Chapter 13

More Abodes for Life

Where else can we look for life? I am going to double back now and recheck places that astrobiologists often cross off the life list. These include Venus, large asteroids, planets around small red dwarf stars, and planets around large red giants. I also check out prime habitats in the icy bodies in outer solar system.

Venus: Hell and Purgatory

Our cannons' malice vainly shall be spent

Against the invulnerable clouds of heaven

The Life and Death of King John, Act II. Scene I.

William Shakespeare (1564–1616)

The Oxford Shakespeare, 1914

The surface of Venus is hell, 730 K (Figure 1). Nothing that we can imagine can live there. To boot, the logistics of probing the surface are terrible. Yet Venus does interest astrobiologists.

Figure 1: The Soviet probe Venera 14 imaged the hellish surface of Venus. It revealed cracked basaltic rock similar to that erupts on oceanic islands on the Earth.
http://nssdc.gsfc.nasa.gov/image/planetary/venus/venera14.jpg

First, we have considerable hope of finding evidence of past clement climates from the ancient past when our Sun was dim. The products of weathering by liquid water deposited in shallow seas survive in the chemical composition of rocks. Shales (mudstones) accumulate from clays left over after weathering removes more soluble components. They are rich in aluminum oxide. The excess aluminum oxide remains even after the shale melts to form granite (Figure 3). Small inclusions in crystals indicate that liquid water was present on the Earth by 4.3 billion years ago. Limestone loses its carbon dioxide but the excess of calcium over normal igneous rocks remains. I have seen the chemical remnants of limestone in rocks heated to 1200°C at 22-km depth in an outcrop in Alaska (Figure 2).

Figure 2: The rocks in the foreground were once part of a volcanic island with limestone reefs. Movements in the Earth's crust carried the rocks down to about 22 km depth where they partially melted at about 1200°C. The pink rock in the foreground was once limestone $CaCO_3$. It retains a calcium-rich composition. Nelchina Glacier, Alaska. Photo by author.

We need merely find outcroppings of ancient rocks on the Ishtar region of Venus, which resembles an Earth continent. Then we are in business, as the chemical signature survives even melting of the rock.

We have much less hope of finding preserved macrofossils and none for microfossils. Morphological fossils do survive high temperatures on the Earth but only when the rock does not get deformed in the process. We would need a well-exposed section that we could image from various angles. We are not likely to get this from a drop-and-die probe.

Figure 3: New Hampshire is the Granite State. Here is granite on the right intruded by basalt on the left. Note the thin stringer of basalt above and to the right of the pen. Chemical analyses for aluminum oxide would quickly tell if the granite formed from melted sedimentary rocks. This is a way to look for past clement environments on Venus. Photo by the author.

What about extant life? The surface is hell, but the clouds are merely purgatory. The cloud tops are clement and contain drops of sulfuric acid (Figure 4). (Brimstone without fire.) We would die if we drank a glass of Venus cloud drops, but some terrestrial microbes thrive in very acid environments. There is plenty of light for photosynthesis.

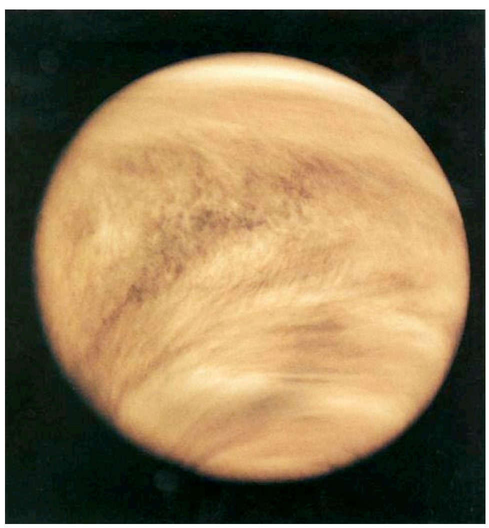

Figure 4: Ultraviolet image of Venus cloud tops reveals some structure. The clouds tops are very acidic but clement. http://nssdc.gsfc.nasa.gov/photo_gallery/photogallery-venus.html

David Grinspoon has been actively urging that NASA check out the Venus clouds for life. You may be thinking that clouds are not green on the Earth. True, there is not much photosynthesis in Earth clouds, but they do contain microbes. Drops rain out or evaporate quickly so they are not much of a niche for life. Still some microbes appear to have evolved UV light resistance and hence are residents of not merely visitors to clouds.

The Venus cloud drops are much more long lived. Air currents rarely sweep the drops down into the hell that lies below. (Getting swept into the underlying hell is what keeps clouds on the giant planets sterile.) There is a problem in how life evolved to live in the clouds before Venus' surface became too hot. There may be a problem of the supply of nutrients like phosphorus, which is scarce in Earth clouds. There is some evidence that phosphorus is present in Venus air. As in all astrobiology, the problem may be our own lack of imagination. In any case, the logistics are much kinder than the surface of Venus. An acid-safe balloon would last a long time. There is sunlight for solar cells. A nitrogen-filled balloon would supply buoyancy in the carbon dioxide atmosphere if helium leakage poses a problem. Even if no life is found, we will learn a lot about the chemistry and physics of the Venus atmosphere.

