Scientist's Notebook

A look at space science research under way

George C. Marshall Space Flight Center, Huntsville, Alabama 35812

Clues to possible life on Europa may lie buried in Antarctic ice

More than a century ago, science fiction pioneer Jules Verne wrote about people swept "Off on a Comet" and into space where they lived more or less happily ever after.-

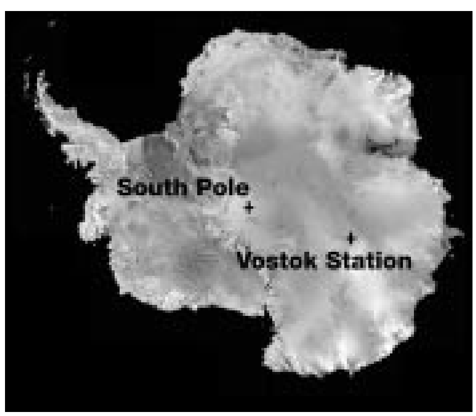
Verne's 1877 book (also published as "Hector Servadac") was a bit fanciful, but it may have had an element of truth: life may have hitchhiked across the solar system. The proof may be found at the ends of the Earth. In March 1998, American and Russian scientists found microbes in deep ice from the Antarctic as they sought clues that fungi, bacteria, and even diatoms could survive conditions in icy solar system bodies. This makes the South Pole one of the first destinations for the growing field of astrobiology.

Frequent fliers?

"It is likely that ancient impacts of asteroids on the Earth could have ejected soil, rocks, sediments, sea water, glacial and polar ice containing dead and live cells of microorganisms into space, and that they may have made it to other places in the solar system," explained Richard Hoover at NASA's Marshall Space Flight Center. Hoover is an X-ray astronomer who is also is internationally known for his work on diatoms, single-cell golden-brown algae that build intricate and beautiful shells of opaline silica.

Diatoms make up the major plant component in the plankton of our planet's oceans and are sometimes called the "grasses of the sea." Hoover has concluded that since live microbial cells have been found in deep ice and crustal rocks to 3.5 km beneath the Earth's surface it is conceivable that ancient impacts of comets or asteroids on Earth could possibly have ejected viable microbes into space. He also knows that viable cells can remain alive for long periods of time when freeze-dried at very low temperatures. For example, cultures of microorganisms and even mammal cells are routinely deep-frozen in a vacuum at liquid nitrogen temperatures, which simulates some aspects of deep space.

Richard Hoover of NASA's Marshall Space Flight Center (left) and S.S. Abyzov of the Russian Institute of Microbiology (right) examine microbes found in ice extracted from deep cores at Russia's Vostok Station in Antarctica (below).



Using the Environmental Scanning Electron Microscope (ESEM) at Marshall, Hoover, in collaboration with Dr. Sabit Abyzov of the Institute of Microbiology of the Russian Academy of Science, has been investigating deep ice microorganisms from Vostok Station, Antarctica.

"We have found some really bizarre microbes— things that we've never seen before," Hoover said. He and Abyzov gave some of the objects fanciful nicknames — like Mickey Mouse and Klingon — based on passing resemblances. Hoover expects that most will fall into known categories of microorganisms as he and Abyzov study the images.

"We're exploring a new world," Hoover said. "Until we get a lot more experience, we're going to see brand new things all the time."

The current debate over whether the Antarctic Allan Hills meteorites (ALH84001) brought life from Mars (or were contaminated by life on Earth) highlights the need for more thorough study of chemical and physical biomarkers, including the shapes of living and fossil microorganisms. In the past, contamination has been considered as possible only after an object lands on Earth. However, Hoover thinks that contamination with living and dead biological material could occur in space. Hoover said that evidence for this hypothesis abounds, including meteorites on Earth from Mars; the presence of gigantic impact craters on Mars, Earth and the Moon; Shoemaker-Levy's colossal impacts on Jupiter; and the survival of *Streptococcus* bacteria on the *Surveyor 3* moon lander.

