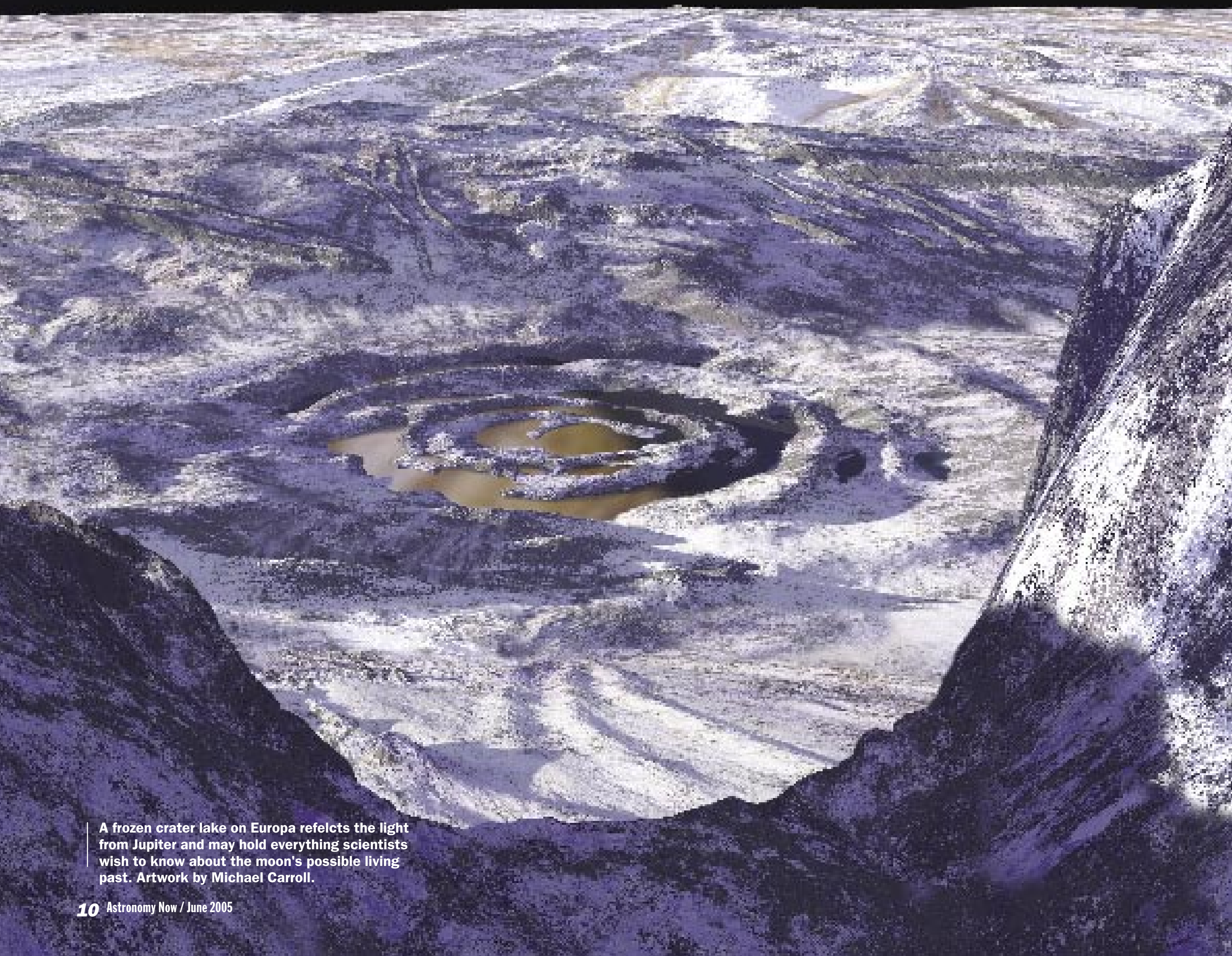
The Europan safari

Forget expensive mining equipment, massive missions and submarine robots to search for life on Europa. All you need is a lander and convenient impact crater, says **Donald F Robertson.**



A frozen crater lake on Europa refelcts the light from Jupiter and may hold everything scientists wish to know about the moon's possible living past. Artwork by Michael Carroll.

