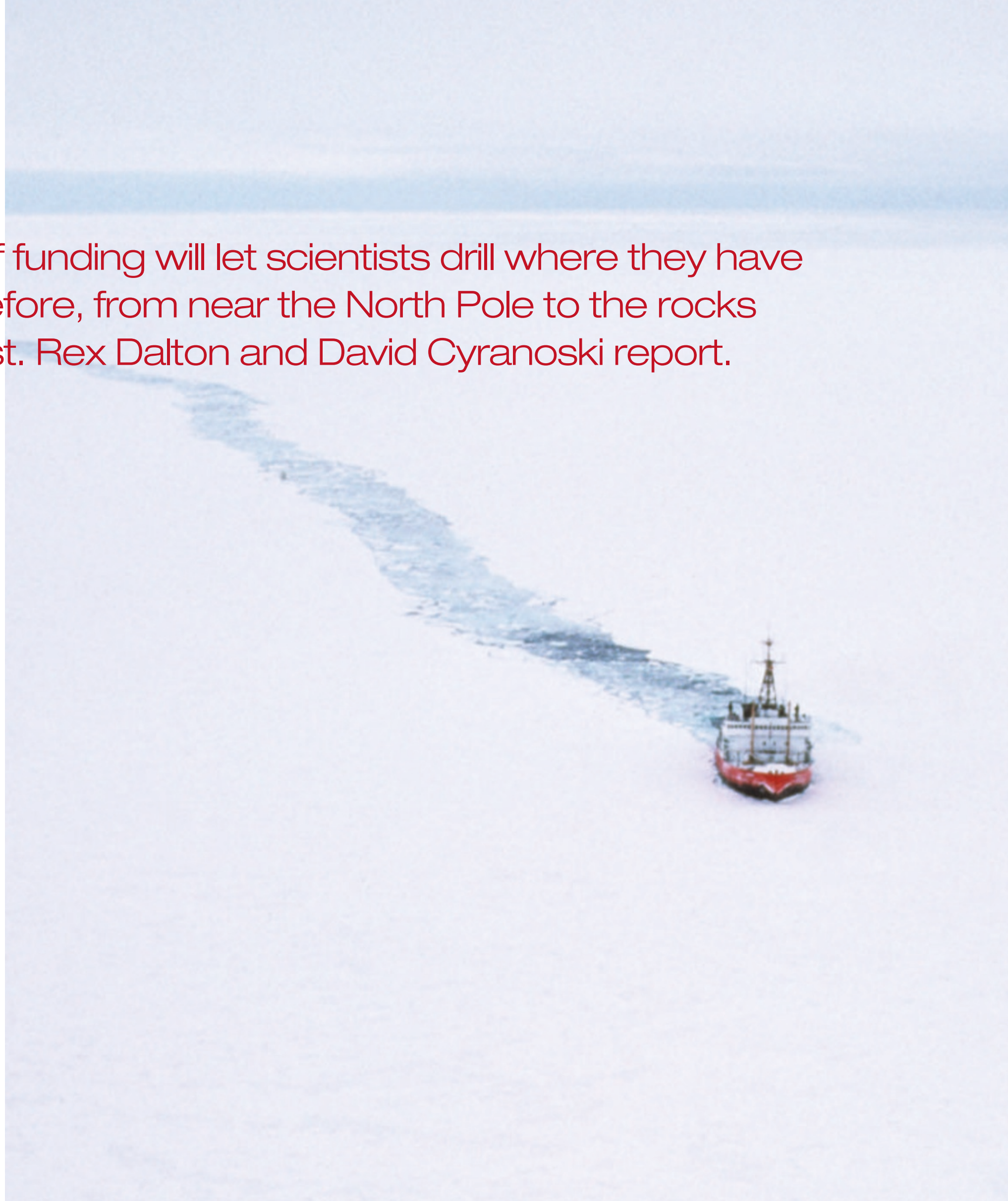
Digging in



A new ship and a wave of funding will let scientists drill where they have never been able to drill before, from near the North Pole to the rocks lying beneath Earth's crust. Rex Dalton and David Cyranoski report.

Late next summer, when the Arctic pack ice has receded, three icebreakers will head north from Siberia to escort a drilling ship into the treacherous Arctic Ocean. Cutting through ice floes, the convoy will launch one of the most ambitious ocean-drilling projects ever undertaken, in an attempt to find a missing piece of the puzzle of our planet's climatic past.

