WOODS HOLE OCEANOGRAPHIC INSTITUTION 1930

OCEAN explorer

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Magnified many times, these are fossilized shells of one-celled deep-sea creatures, a Foraminiferan (the larger three-lobed, spiny shell) and a Radiolaran (the smaller cone-shaped shell on the right).

LOOKING BACKWARD

Piecing Together the Earth's Mysterious Past

Almost two hundred years ago, the poet William Blake wrote of his wish "To see a world in a grain of sand." He hoped to understand something very large by studying something very small.

Paleoceanographers (the prefix *paleo* comes from the Greek word for ancient), have the same hope. They study clues to the earth's past, including fossils, many of which are much smaller than grains of sand. They find these fossils by scooping up the mud of the deep sea floor and painstakingly sifting through it.

The earth is hundreds of millions of years old. But direct climate records only go back about a hundred years. To better understand today's problems, it's helpful to understand as much as possible about what the earth was like in the past.

When the paleoceanographers bring the fossils back to their labs, they use sophisticated analysis techniques to break the samples down into their atomic components. By studying the results of these analyses, they hope to learn what the earth's climate was like in the distant past. These tiny specks might help reconstruct the history of the earth. Perhaps a better understanding of the past will help scientists better predict the future.

Read on, as *Ocean Explorer* takes you back in time...WAY back in time.

CORE MATTERS:

How a Tube of Mud Travels from the Deep Sea to the Laboratory and Offers a Peek at the Past

COLLECTING THE CORE

The sun is shining, the air is still, the seas are calm. The research vessel is far from shore. Slowly, carefully, the on-deck crew releases a piston-corer over the side and into the sea. For the next few hours, heavy-gauge wire attached to the corer unspools slowly from a huge onboard winch. The corer is lowered to the seafloor. Once there, it plunges a long, hollow tube, called a core, straight down into the mud. The core is twenty meters long—about as tall as a six-story building. When the core is recovered and carefully stored on the ship, it brings to the surface mud and fossils that may have laid on the seafloor for hundreds of thousands of years.

Taking a core successfully is a matter of luck, timing, and great skill. The WHOI coring crew is very good at its work. Says Eben Franks, who has been in charge of many WHOI coring operations throughout the world, "Overall, we get excellent results."

FROM SEAFLOOR TO ARCHIVE

A few weeks later, the core arrives at WHOI with others taken on the same cruise. The cores are delivered to the Seafloor Samples Laboratory, a warehouse-sized room that holds more than 3500 tubes of mud, stacked horizontally floor to ceiling in wire shelves. The cores were collected over many years on research cruises all over the world. Hundreds of new cores are added to the archive each year.

The core is sliced open and lies on a table, displaying a big hunk of the earth's history, told in layers of mud that look, at different parts, like brownie mix, peanut butter or beach sand.

What scientists hope the core contains is invisible to the eye. But it can be felt. If you scooped up a little of the mud and rubbed it between your fingers, it would feel gritty. That grit is really tiny fossilized shells.

Before the core is stored, researchers must archive it, describing the colors of the mud at each level, and smearing small portions of it onto slides for later study. Noting the exact level at which the mud is sampled is very important, because the mud is laid down layer by layer over time. Within the layers, the chemical properties of the mud and the tiny fossilized shells change, according to shifting environmental or climatic conditions, and according to the circulation of the ocean.

Each core that is recovered is assigned a number code and is described on a gigantic computer program called MUDDIE. Geologists from all over the world have access to MUDDIE. Someday, a scientist will probably call up this core on MUDDIE, and may ask to study it.

SIFTING AND SORTING

A thumb-sized plug of gritty, chocolatey mud is next scooped out of the core by researcher Ellen Roosen. Samples are taken from a core every few centimeters—which can represent the passing of dozens or thousands of years, depending on how quickly the sediments were laid down. Each individual sample provides a snapshot of an instant in the earth's climate history.