The fractured surface of Europa. Could these cracks extend down to the ocean underneath? Image courtesy: NASA-JPL.

The entire world is covered with ice floating on a deep salt-water ocean. Intense tides distort the world's shape, stretching and cracking the frozen shell. Undersea volcanoes or currents in the water may warm an area of ice enough to melt it, creating an occasional unfrozen sea crowded with drifting icebergs.

The world is Europa, the second of the four Galilean moons of Jupiter. If ever there were a likely place in the Solar System for familiar water- and carbon-based life, it would be here.

How do we look for life? Europa's shell of ice is at least hundreds of metres deep and probably tens of kilometres in some places. So digging to the ocean with robot submarines is a difficult, not to mention expensive, proposition. The high hopes that many had when such missions were proposed are gradually being eroded by the technology tests that show tunnelling to the ocean is anything but easy. In fact, some now believe it is virtually impossible with foreseeable technology.

Have we lost all hope of looking for life on Europa? No way. Recently, some scientists realized that reaching through the ice may not be required. Geological events may bring any evidence of life, in the form of traces of biochemistry or even fossils, onto or close to the surface where they might be sampled by automated landers. Conceivably, biological chemicals could even be sensed remotely from orbit. At last, the emerging science of 'astropalaeontology' may have something to work with.

Unique world

Why is this moon – about the same size as Earth's Moon and located at the inner edge of the cold outer Solar System – such an interesting place? The answer is the giant tides driven by Jupiter, combined with the subtle pulls of two of the other three large moons.

Over the lifetime of the Solar System, Europa has settled into a set of two-to-one orbital resonances with Io, closer to Jupiter, and with Ganymede, the next moon out. While Europa orbits Jupiter once, Io orbits twice. Every time Ganymede completes one orbit, Europa completes two. That is to say Io does four turns in the time it takes Ganymede to struggle once around Jupiter's massive girth.

Over the course of each orbit, each of these three Galilean moons is stretched and pulled slightly out of shape by the intricate pulls of gravity from Jupiter and the other two resonant satellites.

Tides generate heat, and the closer you are to Jupiter, the larger the tides and the hotter you get (see *Feeling the stretch*). Europa seems to inhabit a Goldilocks orbit: not too hot and not too cold.

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As a result, Europa's surface ice is very young – based on crater counts and other information, the oldest parts are believed to be less than sixty million years old, and most of it is younger still. Much of this surface is saturated with closely spaced pairs of ridges that may be cracks, with newer cracks covering and destroying the remains of older ones. Elsewhere, the surface ice is shattered into regions of 'chaos' where blocks of displaced ice, sometimes tilted, sometimes containing bits of the old crack-lined surface, look remarkably like broken pack ice on Earth's polar oceans. While the thickness of the ice remains a subject of intense controversy in the scientific community, a casual look at surface photos appears to give the clear impression of a thin shell of repeatedly broken pack ice floating on the ocean.

The Europan ocean is very different from any Earthly sea. The icy moons of the outer Solar System generally consist of an iron core surrounded by a mantle of rock and a thick outer shell of water ice. Close to massive Jupiter, Europa's outer layers stay liquid, creating a 'sea' ten times deeper than the deepest parts of Earth's oceans. It must be very dark and cold down there, though much of

Feeling the stretch

The tides and the resulting internal heat govern the interiors of Jupiter's four largest, so-called Galilean, moons. The closer to Jupiter, the more they feel the stretch.

Innermost Io is a desiccated volcanic hell of molten rock and sulphur. Next out, again distorted by tides, Europa's outer layer of ice is, to some unknown but probably large degree, melted into a relatively warm, salty ocean that may be 150 kilometres deep. If so, there is more water on Europa than on Earth.