Tentatively approved last month, the expedition will be one of the first projects of the new Integrated Ocean Drilling Program (IODP) — a scheme that will unite equipment and expertise from the United States, Japan and a consortium of 15 European nations. The programme aims to drill where no ship has drilled before, from the icy North Pole to deep inside a fault line off the coast of Japan, and to study the life forms they find deep beneath the sea floor along the way.

After a decade of planning, the IODP was officially born on 1 October. It replaces the Ocean Drilling Program (ODP), an enterprise of 20 nations that was phased out in September after nearly 20 years of expeditions. The ODP had only a single ship — the US vessel *JOIDES Resolution* — which sailed the globe, sinking holes into the ocean bottom and retrieving a huge volume of sediment cores (see 'Core values', overleaf).

Over two decades, the *Resolution*'s bounty has helped to prove that asteroids such as the one that slammed into Mexico 65 million years ago — thought by some researchers to have caused the dinosaurs' demise — can create clouds of dust that settle all around the world. Sediment cores pulled from the Indian coast helped to put a date on when the Himalayas were born, as they revealed a mass of rock that was weathered by rain as the mountains were pushed up. And researchers have gained clues about Earth's ancient climate — the fossils found in layers of mud laid down on the ocean floor over millennia have revealed the temperature of those waters long ago.

But the *Resolution* couldn't go everywhere, and never mounted a campaign on the North Pole. In 1996, geologist Jan Backman, of Stockholm University in Sweden, and his colleagues took a lone icebreaker — operated independently of the ODP — and tried to drill a deep core on the Lomonosov Ridge, an undersea mountain ridge that meanders across the top of the world. The wind blew ice into the side of the ship, making it difficult even to stay still, and the team only managed to get a few, small cores by dropping a weighted pipe off the back of the ship. "The ice does terrible things up there," says Backman. "When I came out, I said I would never do that again without the proper vessels."

ODP

Illustrious career: the research drilling vessel *JOIDES Resolution* has sailed the world for more than two decades.

Pole position

Now Backman has a second chance, as head of a mission that will return to Lomonosov in August. With US$12 million from the IODP, Backman will this time have at his disposal satellite-borne radar that can see through clouds, real-time weather updates, three ice-breaking escort vessels, and an oil-industry drilling ship, on which the party will steam to a location 130 kilometres south of the North Pole. There Backman hopes to sink three holes into the ridge and retrieve 500 metres of cored sediments, which will give a glimpse of the past 50 million years. The sediments will be examined for minerals that have been transported by ice from nearby land, or fossils of tiny creatures that thrive in specific climates — tell-tale signs of when the pole was free of ice, or completely iced over.

If the mission succeeds, it will be a coup for climatologists, for whom the North Pole's ancient climate is still a mystery. But the IODP has other ambitious projects in mind too. Along with its ice-breaking facilities, provided mainly by the European project members, it will also have a Japanese ship designed to drill deep into the Earth — the US$500-million *Chikyu*. Unlike the *Resolution*, which was an old oil-exploration vessel converted for use by scientists, the *Chikyu*

R. WHITE/CORBIS

Breaking the ice: lone vessels have had scant success in polar drilling projects. Researchers now plan to take a party of boats to the Arctic.

With an onboard geology lab and the ability to drill 7 km beneath the sea floor, the *Chikyu* aims to find out why Japan is plagued by earthquakes.

has been designed from the keel up specifically for research. The ship has equipment for dating and analysing cores that is more comprehensive than that in most land-based labs, says Millard Coffin, a marine seismologist at the University of Tokyo's Ocean Research Institute and chair of the IODP's Science Planning Committee. Most importantly, the ship has a half-metre-wide pipe that can extend from the ship's bottom to the sea floor in water up to 2,500 metres deep. A 14-centimetre pipe fits inside this 'riser', through which a drill can then bore a further 7 km into the Earth.

This impressive drilling capacity will allow the *Chikyu* to drill into untouched areas of Earth's interior. So far, everything dug up has been from the upper portion of the crust, a layer of rock that is an average of 75 km thick on land and 10 km thick in the ocean — although this varies from place to place. Geologists are fascinated to find out more about what is happening deeper still, in the zone called the mantle. This region, which extends for 2,800 km beneath the crust, carries heat from Earth's core towards the surface and helps to drive plate tectonics. Although heated to more than 1,000 °C, the rock here is not molten, thanks to high pressures, but moves plastically over long time scales. "This is the Earth's heat engine that makes everything happen at the surface," says Donna Blackman, a geophysicist at the Scripps Institution of Oceanography in La Jolla, California.