Ceres: seeds of life?

Ceres is the largest asteroid in the solar system, about 950 km in diameter (Figure 5). Telescopic observations indicate that its surface is made of the same material as the carbonaceous meteorites that contain complex organic commands, including amino acids. We do not know which of these meteorites come from Ceres, as there are numerous smaller asteroids with similar surface characteristics.

Ceres is now a dead body with no tectonics and freezing temperatures well toward to the center. However, its insides were clement early in the history of the solar system. Liquid water flowed in its interior. Hot water coming from depth was out of chemical equilibrium with cooler surface rocks. It had the basic ingredients to start life, including several percent by mass of organic matter. It was large enough that it stayed clement for hundreds of million years, long enough for evolution to occur.

Figure 5: The Hubble telescope imaged Ceres. The dark feature Piazzi is at the center of the image. We know from spectra that carbonaceous material exists at the surface, but available images reveal very little. http://www.jpl.nasa.gov/news/features.cfm?feature=545.

Ceres is an excellent astrobiology target to catch prebiotic evolution in the act. It may have even provided the seed of life to the inner solar system. It was a clement solid body before the Earth-Moon system formed and probably before the surface of Mars was habitable. Geochemists know this from analyzing the products of radioactive decay of short-lived radioactive isotopes that nearby supernovae added to the solar nebula. The low gravity of Ceres made it easy for impacts to eject rocks. Some of these ejecta hit the Earth and Mars just like the carbonaceous meteorites do today.

Ceres is an easy exploration target. It has some gravity to keep a lander in place but not enough to make landing difficult. There is no need to drill deeply as craters have exhumed the subsurface over geological time. The Dawn mission will arrive at Ceres in 2015.

Ice worlds

Water ice is stable is the cold outer solar system. It is in fact a hard rock at the temperatures of below 100 K found on the surfaces of outer solar-system objects. ET evolved in that environment might use ice for building stones and ground up ice as an abrasive. In the larger objects, temperature increases with depth rapidly enough that liquid water exists in the subsurface. Space probes have compiled a nice shopping list.

Jovian moons. Galileo viewed Jupiter and its four large moons as a miniature solar system. This analogy is far more applicable today than Galileo imagined. The moons condensed out of a dust and gas nebula surrounding Jupiter, like the inner planets formed from the solar nebula. At the time of moon formation, Jupiter was hot from the gravitational energy of accretion. Io accreted nearest Jupiter. It retained rock, iron, and sulfur. It is very volcanically active. Any water it had has been since lost. It is likely to be sterile. Europa accreted out next (Figure 6). It retained a 100 to 200-km thick layer of water over rock. Its interior likely melted, forming an iron core like the Earth's. It is at the goldilocks distance for life from Jupiter so I return to it after discussing the other moons. Ganymede is next out. It got hot enough to differentiate ice and rock. The ice layer is hundreds of kilometers thick. There is evidence that the liquid water has erupted to the surface. If there is still liquid water at great depths the situation is similar to Europa, except the logistics are not good. Callisto, the farthest out, has never melted. It is a sterile mixture of ice and rock.

The Neptune moon Triton has an active surface and a tenuous nitrogen atmosphere that freezes out on the surface. Liquid water may well vent through cracks. More exotic fluids like carbon dioxide or methane are conceivable.

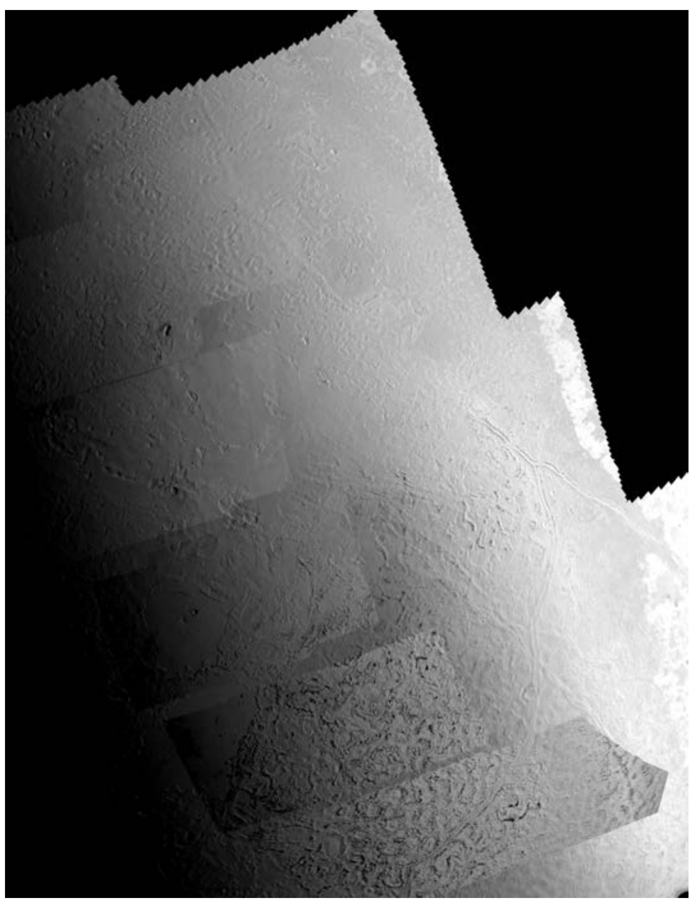

Figure 6: Space photograph of Triton reveals a young surface with few craters. Nitrogen ice covers much of the surface. Liquid water may well have escaped from the major cracks. Voyager 2 photo: PIA02235.jpg

Pluto and similar numerous large objects that are just being found beyond the orbit of Neptune may be active bodies with liquid water deep in the subsurface. These objects have not been visited by space probes. Available images do not resolve enough detail to look for either cracks or craters.

