstrated by the very active volcanism of Io. While Earth's Moon (radius 1738 km) shows no trace of volcanic activity, the similar-sized Io has very active volcanism, which is attributed to the heating by tidal friction exerted from the nearby Jupiter. The surface of Io consists largely of sulfur and sulfur dioxide, with lakes and lava streams composed of liquid S and SO_2. Hot spots on Io show temperatures of 17°C, while the surroundings are as cold as −178°C. Here one would not expect life based on organic chemistry. Because the tidal interactions decrease rapidly with distance, the second moon Europa receives much less heating, and Ganymede even less.

8.2 Europa's Ocean

Surprisingly, Europa has a surface that is practically devoid of craters (see Fig. 8.1). The figure shows that large plates or rafts of ice seem to have been sliding over deeper layers on Europa, in much the same way as Earth's continents move over our planet's oceanic crust. The parallel linear ridges (Fig. 8.1, left panel) between the plates have many similarities to the mid-ocean ridges on the Earth's sea floor, where new crust forms due to upwelling material between the separating plates. As the pieces of plate fit together like a jigsaw puzzle (Fig. 8.1, right panel), plate-tectonic-like activity might be occurring on Europa. The material between the cracked and separated plates looks like slush, which is now frozen solid at the very low surface

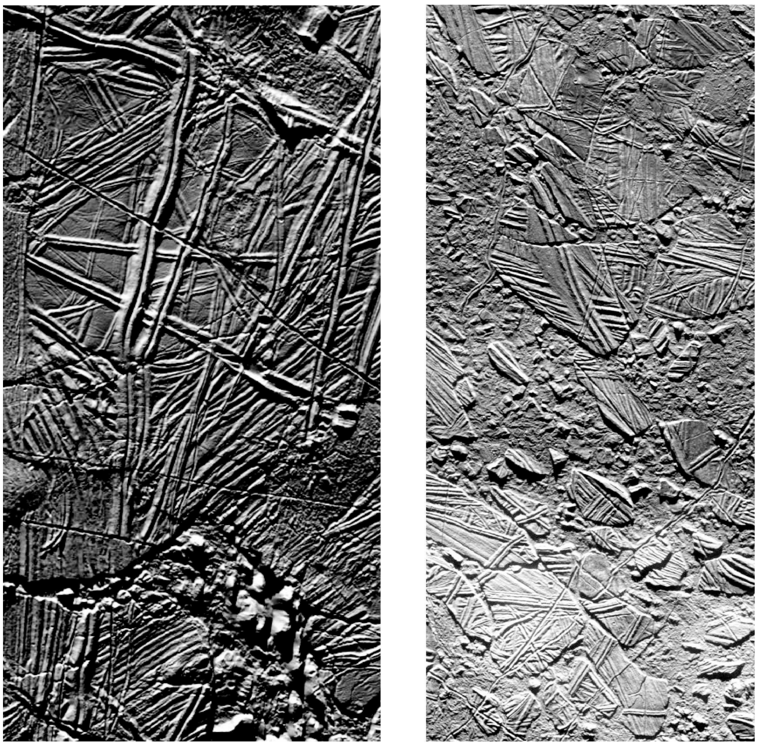

Fig. 8.1. The surface of Jupiter's moon Europa, observed from the Galileo spacecraft (courtesy of NASA)

temperatures (−143°C). Strangely shallow impact craters and basins indicate that subsurface ice was warm enough to fill in the deep holes. From the appearance of a reworked surface and the fact that there are so few craters on Europa, it appears that the surface is very young, and that in places the ice surface is possibly only about 3–4 km thick (Turtle and Pierazzo 2001).

All this evidence suggests that there could be an ocean of liquid water under the surface ice of Europa and that the above-mentioned 350 km ice layer could be partly melted. Moreover, observations of surprisingly strong magnetic fields also point to subsurface oceans of liquid water on Ganymede. Such bodies of water with a frozen surface are well known from the ice lakes of the Earth's Antarctic regions (see Fig. 8.2). As these lakes teem with life, this might also be the case for Europa and Ganymede. Although life usually needs energy in the form of light to carry out photosynthesis, it was discussed in Chap. 6 that at hydrothermal vents on the ocean floor and at geothermal hot springs life is sustained in complete darkness, using heat and chemical energy from volcanic fluids, and that some of these organisms – such as

Fig. 8.2. Lake Bonney, a dry valley ice lake in the Taylor Valley of the McMurdo Sound region, Antarctica (after Priscu 2001)

thermophilic (heat-loving) bacteria – are among the most ancient life forms on Earth.

It is not surprising that these observations have generated intense interest in Jupiter's Galilean satellites, which has resulted in a series of space missions (see LP missions 2005). The Galileo spacecraft, that arrived in 1995 and till its planned fiery end in the atmosphere of Jupiter in Sept. 2003 completed 34 orbits around Jupiter, had numerous close encounters with its four large moons. A dedicated mission to search for the existence of oceans of liquid water on Europa, Ganymede and possibly Callisto, to determine their depths and investigate their nature and global extent, the *Jupiter Icy Moons Orbiter* (JIMO) is planned to be launched in 2015 and will orbit these three moons.

8.3 Life on Mars

Since it orbits in the habitable zone, Mars represents the greatest hope for finding traces of extraterrestrial life in the solar system. In its early history, this planet had a dense atmosphere and liquid water on its surface. At this time, primitive life could well have formed, traces of which might still exist today or might be found in fossilized form. To look for such traces is one of the main aims of the Mars missions planned in the near future.

8.3.1 Early Searches

In the year 1877, G. Schiaparelli, an astronomer from Milan, Italy, discovered canals (canali) on Mars, which were immediately attributed to intel-