Ellen dries the mud plug in an oven and then puts it on a fine-mesh screen, over which she runs water. Dirt is rinsed away through the

A *MUDDY* TRAIL FROM SEAFLOOR TO LAB

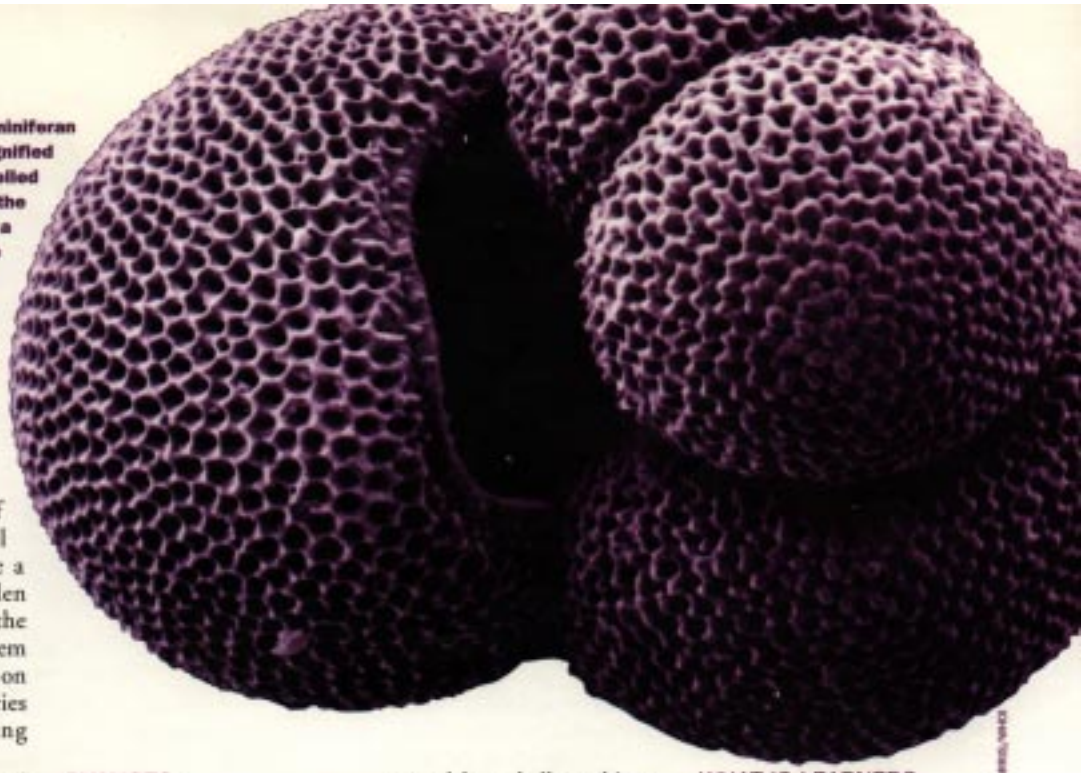
JAMES BROOKS/WHOI

1. **Scientists deploy a piston core that weighs more than one ton. It will take several hours for the device to reach the sea floor.**

EBEN FRANKS/WHOI

2. **Recovering a core sample filled with twenty meters of deep-sea mud.**

TOM KLEINDINST/WHOI



This ancient Foraminiferan shell, here magnified many times, travelled from the seafloor to the laboratory as part of a twenty-meter long core sample. In its small way, it is helping scientists learn about the history of the earth.

EBEN FRANKS/WHOI

screen. But thousands of tiny shells remain. All together, they look like a teaspoonful of sugar. Ellen puts the shells back in the oven for a while to dry them out, and then puts them on a gridded slide. She carries the slide to her picking microscope.

For the next several hours, Ellen peers through the microscope's eyepieces as soothing music plays in the background. She examines each shell. Ellen is trying to find examples of a certain species. Out of 60,000 individual fossils per tray, as few as six or eight hundred might be of the correct type. When she finds a shell of the type she is looking for, she wets her brush and uses it to flick the shell to one side of the slide. When she has found a few hundred of the shells, she carries them all to the mass spectrometer.

CHANGES

The mass spec will figure out how old the shells are by analyzing the chemicals and gases that make them up. Eben Franks, who operates the mass spec when he is not at sea collecting cores, places the shells in a little stainless steel container called a boat.

Over the next few hours, the shells are cleaned in an ultrasonic bath, roasted under vacuum, dissolved in acid, and distilled at a very low temperature with the aim of getting rid of any organic material that might throw off the analysis. As Eben says, "What you end up with is a toasted bug shell, nothing but calcium carbonate."

When the shells are as pure as possible, they are warmed to room temperature with a heat gun. This turns them from solids to gas—carbon dioxide. The gas journeys through the mass spectrometer, where it is analyzed.

A reading results that lists the sample's ratio of oxygen-16, oxygen-18 and carbon-13. Studying the ratios of these components helps scientists guess the sample's age and the temperature range of the water in which it lived.