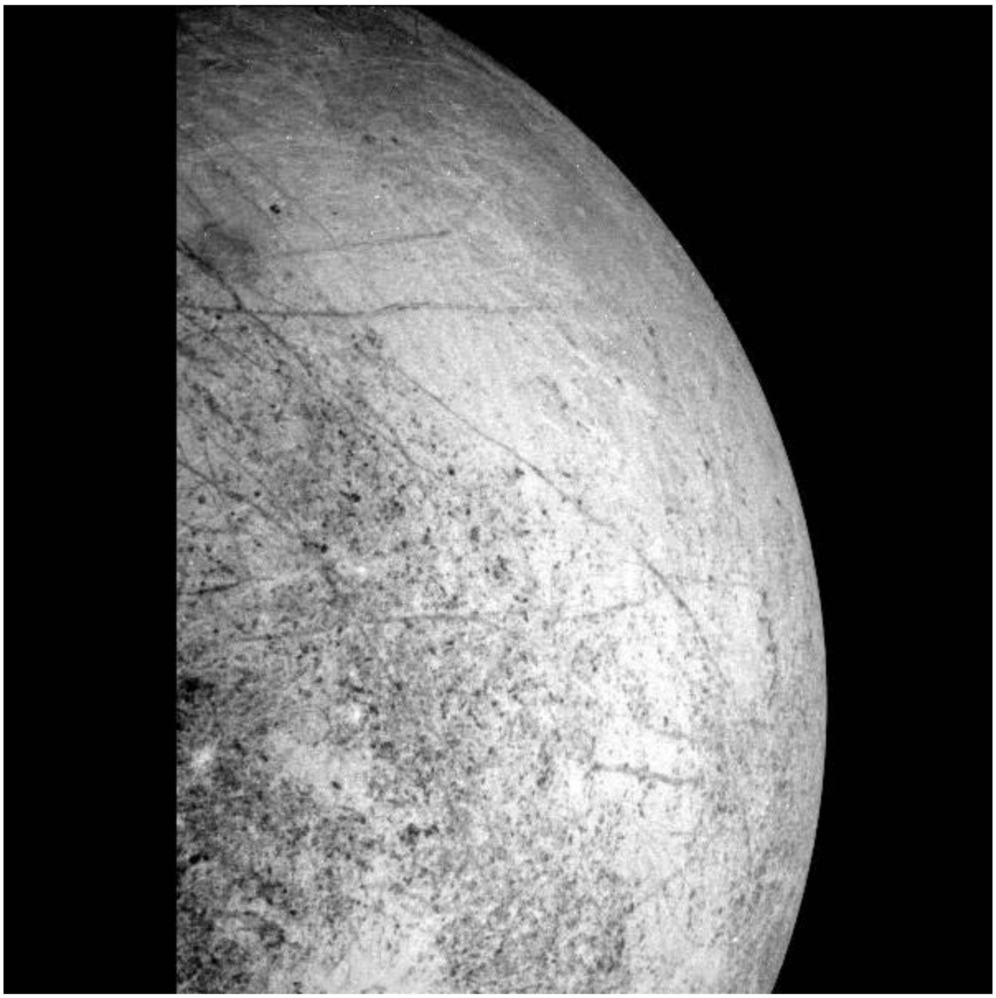

Figure 7: Photo from the Galileo spacecraft shows long linear features on the surface of Europa. The long dimension is 2000 kilometers. We have good images of the surface of this Moon but no samples other than from spectra of remote sensors. http://photojournal.jpl.nasa.gov/catalog/PIA00874

Returning to Europa, photos from the Galileo probe show a complex active surface resembling frozen pack ice (Figures 7 and 8). The lack of craters, as on the Earth, indicates the surface is youthful, resembling pack ice. It appears that water or slush erupts to the surface. Large blocks of ice have turned over like unstable icebergs. The ice layer may be about 10 km thick on average. The gravity of Europa is about 1/8 of the Earth's. The pressures at the bottom of the ocean are like those at 12- to 24-km depth of water on the Earth. The deepest Earth ocean is not quite 11-km deep. It teems with life. Pressure is not a serious restriction to life on the Earth. Europa is habitable by microbes if a biological energy source exists.