The division between the crust and the mantle has been studied with seismic waves, revealing a marked difference in physical properties between the two layers. But no one is sure whether this is because the rocks have different mineral compositions, or have simply been altered by the pressure, the presence of liquid, or some other factor. Researchers have pulled up samples of mantle rock that have been thrust towards the surface, but no one has managed to study it in its native environment. Retrieving such a sample would fill in a lot of the gaps in our knowledge, helping geologists to understand better how heat flows through the mantle and to interpret the results of seismic tests.

In the *Chikyu*, Japan has created a ship that can pierce the ocean's relatively thin crust and dig into the mantle — although it won't be easy. To reach the mantle in relatively shallow waters of 2,500 metres, the vessel will have to drill into an ocean spreading ridge — a place that sits high in the water and where the crust is thin enough for a 7-km drill bit to get through it. But these spreading zones are incredibly hot — up to 1,200 °C at depth. No one has yet designed a drill to deal with these temperatures, so it is hard to know how easy it will be to extract cores of solid rock from this section of the mantle.

Although the *Chikyu* was designed with the aim of obtaining mantle rocks in mind, that feat is still a long way off — researchers don't expect it to happen for at least ten years. But Japan has a more pressing motive to drill deep into Earth — to learn more about earthquakes. Japan sits on four shifting tectonic plates and experiences hundreds of earthquakes a year. The fault line southeast of Japan, where the western edge of the Pacific Ocean slides beneath the Eurasian plate, experiences a major earthquake nearly every 180 years, and is one of the most active sites in the world.

Finding fault

One of the *Chikyu*'s first missions will almost certainly be to drill straight into the heart of such a fault — a spot between 10 and 30 km down called the seismogenic zone, where the stress builds up between plates before they slip, causing an earthquake. "The material down there determines how the plates slide, but the truth of the matter is that no one knows exactly what it is," says Kiyoshi Suyehiro, a geophysicist and executive director of the Japan Marine Science and Technology Center in Yokosuka. The *Chikyu* will be able to pull up material from a depth of 7 km — close enough to approximate the zone's geochemistry, says Jim Mori, a seismologist at Kyoto University. This should give a picture of the fault's mineral composition, along with factors such as grain size and water content, and will inform models of how the plates slide against each other. "Until now, earthquake models have always had to use a somewhat arbitrary constant for the friction that affects plate movement," says Suyehiro.

The *Chikyu* has been built, but it will take some time for it to be fully fitted for work, and it is not scheduled to embark on its first scientific mission until October 2006. In the meantime, IODP researchers have some exciting plans for the *Resolution* too.

One focus for both the *Resolution* and the *Chikyu* will be to investigate the incredibly rich diversity of bacteria and other creatures that live up to 1 km below the sea floor — a biological treasure trove uncovered by ODP missions over the past four years. The IODP will enlist more microbiologists to study these life forms, some of which are thought to have lived for 200 million years in environments of extreme pressure and temperature, without sunlight or oxygen. Examination of these bacteria will fill evolutionary gaps in the bacterial family tree, says microbial ecologist Kenji Kato of Shizuoka University in Japan.

The researchers will be keen to learn more about how these bacteria interact with the rock around them. "We are going to examine some riddles about how microorganic life cycles affect geochemical processes and vice versa," explains Kato, the sole biologist on the IODP's Science Planning Committee. One such riddle is the question of whether and how bacteria are responsible for the produc-

Core values

If you want to know what's hot in the field of palaeoclimatology, John Firth would be a good person to ask. As curator of one of the core repositories of the Ocean Drilling Program (ODP), the Texas A&M University geologist has had the difficult job of distributing and preserving much of the material that this project has pulled up from the ocean floor.

If Firth lined up all of his ODP cores end to end, he would have an astounding 120 km of sediment. From this he hands out 150,000 samples to researchers each year. "Once someone latches onto a new event, requests start pouring in for samples from that interval," says Firth. At one time the hottest cores were ones that represent the brief flash in time, 65 million years ago, when an asteroid slammed into Earth, possibly killing the dinosaurs. Now, he says, the cores most in demand are from a period 10 million years later, when a spurt of rapid climate change might have caused a mass extinction of marine life.