WHAT IS LEARNED?

By analyzing the results of the sample, it's possible to pinpoint times in the past when the ocean's chemistry and temperature changed. This information helps scientists make guesses about ancient weather patterns on the planet. Those guesses help support theories about the earth's climatic future.

Much can be learned from tiny shells, mere specks to the naked eye. Understanding past trends is vitally important today, as evidence mounts that our planet is in the midst of an overall warming trend.

3. Peter Mills studies a split-open core in the WHOI Seafloor Samples Laboratory. One of the largest facilities of its kind, thousands of mud samples are stored there.

TOM KLEINDINST/WHOI

4. Ellen Roosen sifts through thousands of microfossils to find a few of the species she's looking for.

DAVE MCCARTY/WHOI

5. Eben Franks freezes samples in the mass spectrometer to remove any trace of water.

TIME MACH

How an Accelerator Mass Spectrometer Sheds Light on the Past

This mastodon tooth, shown slightly enlarged, was found in a fishing net. With AMS analysis, it revealed a bit of earth history.

Filling half a building at WHOI is a machine called the Accelerator Mass Spectrometer (AMS). It is the most advanced of the seven of its kind in the world. The AMS can date virtually anything up to 50,000 years old that contains carbon — that is, anything that has ever been alive during that time. This device can be compared to a time machine, offering scientists a window on earth's history.

EVERY SEASHELL TELLS A STORY

Glenn Jones, a geologist who directs the AMS facility at WHOI, holds up the shell of an ocean quahog *(KO-hog)*, a type of clam.

"One of the things we're doing is studying *Arctica islandica*, the ocean quahog," he says. "These animals live to be one hundred to two hundred years old. Their shells are just like tree rings."

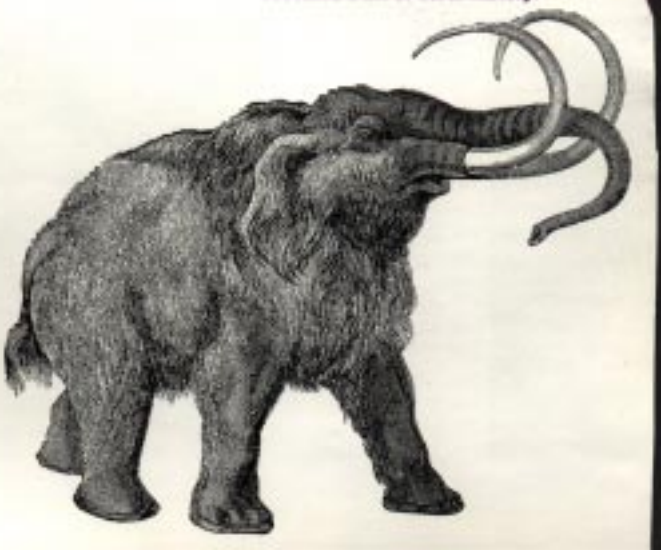
If you know the year in which a tree was felled, you can count the rings and know the year it began to grow. With AMS, quahog shells can be studied the same way. Chris Wideman, a WHOI graduate student who is using this technique, has collected quahog shells from many locations. He slices the shells and photographs them, to record their annual bands. The chemical composition of each band changes according to the temperature and salinity of the water in which the shell lived during that year.

"With AMS, we can go in and sample across each band, to find information about each year the shell was alive," says Glenn. "We actually get a seasonal record: spring, summer, winter, fall." By knowing where the shell was collected, how old it was, and by analyzing the chemical events that took place during the shell's lifetime, it's possible to construct seasonal and annual records of temperature, going back centuries or millennia. Wouldn't you like to know the temperature of the water off Provincetown, MA, in the summer of 8,000 BC?

This ability of AMS is helping scientists reconstruct detailed records of the Earth's climatic history, which can help them make predictions about our planet's future.

MASTODON MYSTERY

Next, Glenn holds up a very old-looking tooth that is about as big as his hand. "This was brought to me by a fisherman who pulled it up in his net off Cape Cod," says Glenn. "It's a mastodon tooth." Using AMS, the tooth is helping scientists reconstruct the history of the Cape Cod coastline. "When fishermen find something like this, they sometimes record where they were, and what the water depth was," says Glenn. With that information in hand, analyzing the tooth with AMS has produced a piece in the puzzle of Cape Cod's past.