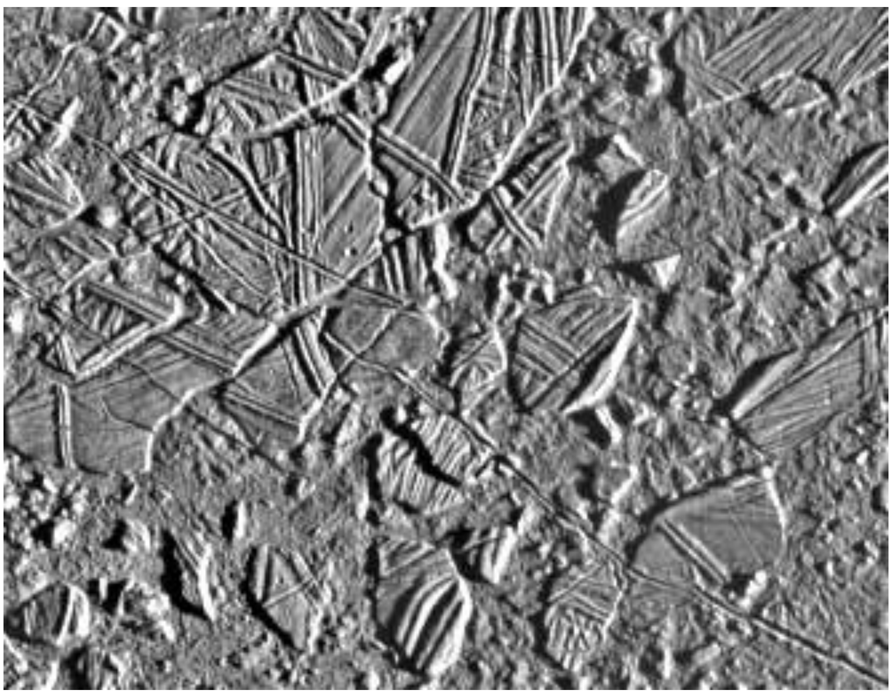

Figure 8: Photo from the Galileo spacecraft shows chaotic terrain on Europa, resembling repeatedly cracked pack ice. Liquid water may have reached the surface numerous times. The photo is 42 km across. http://photojournal.jpl.nasa.gov/catalog/PIA00591

Europa is too small for radioactive heat to drive tectonics. It would be more inactive than the Moon. However, tides heat the water and the interior of Europa. Io gets too much tidal heating and is a mass of partially molten rock. Ganymede gets too little and liquid water exists only at great depths. Europa gets the right amount. Enough to keep the Moon and the ice active, but not enough to drive off the ice and water. Tidal heating may drive rock volcanism and hydrothermal vents beneath the Europan ocean, just what nourished early life on the Earth.

Much of the interest in Europa arises because we have an independent place from the Earth for life to evolve. Exchange of life with the inner solar system is unlikely. Ice knocked off Europa vaporizes like a comet before it can hit within the inner solar system. Earth and Mars rocks can hit Europa, but the current rate is well below 1 rock per million years. When they do hit, they strike the icy surface with cosmic velocity. The hard shock is not good for microbes.

Physically rocks in solar orbit that come within the region of the large moons tend to get ejected from the solar system by the gravity of Jupiter. If they do not hit a moon on their first couple of passes they get no more tries. NASA engineers use the gravity of Jupiter to eject space probes from the solar system.

There is hope of both catching prebiotic chemistry that did not form life in the act and finding dead evidence of extant life on or near the surface. Atomic particles trapped in Jupiter's magnetic field sterilize any exposed frozen life. We will probably have to drill into the ocean or meters down into recently vented frozen water to get anything live.

Conversely, the surface ice returns to the interior. It could form a rich broth with the products of ice photolysis from ultraviolet light, changed particles, and cosmic rays. It would also supply meteoritic iron-nickel and silicate.

Titan: An airy moon. Christiaan Huygens discovered the large moon Titan orbiting Saturn in 1655. Its thick atmosphere is visible from the Earth. I remember the pre-space exploration question trivia question: “What planetary satellite has an atmosphere?”

The Voyager mission revealed that the atmosphere is nitrogen with a little methane, ethane, carbon monoxide, and hydrogen cyanide. The latter is very poisonous to us. It was used in gas chambers. However again, “toxic” is in the eye of the beholder. Hydrogen cyanide is one of the basic building blocks of life.

Titan’s surface is 95 K, far too cold for terrestrial life. There are methane-ethane lakes or seas on the surface. This environment does not occur on the Earth and would require a different chemistry than water-based life. We would not expect to find life on the Earth fit for conditions that have never occurred here.

There are certainly chemical disequilibria that might support methane-based life. Ultraviolet light from the Sun continually produces complex organic compounds in the upper atmosphere. Ammonia-water solution may exist within the icy shell and, as within Europa, the liquid ocean at depth may be inhabited. More relevant to feasible exploration, the surface of the moon is quite active geologically. Similar to the Earth, there are few impact craters. The water-ammonia solution erupts to the surface and then freezes. Disequilibria within the ice may feed methane-based microbes. The ice itself may be food. Where it freezes quickly, it forms an amorphous glass. Microbes potentially may get energy by turning the glass into crystals.