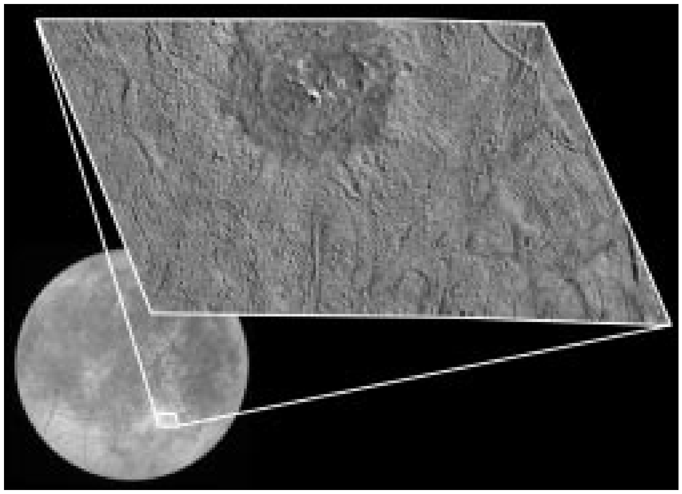
The field of astrobiology expanded in March when NASA released images and data showing that Europa, one of Jupiter's moons, has slush and perhaps liquid water near the surface. That raises the intriguing possibility that Europa may harbor life.

Deep ice samples

Discoveries on the Earth over the last few years show that life thrives or can be preserved in a range of "hostile" conditions, from volcanic vents deep in ocean trenches, to ice more than 400,000 years old, to Siberian permafrost more than 5 million years old.

Hoover and Abyzov examined ancient ice drilled at Russia's Vostok (East) Station about 1,000 km (1,600 mi) from the South Pole. Eventually, they hope to examine water taken from inside a lake — liquid, not ice — discovered under Vostok Station in 1996.

Hoover and Abyzov's work is a collaborative effort between NASA/Marshall and the Institute of Microbiology of the Russian Academy of Sciences working in collaboration with the St. Petersburg Mining Institute and the Institute of Arctic and Antarctic Research in St. Petersburg, Russia.



Images from the Galileo spacecraft orbiting Jupiter have revealed large rafts of ice covering the surface of Europa, one of Jupiter's four large moons. Wrinkles and breaks in the ice indicate that slush or liquid water exist below the frozen surface.

The first samples examined came from 386 meters (1,266 ft) down; the deepest in this set is from 2,287 meters (7,501 ft). Samples from as deep as 3,610 meters (11,840 ft) are on their way from Vostok to the Institute of Microbiology. Abyzov says that portions will be brought to Marshall later in 1998.

Russian scientists have been drilling at Vostok since 1974. Seismic and other tools revealed the lake's presence in 1996. Lake Vostok is overlaid by about 3,710 meters (12,169 ft) of ice and may be 500,000 to 1 million years old. Since the discovery, drilling has gone slowly while procedures are worked out to keep it pristine. No one has seen or sampled the lake — the deepest ice sample is from 100 meters (328 feet) above the liquid surface — nor is anyone sure why it is liquid, hence the scientific curiosity.

While Lake Vostok holds clues about life on Earth, it also is a good model for conditions on Europa. The lake is about 48 by 224 km (30 by 140 mi) in size — about the size of Lake Ontario — and 484 meters (1,600 ft) deep. Recent data indicate that it has about 50 meters (165 ft) of sediment at the bottom.

"Recent research [shows] that extremely severe conditions of cosmic environments do not exclude the possibility that microorganisms may exist in anabiotic states at high altitudes in interplanetary space," Abyzov wrote in a recent paper. Anabiotic means alive but inactive, like suspended animation. The only way to resolve the question is to use the Antarctic as a model for conditions in comets, the Martian ice caps, and icy moons orbiting Jupiter and Saturn.

Unusual spectra

At Vostok station in 1975, Abyzov discovered — and in some cases revived — bacteria, fungi, diatoms, and other microorganisms from ice that conventional wisdom had said was sterile. In the upper layers, most of the organisms were blown to Antarctica by winds from lower latitudes (*i.e.*, closer to the equator). The numbers of the organisms at different depths, and thus different ages of the ice, vary with major climate changes on the Earth. Some of the microorganisms from the deepest ice may represent life forms that were once living on the underneath surface of the ice sheet and that then have been frozen in the ice when the ice-water interface may have shifted due to changes in the temperature or salinity of Lake Vostok. So the very deep ice forms may provide early clues as to the types of microbial life that might be found once the lake is reached

"These are very important questions for future cosmic research on places like Europa, comets, the Martian ice caps," Abyzov said of the mysteries in the Antarctic ice.

Abyzov brought his samples to Marshall to use the Environmental Scanning Electron Microscope (ESEM), a relatively new tool that Marshall uses to analyze how materials fail and break.