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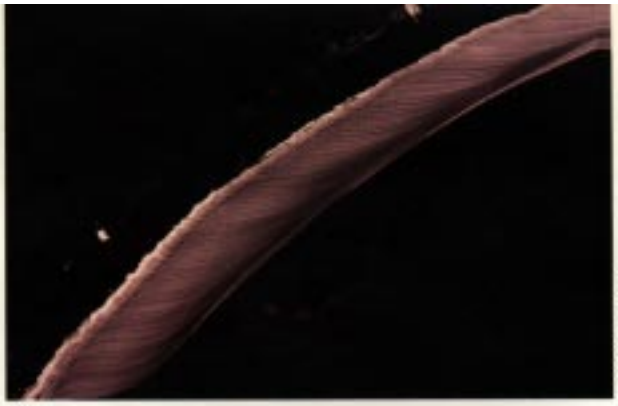


CHRIS WOODWARD/WHOI

A cross-section slice of a clam shell *(Arctica islandica)*. Each groove in the shell represents one year in the clam's life.

"We know that mastodons didn't swim around," says Glenn. "At the time that the mastodon was alive, it was walking on land." When did it live?

After AMS dating, it was determined that the tooth was 11,000 years old. Maybe at that time, a forest grew where there is now ocean. Perhaps the long-dead mastodon once clumped through that forest.

HELPING FISHERMEN MAKE PREDICTIONS

In the U.S. territorial fishing waters of the North Atlantic, the population of codfish and haddock, the two most important species in that area, have declined dramatically in recent years due to overfishing. Some scientists think that in future years, these populations of fish will simply move northward, if the waters in the North Atlantic grow progressively warmer. Some predictions have this region of the North Atlantic warming up by 2-4° C over the coming years. Is there a way to predict what may happen to these fish populations?

There is a pre-historical precedent for this situation. Six to eight thousand years ago, in a period called the Climatic Optimum, the ocean in that area was 2-4° C warmer. Where in the North Atlantic were codfish and haddock living at that time? The answer may lie in the otoliths (fish earbones) of those fish.

Though most fish remains are not preserved, otoliths endure. Glenn and others have been looking for cod and haddock otoliths in deep-sea cores taken in the U.S. territorial waters of the North Atlantic. By dating the otoliths with AMS, they hope to figure out where those fish lived during the Climatic Optimum.

Before AMS, it would have been necessary to collect several hundred samples of otoliths from an area in order to date them. This would be an impossible task, because not that many otoliths are found in deep-sea sediments. "With AMS technology, we can answer this question from just one otolith," says Glenn. "We can do a much longer time history of the distribution of the fish. If we can go back to a time when the climate was different than it is today, and can reconstruct the fishery of that time, we can use that reconstruction to make predictions."

FROM MUD TO AMS

Glenn is a marine geologist, long interested in deep-sea mud. About ten years ago, he began to wonder about ancient earth climates. He saw AMS as a tool to help answer some of his questions. Today, working with one of the newest AMS facilities in the world, Glenn sees results.

He sometimes thinks of himself as travelling through time as he analyzes data. "You have to put yourself into another dimension," he says. "You look at the information and say, "What this is really telling me is that in that long-ago summertime, this was what the temperature was. Is it like Bermuda today, or like the coast of Maine?"

He studies the mastodon tooth in his hand "What we're finding out about the past wouldn't be possible without AMS technology."

HOW DOES THE AMS WORK?

The high-energy AMS facility is basically a computerized racetrack for atoms. Before entering the accelerator, the material to be dated is chemically reduced to almost pure carbon: a minute bit of graphite that looks like the tip of a pencil. This nib of graphite is pressed into a tiny hole at one end of the machine. Its journey is about to begin.

But the speck of graphite itself isn't actually going to go anywhere. It will be bombarded with particles of a material called cesium, which cause the atoms of carbon to sputter off the graphite and race through the 60-foot long track.

The charged particles travel as a beam of light through a series of magnetic and electrical fields. These pass by a powerful magnet that bends the atoms of carbon-12 and carbon-13 into a cup to be measured as a current. The heavier atoms of carbon-14 travel to the end of the track where they are counted and recorded by computer. This final readout provides the age of the sample, because every 5730 years, half the atoms in a sample of carbon-14 decay, turning into nitrogen.

The Accelerator Mass Spectrometer facility at WHOI.