The third moon, Ganymede, bigger than Mercury, has an older surface and is undoubtedly much colder inside. Still, areas on Ganymede have seen substantial geological activity. There is circumstantial evidence from the Galileo spacecraft's magnetometer for a conducting (i.e. salty) ocean, deep under the ice.

Callisto, the fourth Galilean satellite, dances to its own tune. Unlike the others, Callisto is not tugged by regular approaches to other satellites while in line with Jupiter. There is some evidence for a deep layer of salty water or slush on Callisto, too, but there is no evidence of recent geological action near the crater-saturated surface. Callisto appears largely frozen and near geologic death.

Europa (below left of the Great Red Spot) and Callisto are held in thrall of Jupiter's tides. Image courtesy: NASA-JPL.

Earth's ocean, too, is very cold.

Professor Jere H Lipps of the University of Berkeley and Doctor Edward B Bierhaus of Lockheed Martin Space Systems believe that occasional impacts may excavate the icy crust and expose material from Europa's ocean. "The main point," Bierhaus told *Astronomy Now*, "is that the large impact craters excavate close to or through to the ocean below, so rather than drilling through the full thickness of the ice shell to sample ocean material, one could sample underneath large craters."

Moreover, following an impact, a 'lens' of meltwater would form under the crater. Depending on the thermal properties and composition of the ice (e.g. how much salt there is present) this lens could remain liquid for thousands of years.

Impact excavation "is essentially immediate," said Lipps and Bierhaus, "leaving no time for existing life to escape" away from the crater. "The survival rate of some [terrestrial micro]organisms is small, but not zero, when exposed to the tremendous pressures associated with an impact." If a sufficiently young crater were found, and Europan organisms made it alive into the meltwater under the crater, it might be possible to sample living Europan organisms close to the surface.

JIMO jeopardy

Does life actually exist in Europa's global ocean? Our best chance of discovering the answer soon would have been the Jupiter Icy Moons Orbiter (JIMO), a massive nuclear-powered spacecraft intended to orbit each of the three icy Galilean satellites in turn. Even though the United States' National Research Council ranked Europa one of the highest priorities in planetary exploration, the Bush Administration did not include money for that mission in the 2006 budget. The official story is it has been delayed, but many space policy experts believe the expensive mission has effectively been cancelled in favour of preparing to return astronauts to Earth's Moon.

Looking further ahead, Bierhaus thinks that Europa's surface may be too rugged to easily operate a mobile rover. "Even in the highest resolution images from the Galileo spacecraft, with ten metres per pixel, Europa displays 'rough' terrain, with ridges, valleys, and lumpy topography down to the limit of resolution." Lipps added that it may also prove hard to design a rover that could function on ice.

Although we cannot determine the presence or absence of life with the evidence that we have now, Lipps and a large group of scientists said in a recent paper that Europa, and probably Ganymede, have all the requirements for carbon-based life. These include liquid water, an energy source, and access to biologically relevant molecules and elements. The latter are assumed to be imported by comets falling onto Europa and, presumably, smashing through the ice. While Ganymede's ocean may consist of a layer of water or slush between other layers of solid ice, Europa's should extend all the way down to the rocky mantle, providing any life with access to minerals and a place to anchor themselves. The tides could generate volcanic activity in the mantle, as they do on Io, creating sources of heat, fresh minerals, and seamounts (underwater volcanoes) with many different environments.

So long as there is some accessible liquid, life on Earth thrives in almost completely icy environments, as in Antarctica today. Lipps et al, argue that, on Earth, glaciations and mass extinctions in the fossil record are not well correlated with each other. Beyond local extinctions, "life survived and flourished" even when our world was covered by ice.