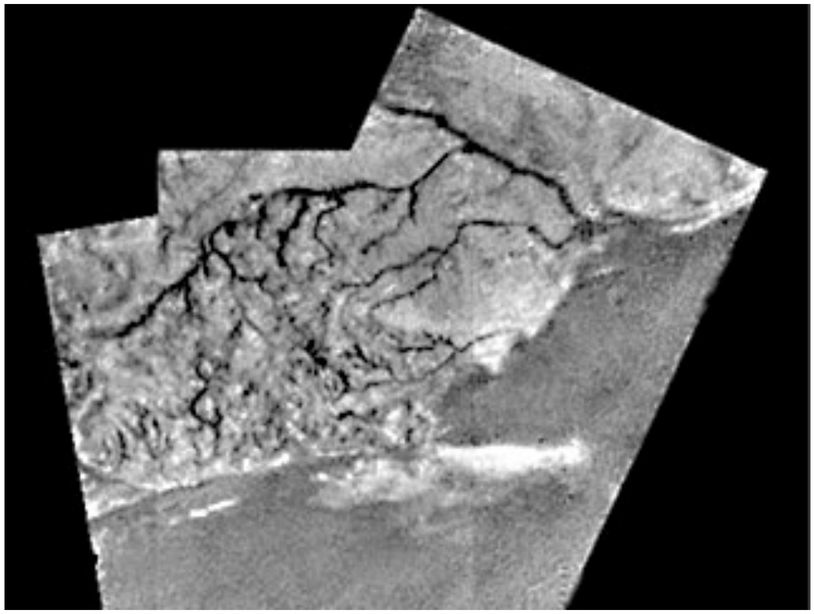

Figure 9: Photo from the Huygens probe of the surface to Titan. Liquid methane rives flow into a methane sea. The hills are probably composed of water ice with some ammonia. Scientists have processed the image so that it appears to be viewed directly from above. The imaged region is 5 km across at the bottom. http://photojournal.jpl.nasa.gov/catalog/PIA07236

The Huygens probe descended to the surface of Titan and provided our first look at this strange (to us) environment in 2005 (Figure 9). (ET from this environment would consider the Earth and its liquid water like we regard molten lava.) The probe analyzed the chemistry of the atmosphere and the landing site. The moon is geologically active (Figure 10). The cameras showed valleys cut into water-ammonia ice by methane rivers and possible coastlines of a methane sea. The lander came down in a delta. The surface analyses are of particularly biological interest. The science team is searching for any signs of pre-biotic chemical evolution.

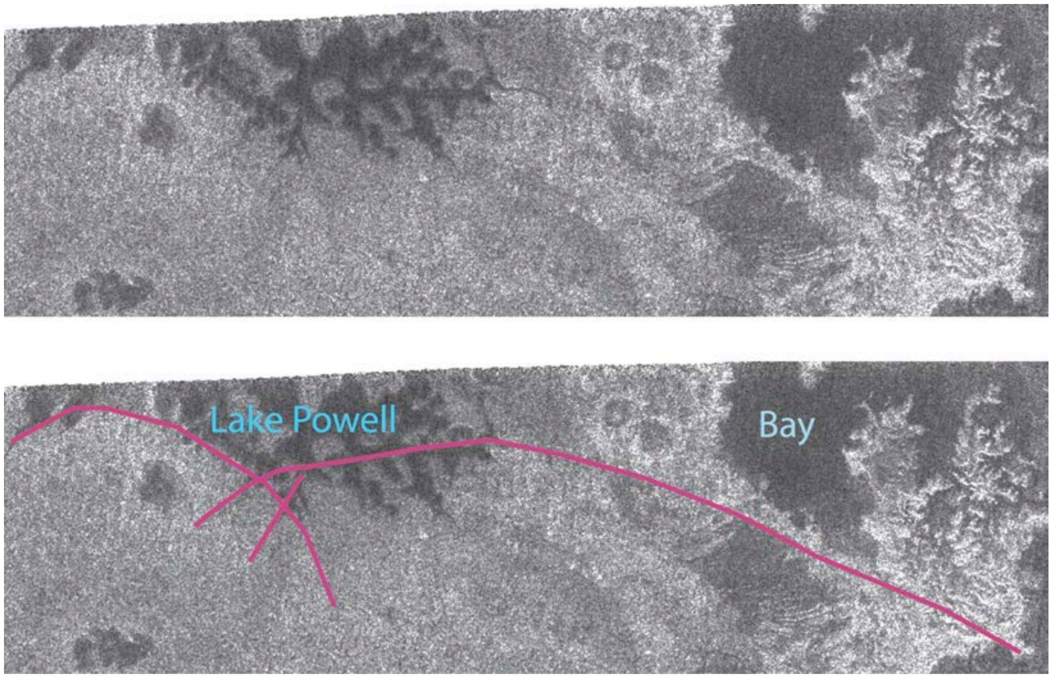

Figure 10: Cassini radar image of the Lake Powell area of Titan shows flooded river valleys on the lakeshore and the bay shore. As with a manmade reservoir like Lake Powell on the Colorado River a network of rivers eroded valleys. Subsequent rise in the level of the lake ad the bay flooded the downstream part of the network. Faults (red lines, below) in the underlying ice affect the valley network. As on the Earth, the broken material along a fault is more easily eroded. Uplift outside of the imaged area may have blocked the valley, just like uplift blocks drainages on the Earth. Image width 220 kilometers. PIA01943.jpg

Enceladus: The fallen giant. Enceladus of mythology was a giant who rebelled against the Greek Gods. He was chained down beneath Mount Etna in Sicily. The frequent eruptions of this volcano and its earthquakes are the giant's struggles to get free.