TOM FLEDERMYST/WHOI

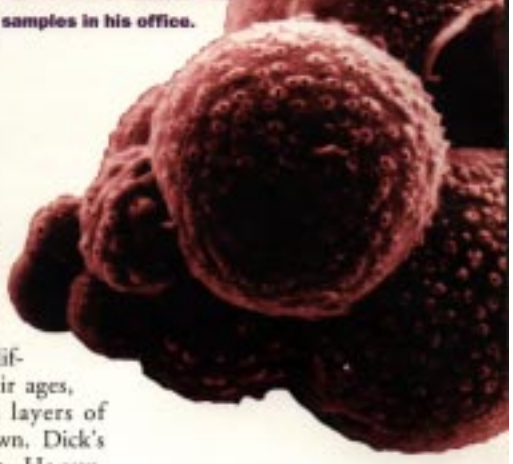
If you looked under a microscope at that nib of graphite, you would see an almost imperceptible depression where hundreds of trillions of atoms were sputtered away.

Adapted from "The Ocean Would Be Its Heart" by Victoria A. Kahari.

LITTLE SHELLS RAISE BIG QUESTIONS

TOM KLEINSCHMIDT/WHOI

Dick Norris studying samples in his office.



"If I had decided to study dinosaurs, I would have been lucky to find one *Tyrannosaurus rex* in my entire career. There just aren't that many specimens to work with," says Dick Norris, a WHOI paleobiologist who studies ancient life forms.

Instead, Dick spends his days sifting through dried deep-sea mud, looking for microscopic shells of simple, single-celled creatures known as Foraminifera (often called Forams for short). Unlike dinosaur remains, these shells are abundant. "In one glob of mud, I can collect thousands of specimens," says Dick, whose office is a museum in miniature, housing thousands and thousands of shells in cabinets that fit easily on a tabletop.

For a visitor in his office, he pulls out tray after tray of these amazing shells. Studied under a microscope, they reveal an astonishing variety and complexity of form.

Dick sometimes wonders what it's like to be a microbe. "It's tough enough for us to swim in the ocean," he has written, "but to a creature half the size of the period at the end of this sentence, water is as sticky as Elmer's glue." Just imagine what it's like to swim, breathe, and catch your lunch in stuff that sticks to you all the time!

"I marvel at how these creatures can make a living in a world so different from our own," says Dick. "I do not doubt their ability to survive, since they have done quite well for about 160 million years!"

Micro-paleontologists (who study fossils of microscopic creatures) generally aren't interested in evolution. Mostly, they study the relationship of rocks in different places, their ages, or when various layers of rocks were laid down. Dick's interest is different. He says, "I want to know how the diversity within and amongst species came to be."

Dick holds up a slide that contains hundreds of Foraminifera shells. They look like grains of sand. "Some geologists think of these little shells as nothing more than colored beads." To them, the principal importance of those shells is their age *(see pages 2-5)*.

But Dick is more interested in the changes in shell shape of these creatures as their species have evolved. "How did these shells develop their shapes? How did the tremendous variation of colors and textures of these living things, or, for that matter, all living things, ever come to be?"

He believes that finding the answers to his questions will help him create theories to answer even bigger questions. "I want to know what our place is in the universe—in the world." By studying some of the smallest, simplest and oldest life forms on earth, Dick hopes to gain a better understanding about the origins of larger and more complex creatures. "Lots of people want to know—why am I like this? Was I just created, or is there a purpose for my being here? We are all the products of a large sequence of changes."

As a child, Dick was always turning over rocks and seeing what was underneath. "There were some things I didn't want to

