23. Extraterrestrial ice

John Moore

"Now he could see, glistening like silver bubbles in the earthlight, a group of pressure domes - the temporary shelters housing the workers on the site. Near these was a radio tower, a drilling rig, a group of parked vehicles, and a large pile of broken rock, presumably from the material that had been excavated to reveal the monolith. This tiny camp in the wilderness looked very lonely, very vulnerable to the forces of nature ranged silently around it. There was no sign of life, and no visible hint as to why men had come here, so far from home."
Arthur C. Clark, 2001: A Space Odyssey.

The quotation above, like much of Arthur C. Clark's work, is likely to be precocious and realistic. Though we have not yet operated on such scales on planets other than our own, there are parts of this planet where similar scenes to the one described are played out daily. Of course it is in the polar regions that man is most often made feel far from home, in an environment not made for life. The nature of field work on the polar ice sheets is unique in many ways, and has long been recognized as the closest one can come on Earth to simulating conditions expected on a long space exploration trip, to Mars for example. Temperatures in central Antarctica can dip to -90°C, making it the coldest as well as the highest, driest and most remote continent on earth. Even so around the edge of the continent life abounds, and in the summer if melting occurs on the inland ice, life quickly occupies the niche. Beneath the deepest parts of the Antarctic ice sheet lakes have been found which will soon be reached by ice drills that are already at depths greater than 3.5 km. Life may be found in these ancient lakes that have been covered by ice for many millions of years.

It is likely that the first destinations of man in the long term exploration and colonization of the solar system will be the polar regions of first the Moon and then Mars. This is for the simple reason that only in these areas is the primary requisite for life—water (in the form of ice)—be found.

Earth Glaciology

Before I consider ice (and water) on other worlds I should tell a little about what glaciologists such as myself find so interesting about this material that many people who live or work in the Arctic region find an inconvenience to avoid whenever possible. Ice and snow dominate the polar landscape now and, and have done so for the past several million years. We are living in a glacial epoch, the present extent of the ice sheets represents only about 1/3 of their typical extent, as we are in a rather rare warm period. To glaciologists and scientists concerned with reconstructing the earth's past climate, ice represents a great library of detailed information on the paleoclimate. Suitable ice for interpreting the past climate is found where the ice flow is very slow and not complicated by the presence of mountainous topography. The best place for such conditions in the Northern Hemisphere is at the summit of the Greenland ice cap, in the south the best places are from the interior of Antarctica. Here the ice is over 3 km thick. An ice core drilled in such places penetrates successive years of snowfall as it goes deeper. If the bedrock is flat and the ice flow rate slow the annual layers are undisturbed until very near the bottom. The layers are simply thinned by the pressure of the ice above, so that while at the surface a year's snowfall may be 0.5 m thick, half way down they are 10 cm thick, and close to the bedrock only few millimeters. I was involved in the recovery of an ice core to bedrock in central Greenland that penetrated the whole of the last climate cycle, that is the last 10,000 years when the climate was rather similar to now, and the previous 90,000 years that spanned the last glacial age when temperatures were 15°C colder in Greenland than today.

More recently I have been involved with an ice core from Svalbard, the ice is warmer than Greenland, less thick and more subject to summer melting. All these factors lead to shorter records of climate, but the proximity of Svalbard to Europe and the northern extremity of the Gulf Stream should mean that the data we extract over the coming years will be considerable relevance to the climate debate.

During my work on Greenland and Antarctic ice cores, I developed a technique for studying the chemical composition of ice by measuring its electrical resistance at a range of frequencies. This method led to a more general understanding of the nature of electrical conduction in ice, and as an extension of this I began using radar to map internal structures in ice. Most recently I have been using a commercial radar to study the hydrology of glaciers in Svalbard. It was this combination of expertise that led to my invitation to take part in the team that is doing the initial design work for a radar that will probe the surface of ice from space.

Ice on Other Worlds

The inner solar system is very unlikely to provide a habitat for life of any kind, since water seems to be completely absent, either now or in the past. From very early in the development of the telescope, Mars has been the subject of intense observation and speculation. The 1970s Viking mission finally destroyed hopes for any large scale or advanced life on the planet, but it certainly showed that there was ample water on the surface at some period in the past. There were many dried up river valleys and features that could be interpreted as mud flows that all spoke of a wet and perhaps fertile past. Now we know that the most likely spots to look for water on Mars are the two polar caps, which have been seen waxing and waning with the seasons for many years, and there are plans underway to send a lander that will put instruments into the ice to unlock the secrets Mars past.