The Cassini mission showed that this name is dead on for this satellite of Saturn. This 500-km diameter object is quite active. Much of the surface is free of impact craters (Figure 10). Water vents hundreds of kilometers into space from a network of cracks. Liquid water is near enough to the surface in the south-polar region that it appears warmer than the rest of the Moon to detectors on the Casssini probe.

Tidal energy provides the heat to melt water ice in this moon. The interior of Enceladus would take hundreds of millions of years to freeze if the tidal heat source waned. Still the small size of the object raises the question has to whether it could retain both liquid water and biological energy sources over the age of the solar system. Liquid water may well react with rocks in the interior of the body. As with Europa, irradiated surface ice provides an energy source when it recycles into the interior.

The source of the energy to propel material hundreds of kilometers from the surface is not evident. Pure water at the freezing point is in equilibrium with water vapor with a pressure of only 0.6% of that of the Earth's atmosphere. This pressure is too low to propel much ice from the surface. Most likely water vapor vents into the vacuum of space and freezes as it expands. A dissolved gas would also suffice. Carbon dioxide dissolved in water as in a shaken soft-drink bottle expands rapidly when released into the vacuum of space. Methane and nitrogen N_2 are less soluble in water than CO_2, but more likely considering the chemistry of nearby Titan.

The active area in the southern hemisphere of Enceladus behaves somewhat like a mid-oceanic ridge of the Earth. Water freezes in dike-like bodies in the subsurface and small plates move away from the spreading centers. Heat from the frozen ice conducts to the surface. There is enough heat to warm the airless surface. Infrared light radiates the heat to space. It is readily detected by the space probe. The current rate of heat loss is much too large to be sustained over geological time by the available orbital energy. Rather the interior of Enceladus has had brief periods of activity where orbital energy from a significantlly elliptical orbit is consumed rendering the orbit circular. Its interior then freezes when the heat source is exhausted. Tidal forces then build up the ellipticity of the orbit to the point where tidal forces are able to restart heating. Life might not survive the long (100 of million years) periods of frozen quiescence.

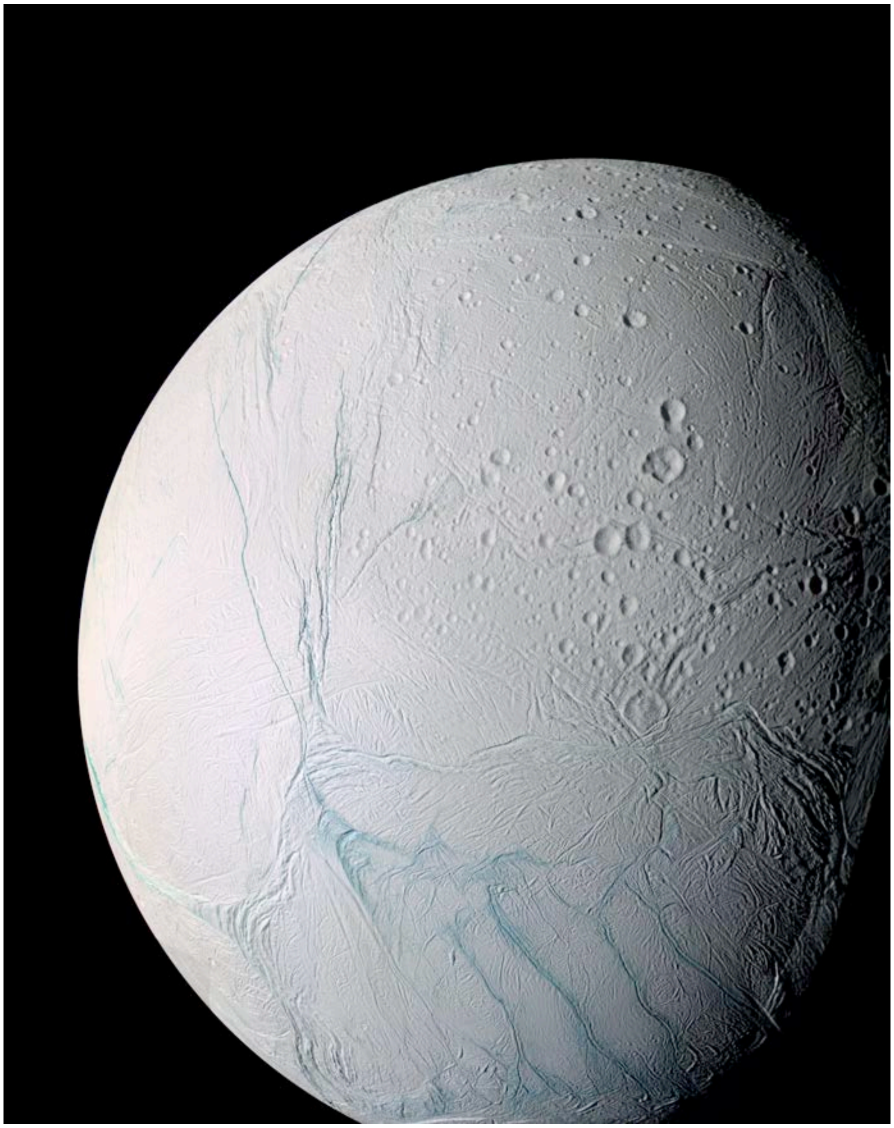

Figure 11: Photo of Enceladus. Note the upper left quadrant has craters while the rest of the moon is crater free. False blue color highlights cracks that actively vent water. The object is about 500-kilometer in diameter. (Enceladus_PIA06254_full.jpg)