"This is very useful," Abyzov said, "because we do not have this equipment in our laboratory. We have scanning electron microscopes, but without the additional equipment you have."

The ESEM was designed to analyze biological specimens in their natural environment, without coating them in reflective gold. And that's ideal for observing whatever is in the ice. It also uses an X-ray scan to analyze the elements in a target, an important step in determining whether an object is organic.

"There are some dust particles with unusual spectra," Hoover said, "which may be cosmic dust particles." The ESEM allows the operator to designate a point on a specimen and then scan with X-rays to determine what elements are present. The ratios found in some of the dust particles do not match ratios expected in terrestrial dust grains.

Seeing new details

The colony of spherical microbes nicknamed "Mickey Mouse" appears to be out of the ordinary. They resemble cotton balls covered with extremely small filaments.

"Here's the shocker," said Hoover, pointing at the ESEM monitor, "these small coccoid bodies are covered with all this incredible fibrous structure." The filaments appear to be about 30 to 40 nanometers wide (that's about 1/10th a wavelength of visible light).

"It's difficult for me to say what it is," Abyzov said, "but I tend to agree that this is biological."

"There are all sorts of microorganisms in the ice. Some are readily recognizable as cyanobacteria (once called blue-green algae), bacteria, fungi, spores, pollen grains, and diatoms, but some are not recognizable as anything we've ever seen before," Hoover said. Many will turn out to be known. It's just that they look different under the ESEM, which provides details that are not available through other microscopes.

Familiar items include bits of sponge and feather, and diatoms, Hoover's other area of personal interest and expertise.

They have also found a number of large cyanobacteria with nanobacteria attached.

Suspended animation

"When microorganisms freeze, they shut down the metabolism and go into this anabiotic state. Apparently they can remain in this type of living, but inactive, state for vast periods of time," Hoover explained. Russian scientists have been able to revive and culture bacteria, yeast, fungi, and other microbes found in ice cores.

Tracing out an image with electrons

Light microscopes are limited in how much small detail they can see because as the magnification goes up, the sharpness and brightness of the picture go down.

A scanning electron microscope uses a different principle. Like a rapid-fire BB gun, it scans electrons across the target which reflect them onto a fluorescent screen where the image is captured by a camera and enlarged. Electrons are much smaller than atoms, so a scanning electron microscope paints a razor-sharp image of the target. This is useful for mapping details of objects that light microscopes cannot see. The downside is that the picture has no true colors, just black and white.

The Environmental Scanning Electron Microscope (ESEM) in MSFC's Materials and Processes Laboratory is the latest advance in electron microscopy by sidestepping the need to contain the sample in a "hard" vacuum.

Most scanning electron microscopes require a hard vacuum in the sample chamber for two reasons.

First, the electron beam, used to image the sample, will be scattered by any gas molecules in the chamber. This is analogous to shining a bright light in the fog. The denser the fog, the more the light is scattered and the less you can see in front of you. Second, the electron signals produced by the sample due to the electron beam must be seen by an electron detector. This detector is analogous to your eyes. As you drive in fog, your headlights must not only penetrate the fog but the reflected light from another car coming at you must be bright enough for your eyes to see.

To eliminate the problem of electron scattering in low vacuum, the ESEM uses two new technologies.

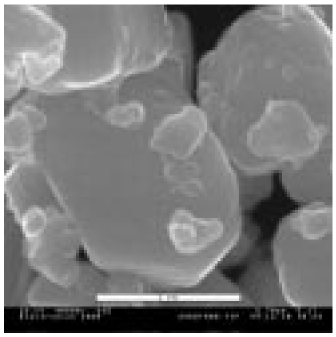
The first technology is a differential vacuum pumping system. This means the electron gun and column where the electron beam is created and focused are at high or "hard" vacuum. The ESEM has two small pumping chambers between the low vacuum sample chamber and the high vacuum electron optic column. The electron beam is thus only scattered by gas molecules over a very short distance.

The other technology is a patented environmental electron detector. The sample chamber is backfilled with a small amount of water vapor and operates at a pressure of 1 to 10 torr, as opposed to 0.0001 torr, the maximum that normal scanning electron microscopes can tolerate. The water vapor is ionized by the electron signal generated on the sample. The ionized gas is then detected by the environmental detector.