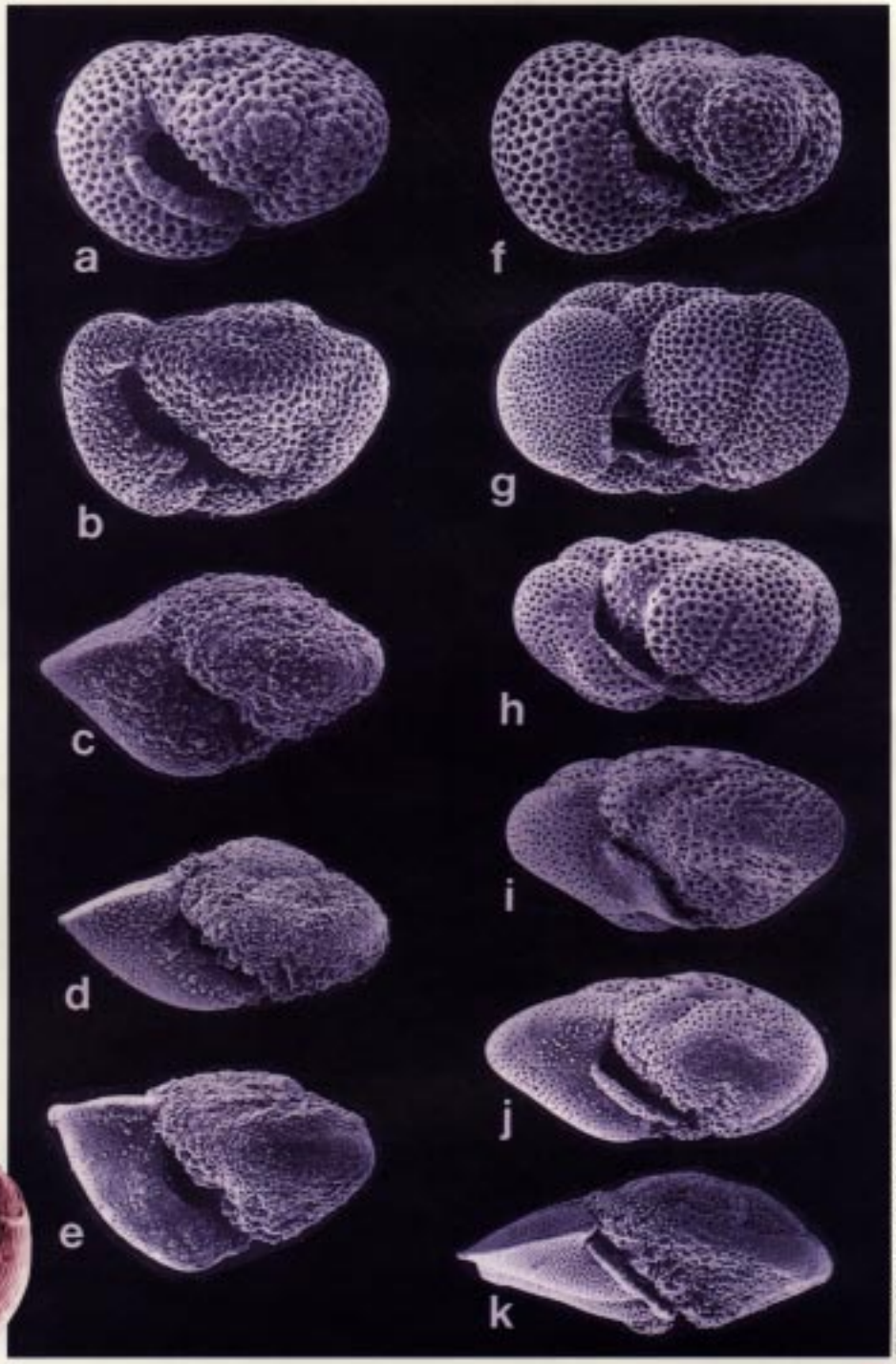
Samples of microfossils that Dick has studied. Each photo is magnified hundreds of times.

Dick has been studying the evolution of two creatures in particular, *Globoconella (a-e)* and *Fohsella (f-k)*. Their images are shown here, magnified many times. About 20 million years ago, the oldest examples of each species were globular in form. The newest examples (a mere 4-12 million years old) have a compressed shape. As he studies the creatures, Dick asks himself why the changes in shape have taken place.

touch!" The son of two scientists, Dick has a life-long interest in natural history. In college, he became interested in geology because he saw it as a scientific framework to use to study the world at large. "If you understand the history of the earth," says Dick, "you can better appreciate the environmental conditions in which life evolved."

Like many scientists who study the ancient past, Dick sometimes thinks of the eons that lie between his own era and that of the fossils with which he works. That distance in time makes him think of stars. "Looking back in time is like looking into space. When we look at stars, we see light that was emitted billions of years ago."

Dick Norris once hoped to spend his career studying dinosaur remains. These days, he says dinosaurs are not exotic enough—their environment is too much like our own! But microorganisms live in a world totally alien to us. "I have grown to love microfossils," he says, as he examines a tray of weird, lovely shells. "You have to love what you work on to spend time on it."



FOSSIL PHOTOGRAPHS BY RICHARD NORRIS, WHOI