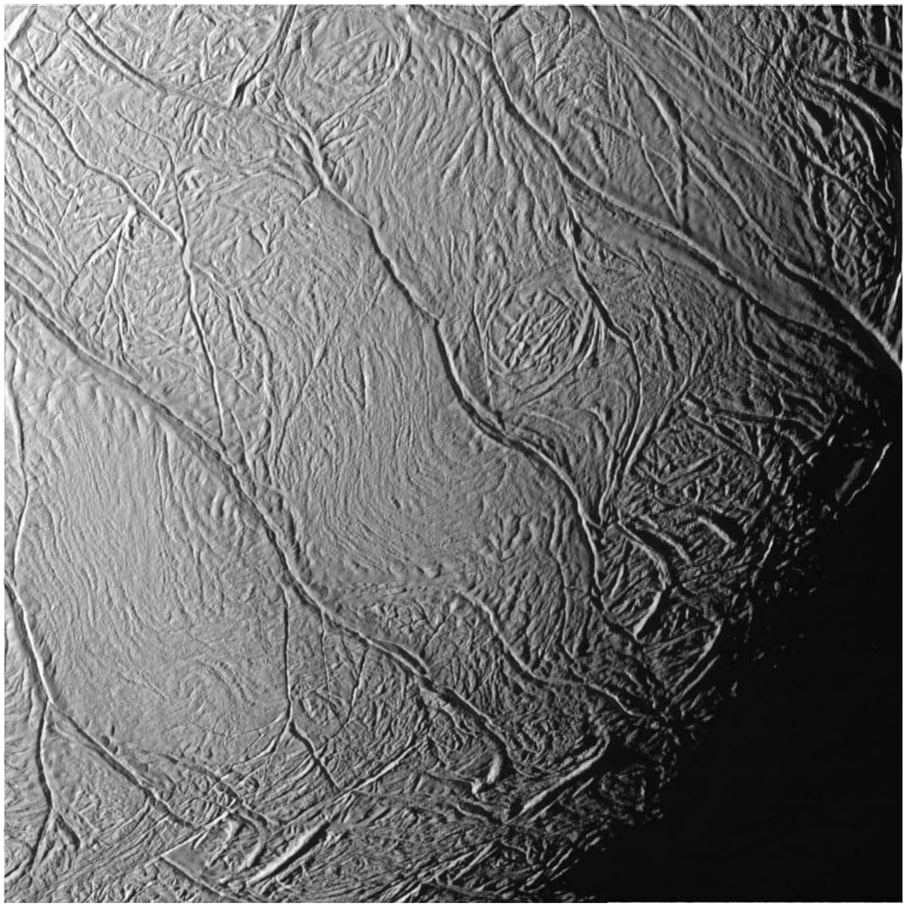

Figure 12: Detailed photo from the Cassini probe of the surface of Enceladus. Water vents from the labyrinth of cracks. Note the lack of craters. The field of view is about 127 km. PIA06247.jpg

Red dwarf planets

Red dwarf stars are the most common type, yet they are so dim that a person with average eyesight cannot see any with the naked eye. They have the attractive astrobiological feature that their luminosity changes very slowly over time. A planet once in the habitable zone stays in the habitable zone. No red dwarf has yet entered the red giant stage and the Sun will be long gone before any do.

The planets within the habitable zone of red dwarf stars experience intense tides. To see this physically, the energy of starlight to a planet scales inversely to the square of its distance and proportionally to luminosity (the fourth power of the star's mass). The tidal force scales inversely to the third power of the distance and linearly with star mass. (For those with calculus, tidal forces scale with the derivative of gravity away from the star. You need math to get this result.) With some algebra not given here, the tidal force at a point of constant starlight (representing the habitable zone) scales inversely with the fifth power of the star's mass. The energy dissipated that tidally heats the planet scales to the inverse of the tenth power of the mass. This yields the attractive astrobiological feature that habitable planets around red dwarfs are tidally heated. Like the satellites of Jupiter, their tectonics do not run down as their radioactivity wanes.

The less attractive astrological feature is that tides de-spin planets, so that one face may end up facing the star, like with the Moon around the Earth. Science fiction writers love civilizations living at the twilight edge. But what happens in reality? An earthlike atmosphere does not freeze out on the backside. Water does freeze, but cannot freeze all the way through to trap an ocean mass of water. Glaciers flow and geothermal heat keeps the bottom of the ocean liquid. There is no problem in habitability to microbes or even multicellular life.