V. DIEKAMP

Matrix of mud: the core repository in Bremen is gearing up to house thousands of new samples.

Only half of each core pulled up by the ODP is openly available for analysis by researchers — the other half is kept as an archive, causing a headache for those in charge of storing it. Every core needs to be kept cold and wet to preserve its chemistry and prevent mould from growing on it. Some cores, such as those that contain methane, require pressurized containers to stop the gas escaping, whereas others need to be kept free of oxygen to mimic their original conditions under the sea. And there's an awful lot of mud to deal with. As of September 2003, the ODP had pulled up 222 km of cores. This figure is set to grow under the ODP's successor, the Integrated Ocean Drilling Program (IODP), forcing researchers to make efforts to keep up.

The biggest effort has been in Japan, where a new drilling ship — called the *Chikyu* — has created a need for better storage. In April, Kochi University completed a ¥5-billion (US$45-million) facility to do the job, with three rooms, each 40 metres long, that can be kept at 80% humidity and 2 °C. Tanks of liquid nitrogen are in stock to keep samples in a state of near suspended animation. And a huge investment in analytical instruments makes it the only geochemical research lab in the world more comprehensive than that aboard the *Chikyu* itself.

Europe's core repository at Bremen University in Germany is updating its equipment too — a project that should be completed next year. So when cores from the IODP begin to arrive in 2004, all three facilities will be ready.

As for Firth, he says that the next must-have cores could come from anywhere — including many old ODP cores that have not yet been fully investigated. "Scientists are looking at more and more of these cores," he says. Whether old or new, the repositories could throw up a surprise at any time. **D.C.**

tion of methane gas that occurs under the sea floor and feeds the formation of hydrates — icy blocks that hold molecules of methane in cages of water. Some researchers claim that large pockets of this greenhouse gas have erupted in the past, triggering climate change and even sinking ships. Much of the methane is thought to be produced in the breakdown of organic matter by bacteria, but no one really knows what bacteria are responsible, where they live, or how fast they produce the gas.

To answer these questions, researchers will have to drill into these methane hydrate layers, potentially releasing the explosive pockets of gas trapped beneath. Drilling ships have to be extremely careful around such pockets, as methane bubbles can burst explosively through the drill pipe, causing massive damage to both the pipe and the ship. But the *Chikyu*'s design should be equal to the task — a 'blow-out protector' installed at the base of the riser pipe on the sea floor can seal both the riser and drill pipes when an area of high pressure is encountered. Drilling into these pockets will be interesting not only to researchers, but also to companies interested in mining the natural gas as a potential fuel.

Together, the IODP's ships and expertise combine to make a very ambitious programme. But some problems remain to be solved if the plan is to bear fruit. The IODP already faces a budget crunch. US researchers had hoped to begin development next year on a new ship to replace the *Resolution*, but that project has been shelved for the time being, and the *Resolution* may simply be overhauled instead.

Unequal arrangement

Meanwhile, the European consortium has pledged less money than was originally hoped for by the United States and Japan, making Europe, for now, a less-than-equal partner in the project. This means that there will only be enough money for one or two European projects a year — Coffin and other IODP members had originally hoped for as many as eight. Those projects are meant to provide equipment on lease for specific missions — such as ships that can handle Arctic conditions or drill in shallow coastal waters.

Funding issues could also pose problems in Japan, which had hoped that Europe would help to fund missions involving the *Chikyu*. Japanese scientists do not yet have enough money for equipment that will slot into the holes drilled at the fault line, for example, which would monitor the chemical, physical and biological properties of the sediments during a quake. And prospects are not bright for Japan's hopes of extending the *Chikyu*'s drilling capacity so that it can reach the sea floor in waters 4,000 m deep — the average depth of the ocean. If this feat can be achieved — something that the oil-drilling community has never managed with a riser apparatus — the *Chikyu* will be able to drill into the mantle in deeper waters where the rock is much cooler, making samples easier to obtain.

But whatever obstacles they face, researchers are steaming ahead with the plan. At the very least, they can keep up the ODP's old reputation for collecting vast amounts of samples and data. Hopefully they will extend the programme's reputation for astounding discoveries too. ■

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