The Earth is the only planet known to have oceans. No one expects that oceans will be found on Mars, only Earth is in the zone of stable liquid water— too close to the Sun and it all vaporizes, too far away and it is frozen. It was therefore a surprise that the best candidate for an ocean on another planet has turned out to be on moon orbiting around Jupiter, where the surface temperature is between -170°C at the equator and -220°C at the poles.

Europa

Ganymede, Callisto, Io and Europa are the four largest moons of Jupiter. Indeed if it were not for the brightness of Jupiter itself, they would be just visible to the naked eye. Probably the most significant contribution that Galileo Galilei made to science was the discovery of the four satellites around Jupiter that are now named in his honour. Galileo first observed the moons of Jupiter on January 7, 1610, through a home-made telescope. After months of observations Galileo determined that what he was seeing were not stars, but planetary bodies that were in orbit around Jupiter. This discovery provided evidence in support of the Copernican system and showed that everything did not revolve around the Earth. For this revealing insight into the nature of the universe Galileo was imprisoned by the Catholic church, which incidentally begrudgingly accepted that Galileo was right more than 300 years after his death.

Europa is the smallest of the four Galilean moons, but it is still the 6th largest satellite in the solar system. With a diameter of 3,138 km, Europa is slightly smaller than our own Moon, with a similar surface gravity, about 13% of Earth's. Europa is the smoothest object in the solar system. The satellite has a mostly flat surface, with nothing exceeding 1 km in height. The surface of Europa is also very bright, about five times brighter than our Moon. Of the four Galilean moons, Europa was the most poorly observed by the Voyager spacecraft nearly two decades ago. It is now of proving of great interest both to scientists and the general public because of NASA's Galileo spacecraft which has recently sent back to Earth amazingly detailed images of the surface of Europa. Many scientists believe the pictures reveal a relatively young surface of ice, possibly only about 1 km thick in places.

Internal heating on Europa could melt the underside of the ice-pack, forming an ocean of liquid water underneath the surface. Galileo had three close flybys of Europa during its primary mission. Galileo is now in a extended mission called the Galileo Europa Mission, which focuses on an intensive study of Europa.

That Galileo has produced so much useful data is a triumph of ingenuity, early on in the mission, the main umbrella-like antenna on the spacecraft could not be fully opened. This has meant that all the data must be transmitted to Earth using a small antenna that can transmit only at a very slow rate. When images are taken of Europa they are stored on tape and then compressed using software developed on Earth and relayed to the spacecraft in flight. The compressed images, which are between 1/2 to 1/80th the size of the original, are then sent painfully slowly to Earth while the spacecraft is cruising between its close encounters. The power transmitted by Galileo is about 20 watts, about the same as used by a refrigerator lightbulb. By the time it reaches the Deep Space Network antennas on Earth, a 70 Meter antenna is able to scoop up only about one part in 10 to the 20th watt, in other words .00000000000000000001 watt.

As part of NASA's Outer Planets/Solar Probe Project, I have been involved in preliminary development of a mission to send a spacecraft to Europa to measure the thickness of the surface ice and to detect an underlying liquid ocean if it exists. Using an instrument called a radar sounder to bounce radio waves through the ice, the Europa Orbiter craft would be able to detect an ice-water interface, perhaps as little as 1 km below the surface. Other instruments would reveal details of the surface and interior processes. This mission would be a precursor mission to sending "hydrobots" or remote controlled submarines that could melt through the ice and explore the undersea realm.

It is fascinating to be involved in trying to design a radar antenna to penetrate a surface that no one has come close to, and in fact, of which we very little. The photographs from Galileo are remarkable, but the highest resolution image shows features down to 6 m in size. But this is still only the resolution a person would have looking out of the window of jet plane. Its obviously hard to see the real nature of the surface. The optical data is supported by some Earth based radar measurements. The radar beam from Earth spreads so wide by the time it hits Europa that only average for the whole disk facing earth are obtained, from this we know the surface is water ice and that the ice looks "clear" at longer wavelengths (about 70 cm) allowing deep penetration in the ice, and that penetration is bad at shorter wavelengths. The gross internal structure of Europa has been inferred from gravitational and magnetic field measurements by Galileo. Europa has a metallic (iron, nickel) core surrounded by a rock shell, this is surrounded by shells of water in ice or liquid form. There must be about a 100 km thick water or ice shell on Europa. This is all the data we have. Of course we cannot build a radar that will actually be the best possible for Europa, because we simply will not know until the radar sounder is used what information we need to design the best radar. All we can do is make educated guesses about what kind of ice might be there, and then design in as much flexibility as possible so that whatever is really there, has a chance of being studied.