On Earth, life likes to live in the complex regions where two or more media come together, for example, the rich and diverse communities in terrestrial tidal pools where the ocean meets the land and atmosphere. In one theory, Richard Greenberg, of the Department of Planetary Sciences and Lunar and Planetary Exploration at the University of Arizona, contends that similar environments may exist on Europa.

Cracking up

Anything we would recognize as life is very unlikely on Europa's surface, but several lines of evidence suggest to Greenberg that the ice is relatively thin – a few kilometres or even a few hundred metres – and that Europa's cracks may extend all the way down to the ocean. If so, the cracks may be pulled a few metres apart by the tides each Europan day (about three-and-a half Earth days). As a long ribbon of liquid water, rapidly boiling in the vacuum,

A chaotic region on the surface of Europa. It is awfully hard not to think that the ice melted here and that for a few hours or days icebergs floated on an unusually deep sea watched only by the orange storms of Jupiter. Image courtesy: NASA-JPL.

is exposed between the deep walls of the crack, a thin skin of slushy ice would slowly form over the top and then quickly grow thicker. As Europa moves around in its orbit, and the tides pull the crack shut again, the skin of slush would crumple and be squeezed to the surface to pile up in mounds on either side of the crack. As this diurnal (daily) cycle is repeated over thousands of years, the slush may accumulate into the long double-ridges that are characteristic of Europa's surface.

Micrometeors and comets hitting the ice would import minerals and carbon compounds, and solar radiation may drive biologically interesting chemical reactions. Ice is a good insulator of radiation, so life might survive very close to the surface, although Lipps believes the available light under the ice on a world so far from the Sun would not be enough to drive photosynthesis. "Photosynthesis is not the only way organisms make their own living," Lipps says, "Chemosynthetic bacteria do it at hydrothermal vents – also a possibility on Europa – in anoxic muds, at volcanic vents, and elsewhere. A bacteria-like chemosynthesizing biota is a very likely possibility for Europa."

The blocks of tilted ice in chaotic terrain may expose the remains of such communities, according to Lipps. Greenberg points to halos of slightly darkened ice a few kilometres wide that surround many chaotic regions and the younger cracks. This darkening seems associated with a softening of the otherwise rugged landscape. He believes this may be evidence of warm water escaping to the surface, discolouring it with salts, and warming the surface ice. If so, the upwelling water may have contained organisms, freezing them as fossils on or near the surface.

However, this is controversial stuff. Many scientists profoundly disagree with Greenberg's interpretation of Europa's environment. They argue for a thick shell of ice more than twenty kilometres deep. Debating about whether the ice on top of a 150-kilometres-deep ocean (that's roughly ten times deeper than an ocean on Earth) is two or twenty kilometres thick may seem like arguing about how many angels can dance on a pin, but it does have serious implications. A shell of ice tens of kilometres thick must insulate the ocean from anything going on at Europa's surface, ruling out Greenberg's tidal communities.

Indeed, the fly in Greenberg's ointment may lie in the cratering record. Edward Bierhaus told *Astronomy Now* that most evidence for thick or thin ice is not strong because nobody really understands "how Europa's astonishing but entirely mysterious surface features formed." Both sides of the debate are "using unknown processes to determine an unknown parameter, i.e., the ice shell thickness." In contrast, craters are a natural probe of the sub-surface and scientists have some understanding of how crater appearance changes with size and excavation depth, and with the properties of the target.

Crater count

Dr Paul Schenk, of Houston's Lunar and Planetary Institute, studied changes in Europan crater morphology with crater size to conclude that the ocean starts nineteen to twenty-five kilometres below the surface. Bierhaus added, "The two largest craters on Europa are Callanish and Tyre – about thirty and forty-four kilometres in diameter – and they likely penetrated to the ocean." Since smaller craters clearly did not, this implies a thick shell. However, there is no reason to think the ice stays that thick all the time or is that thick everywhere on Europa. According to Bierhaus, "Europa is full of wonderful frustrations."

Donald F. Robertson is a freelance space industry journalist based in San Francisco