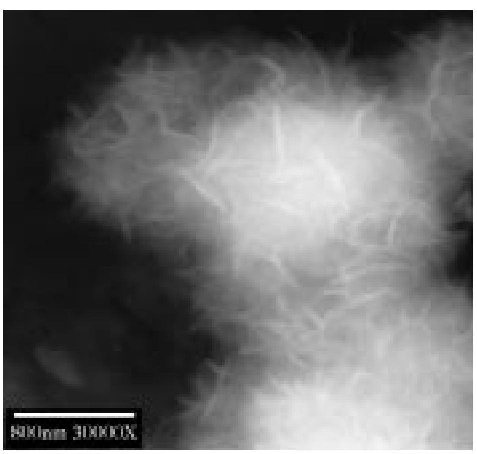
This system has two major advantages over normal scanning electron microscopes. The water vapor acts as the electron ground path away from the sample. Thus you can look at non-conductive samples such as rocks or biological tissue samples without the need for adding a conductive coating (samples usually are coated by a whiff of gold vapor to provide this coating). And, the electron signal produces more than one ion per electron, so the signal is amplified without extra electronics which can add noise to the image.

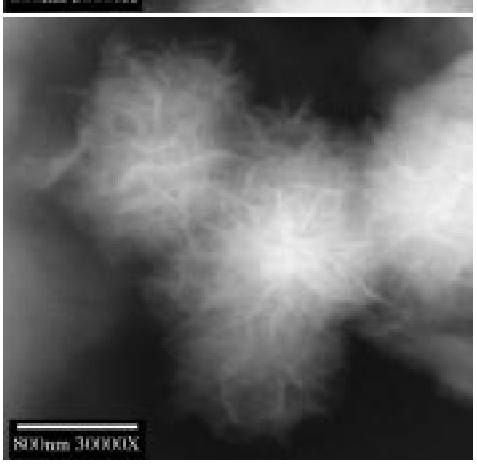
The ESEM can magnify the view as much as 100,000 times. The electrons colliding with the target generate X-rays which an energy dispersive spectrometer spreads much like a grating spreads light into a rainbow. This identifies chemicals as light as boron, just one notch below carbon on the periodic table.

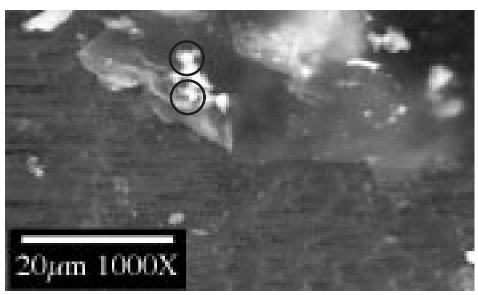
The ESEM was originally designed for looking at biological organisms, even in water. With it, Hoover and Abyzov can examine living microorganisms in their natural hydrated state for comparison to the ongoing findings.




The ESEM can make boulders out of dust — like the laser printer toner at left — or the ordinary seem quite alien — like a household beetle that looks like an extra from the movie Independence Day.







Several of the forms found in the Vostok ice core are clearly recognizable as bacteria, spore forming bacteria, cyanobacteria, diatoms, actinomycetes and mycelial fungi, although detailed analysis is required before it will be possible to classify the as to genus and species. In the meantime some have been given whimsical nicknames, like "Mickey Mouse" (a grouping of coccoid bacteria or archaea covered with nanofilaments), "porpoise" (possibly a protozoan), and "sphere" (possibly a radiolarian with organic coat).

"One of the things that was really exciting was that many of the microbes from 1,243 meters (380 ft) down had lots of antimony," Hoover said. The X-ray spectra showed carbon, nitrogen, oxygen, phosphorus, sulfur, potassium, calcium, sodium and iron— all chemicals common to life. But it also showed an abnormal amount of antimony, a toxic heavy metal.

"It was not just one of these that had it," Hoover said, "but microorganism after microorganism had it."

Gregory Jerman, the ESEM operator, noted that the metal content has varied with depth. At some levels the microorganisms show large quantities of antimony, while in others zinc rings the bell

With more than 150 ESEM images and almost as many spectra recorded, Hoover and Abyzov then took some samples to the Jet Propulsion Laboratory in Pasadena, California. There, Dr. Ken Nealson will try to extract genetic material from the microorganisms.

As Hoover talked, another new image appeared on screen.

"It's pretty big," he said of an object that probably is a protozoan, shaped somewhat like a porpoise.