To judge from the extremely few impact craters on Europa, the surface must be geologically young—the best age estimates are between "recent" and 100 million years, with a best guess of 10 million years. This is not exactly young when compared with any ice sheets we know of on earth, especially those that float on water. The cratering that does exist on the surface is rather different from that seen on bodies such as the Moon. The craters can best be modeled by a thin, weak crust overlying a soft interior, which implies thin ice cover over water. The tidal stresses in the body of Europa caused by the pulls of Jupiter and the other large Galilean moons, adds a significant amount of heat to the planet, which supplemented by decay of radioactive elements present in the body of the planet could keep an ocean liquid and the surface in motion. The surface of Europa, seen at any scale, seems to be dominated by long thin lines or cracks (similar to the imagined canals on Mars, these however do exist!). Current ideas on the evolution of the crust suggest that the long ridges may be the equivalent of the mid-ocean ridges seen on Earth, where volcanic eruptions produce lava flows forming new ocean floor. Other regions on Europa look very much like the break-up of large ice floes, such as occurs in the spring thaw of sea ice. The ice floes are tens of km in size, and when put together like a jig saw, pieces seem to missing. Perhaps the missing pieces have been smashed to pieces, or recycled beneath the crust. These "chaos " regions may be where the old ice crust is destroyed, possibly as a result of warm plumes of water heated by volcanic activity deep in the planet's interior. We know that on Earth life exists near the mid-ocean ridges that is completely isolated from the Sun's energy, relying instead on volcanic heat as their fundamental source of energy.

Naturally with the cost of spacecraft being high, we are spending a lot of time and effort at the crucial planning stage forming a team of the world's best experts on the problem—but time is limited, we must complete our instrument definition by October 1998. There is a great deal of openness in the procedure, most of the documents relating to the process of designing the mission can be found on the internet, the speed of development is so rapid that very little is published in the conventional way. Our team has regular email exchanges, teleconferences and some meetings in the US. Since the radar will be an integral part of the spacecraft, it was recommended to NASA by an independent group of scientists, that the radar be developed as a cooperative instrument rather than bid for in a competitive way, as is normal practice for instruments. This has led to some interesting dynamics in meetings, with various representatives of organizations that could build the instrument advocating their team's particular design merits. But after this, the excitement of the project grips everyone and pretty soon people are just tossing around ideas without any fears of giving the opposition an advantage.

The problem really does grasp the imagination of these apparently hard-boiled engineers as well as scientific types like me. And the engineering side of things is certainly a challenge. The radiation environment in the vicinity of Jupiter is extremely unpleasant, the radiation dose rate is about 100,000 times greater than that permitted by health regulations on Earth. The spacecraft itself also suffers in these conditions, the computers must be shielded in weighty (and therefore expensive to fly) "vaults", plastic and metal can become brittle, and exposed instruments degrade rapidly. The spacecraft itself will be built on the "faster, cheaper, better" philosophy espoused by NASA. This means that that time for planning and building the spacecraft is limited, and it will fly directly to Jupiter, costing more in fuel than more efficient but slower approaches making use of gravity assists from other planets. The weight of the spacecraft is about 3/4 ton, but the whole science payload is 20 kg, the rest is essentially fuel for the trip. The radar, including antennas which will be several metres in length, must weigh less than 10 kg.

Last time I used radar in Svalbard, I collected a gigabyte of data in one month. The transmission rate for data to Earth is limited to about 1000 bits / second, this means that there is no way to send anything like the full radar data collected back to Earth. The data will be compressed using the fastest computers to be used on spacecraft (which are about as powerful as the average desktop machine today), and the satellite will have to spend four orbits of Europa just sending data back to Earth for each orbit it collects data. Add to this the environmental factors such as -200°C temperatures and limited power from a radioisotope source giving only 20 watts for science payload use, and you have some pretty stringent requirements.

Conclusion

Glaciology, the science of snow and ice, is naturally a circumpolar activity. However evidence gained in the polar regions has been seen as important to understanding the whole Earth system, especially its climate. This evidence is the best we have that man's activities are changing the Earth's atmosphere in an important and unprecedented way. Coincidentally it appears that exciting science relating to the origins of life on our own planet and possibly others is fundamentally linked with glaciology. The requirement for life to exist in close proximity to liquid water, and the lack of any surface oceans on other planets means that we must first understand the ice that either shields the oceans of Europa, or contains the story of Martian seas.

Further Information

Much of the data on Europa in this paper comes from the web site devoted to the exploration of Europa:

http://www.jpl.nasa.gov/galileo/europa/

Details of the planned mission to Europa can be found on:

http://www.jpl.nasa.gov/ice_fire//europao.htm