The Kepler mission has imaged as vast number of planets around red dwarfs in transit. (A few are Earth size and in the habitable zone.) The ozone in an oxygen atmosphere is a nice biomarker. Free oxygen forms by photosynthesis on the Earth. Can photosynthesis occur on a red dwarf planet? The oxygen-producing photosynthesis on the Earth requires blue light, which is in short supply around red dwarfs. Solar flares produce intense pulses of ultraviolet light that continually hit red dwarf planets. Our plants would be in deep trouble if shipped there. However, shallow water provides shielding from UV light. Extant life on the Earth is able to gather the light from red dwarf stars with pigments other than chlorophyll. Evolution would tend to adapt photosynthetic organisms for the light actually present. It may well take advantage of sulfate-producing or ferric iron producing photosynthesis. In that case, we will have difficulty recognizing life from Earth.

The transit mode of detection is favorable to red dwarfs. The habitable zone is close to the star so that the geometrical probability of transit is much higher than with the Earth and Sun observed from a nearby star. The Kepler mission has shown that red dwarfs typically have planets.

Red-giant planets

The Earth will get incinerated when the Sun becomes a red giant. However, the Jovian satellites will become clement for around a hundred million years before they too become too hot. This will be enough time for life already present beneath the ice to evolve. It might even become photosynthetic. The Saturn satellites will become clement later and stay clement for a shorter period of time, like ten million years. Further out, the intense luminosity at the peak of the red giant stage will increase rapidly to a few thousand times the current luminosity of the Sun. The Sun, however, loses mass so that the planets move out. The Neptune satellite Triton will be only briefly clement and if it does become clement it will be quickly cooked. The view will be spectacular for an observer in a clement place. There will be plenty in the Kuiper belt beyond Neptune. There may even be undiscovered Earth-sized objects in this region. The Sun will be intense enough to flare the inner comets and probably Pluto. The ice of the Jovian satellites will evaporate but the gas will stay bound to Jupiter. It will form a red-hot disk bigger than the size of the present Sun.

Present technology is not much good for searching around red giants for habitable planets. Astronomers have not given the matter much thought. There are not a lot of nearby red giants. Stars do not linger long in that stage, so statistically this star class is rare. The Kepler mission was planned to eschew red giants. I return to red dwarfs and giants when I consider intelligent life.

Checklist for life hunts: An embarrassment of riches

If we find independently evolved life anywhere in our solar system, we will know life is common in the universe. The space program has given us numerous places to look following liquid water. As discussed in the last chapter, Mars is promising and close by. It had earthlike conditions early in its history. Any extant life has retreated to the subsurface. It may occasionally stick its head up when water erupts to the surface. There are plenty of rocks over 4 billion years old that may contain fossils.

Looking elsewhere, Ceres is a nice place to search for fossils and prebiotic chemistry. The clouds of Venus should remain on the list. Europa has a buried ocean. Titan provides a stable environment that might house non-water-based life. It has a deep hidden water ocean, but its surface is of interest. It presents a methane stage for biochemistry far different than water next to rock. We now have chemical analyses of its surface. We do not have any evidence for biological activity.

The outer of the solar system includes numerous promising objects. Here as in all of science, the perfect is the enemy of progress. One can argue for inaction, on the grounds that we may find a better place to look before a launched probe reaches its destination. The most recently discovered place, currently Enceladus, always looks the most exciting. This problem will become more serious if we find Earth-sized objects about nearby stars or even in the distant reaches of our solar system. The manned space program may well continue to wastefully consume resources at a rate that would shock a wolverine.

We need to select some destinations, plan, and go. Overall, the tendency of expanding freezing ice to expel water from pockets to the surface makes frozen water a common surface feature in the solar system. We will not need to dig or drill to find life from where the Sun does not shine. As with Mars exploration, logistics will greatly limit site selection. At our current stage of ignorance, this is not a great loss.

Notes

An Earth-size planet can develop a greenhouse where liquid water exists on the surface if it is well away from a star. Hydrogen remains gravitationally bound in the cold reaches of space. It is a good greenhouse gas at low temperatures. Methane is another. The greenhouse may also stabilize like Titan so that liquid methane is at the surface. The ecology would need to depend on internal chemical disequilibria like biota in deep rocks on the Earth and a pittance from ultraviolet light on distant stars.

The intensity of sunlight at the distance of Jupiter is 1/25 of that on the Earth. Photosynthesis occurs on the floors of terrestrial rain forests with this much light. Given that evolution tunes organisms for the conditions they face, photosynthesis is a reasonable life style where light reaches liquid surface water or surface liquid methane. For those with quantum mechanics, a photolytic reaction (like the photoelectric effect) occurs as long as any light with the necessary wavelength is present. Titan is the only known extraterrestrial solar system object where a suitable niche may exist.

Like deep drilling in the oceans before plate tectonics to get a complete geological record, scientists promoted exploration of the Jovian satellites on the grounds that they would have dead surfaces that recorded the full impact history of the solar system. Even an off-base theory is useful if it promotes testable observations.

The official name for Pluto and other large similar objects is now dwarf planet. This freed K-12 students from the highly unproductive activity of memorizing lots of names. I have used object as a collective to include both bodies in planetary orbit and in solar orbit. Geologists will still find it convenient to use planet for any object like the Earth's Moon that is big enough to have internal geological processes. Giant planets around other stars may well have earth-size moons. None have yet been discovered.