"The work of identifying and classifying everything in the ice will be long and challenging," Hoover said. He compared it to his own initiation in the world of diatoms where for years he often encountered strange looking diatom that he later realized were common forms that he had just never encountered. After several thousand hours of looking through the microscope, he could readily identify most of the common genera and species

"It's necessary to know what to look for and the kinds of things you can see," he said.

Like the wrinkled object resembling the forehead of a Klingon, a character from Star Trek, or the porpoise. Hoover thinks these bodies may not represent individual microbes, but may simply be organic detritus or pieces of larger, possibly even multicellular organisms.

For now some just have nicknames, until Hoover, Abyzov, and their colleagues analyze their exciting images and obtain more definitive identifications of these microscopic beasts of the frozen underworld.

For current information, visit:
Space Sciences On Line
http://science.msfc.nasa.gov

From X-ray astronomy to diatoms

Richard Hoover's formal training is in optics and advanced mathematics, with a minor in chemistry, first at Henderson State University in Arkadelphia, Ark., then at Duke University, where he did advanced work in mathematics, then at the University of California at Los Angeles and UAH for additional graduate work. He joined NASA's Marshall Space Flight Center where he has worked on X-ray telescopes for the Skylab space station, suborbital rockets, and other missions.

Richard Hoover played an important role in the development of the Multi-Spectral Solar Telescope Array. In a single payload, the array carried several X-ray telescopes which produced images of the sun in several X-ray wavelengths or "colors" at once.

"I have been in training ever since I came to NASA in 1966," Hoover said. "I've been reading everything I could get my hands on."

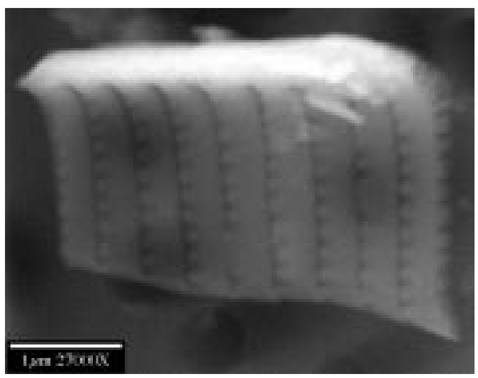
When dating his future wife, Miriam Jackson, he photographed her great-grandfather's collection of diatoms. Hoover was captivated by these miniature jewels of the sea. His interest and reputation grew and, in 1973, the Royal Zoological Society of Belgium invited him to inventory to inventory the diatom collection of Henri van Heurck, the 19th century's version of Jacques Cousteau. During this research in Antwerp, he had access to van Heurck's entire collection and library.

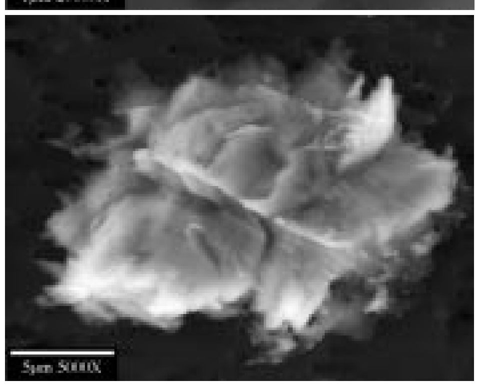
"This was the most important diatom collection made in the last century," Hoover said. "It's one of the most precious in the world." Over the next several years he spent his vacation time cataloging and photographing microorganisms gathered from the ends of the world.

"While working with this fabulous collection, I also encountered many other algae on herbarium sheets and a wealth of silicoflagellates, radiolarians and other microfossils that were not diatoms, so I got to appreciate microbiology and micropaleontology."

Hoover's own diatom photomicrographs have appeared in magazines, books, encyclopedia, and movies. In June, 1979, National Geographic published his article, "Those Marvelous Myriad Diatoms" illustrated with his diatom photos.

He has been interested in exobiology and astrobiology for many years. In 1986, he published a paper in scientific collaboration with the world renowned British astronomer Sir Fred Hoyle, concerning terrestrial diatoms and the possibility that they might find live in the icy crust of Europa or in comets. After all, diatoms are the most abundant form of plant life in the Arctic and Antarctic ice.





Among the dozens of objects found in the Vostok ice cores are (clockwise from above, with their fanciful nicknames): a cyanobacteria, a primitive lifeform that flourishes today; "leftover turkey," which appears to be part of a larger organism; something resembling the forehead of a Klingon; and a fragment of a diatom. Proper names will be given as research progresses and the objects are identified.