COURTESY OF RAYMOND A. BINNS

The Mineral Wealth of the Bismarck Sea

Discoveries of valuable minerals on the floor of the southwestern Pacific have renewed interest in deep-sea mining. But can metallic ores be recovered there without endangering marine ecosystems?

by Raymond A. Binns and David L. Dekker

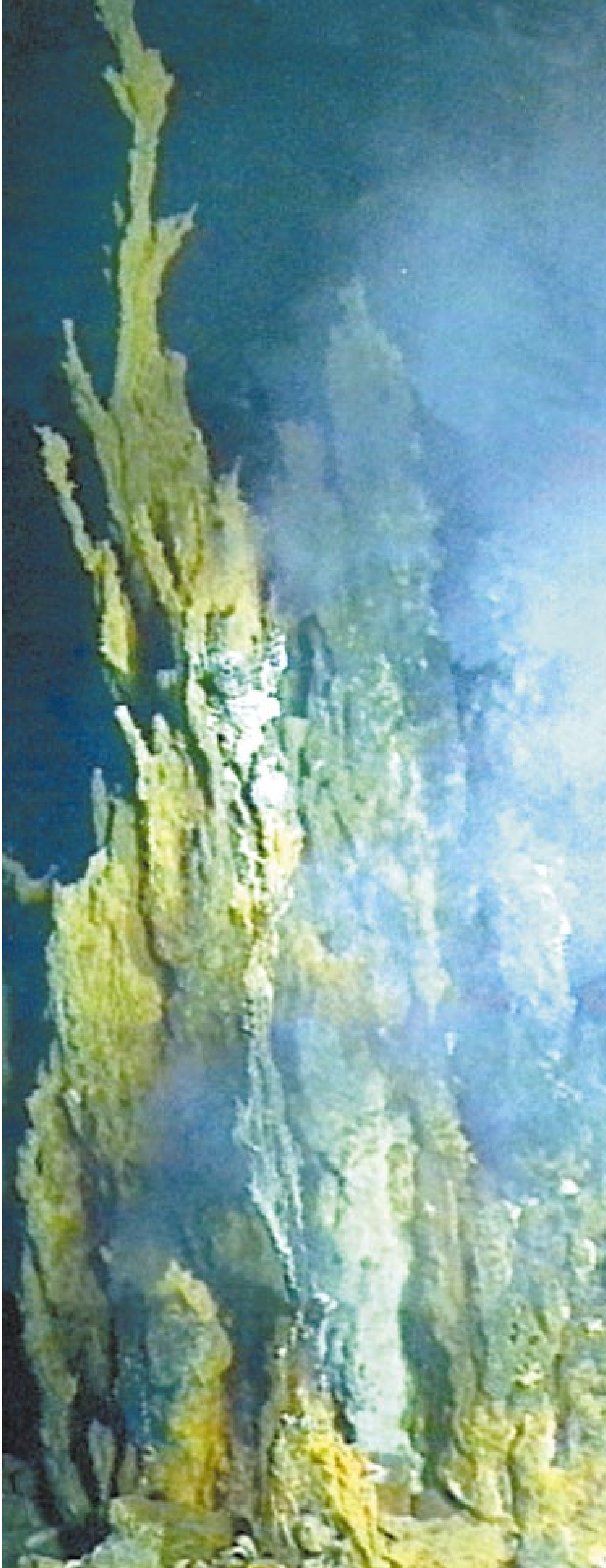
Last November the government of Papua New Guinea granted a private company permission to prospect for minerals on the floor of the adjacent Bismarck Sea. Other mineral deposits on the bottom of the ocean had drawn attention during the 1960s and 1970s, when people talked about mining zinc-rich oozes two kilometers (1.2 miles) down on the bed of the Red Sea or of harvesting nodules with nickel and copper from five-kilometer-deep abyssal plains in various parts of the world. In more recent years, some have considered mining volcanic seamounts encrusted with oxides thought to contain cobalt and platinum. Yet none of those submarine deposits proved sufficiently valuable to make their extraction worthwhile. So why have the deposits under the Bismarck Sea sparked commercial interest now?

The difference is that the newly found sources of ore on the seabed are massive sulfides, dense minerals rich in copper, zinc, silver and gold. To prospectors, massive sulfides are a familiar prize, because these minerals are often mined on land for their metals. Unlike other deep-sea deposits previously considered for mining, the massive sulfides of the Bismarck Sea occur at relatively shallow depths (less than two kilometers). They also lie in calm waters within an archipelago of Papua New Guinea, which thus owns the right to mine them under international law. These attributes, along with the richness of the deposits, make them much more attractive than any deep-sea mineral prospect ever before contemplated.

Scientists first discovered massive sulfides on the seafloor two decades ago in the eastern Pacific using the research submersible *Alvin*. Marine geologists have since found more than 100 similar sites in the Pacific, Atlantic and Indian oceans, all located on ridges where hot magma rises and tectonic plates spread apart. But the massive sulfides of the Bismarck Sea are found in a completely different geologic setting. There metal-rich minerals occur at a subduction zone, where one plate thrusts below its neighbor. The descending slab heats up and gives rise to magma that may erupt onto the ocean bed. Although geologists have only just begun to examine the seafloor for its mineral wealth, they believe that ores in subduction zones may be much richer in valuable metals than those found at mid-ocean spreading centers. Curiously, until about a dozen years ago no one knew that the seafloor near subduction zones contained economically interesting deposits at all.

A Lucky Find

In 1985 marine researchers from the U.S. set sail to the southwest Pacific to study plate tectonic movements. In the course of their expedition, they towed an underwater camera close to the seafloor and were



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METAL-RICH CHIMNEYS called black smokers spew sulfurous particles from the seafloor near Papua New Guinea, as seen in these video mosaics.

C. TAYLOR *CSIRO*

CROSS SECTION of one of the chimneys collected from the flanks of the undersea volcano Su-Su shows an enrichment in copper throughout.

lucky enough to photograph a patch of massive sulfides in the middle of the Bismarck Sea, well away from the major oceanic spreading ridges. Their serendipitous discovery was later dubbed the Vienna Woods because the deposits form a dense forest of narrow chimneys called black smokers, which exude hot water and clouds of black particles superficially resembling smoke. The hot water leaches metals from deep in the crust and deposits them in the walls of the chimneys as it cools.

The Vienna Woods site has since been visited by a German research vessel, which collected large pieces of the massive sulfide chimneys, by Russia's two *Mir* submersibles (now famous for their role in the movie *Titanic*) and by Japan's *Shinkai-6500* submersible. Scientists do not yet know the full extent of these "woods." But this locus of hydrothermal activity must hold an appreciable amount of metal, with its countless towering smokestacks—many 10 to 20 meters high—set on massive sulfide mounds that are 20 to 30 meters across. And this site is not the only metalliferous zone in the region.

In 1991 one of us (Binns) set off with a group of scientific colleagues on an expedition to a depression on the bottom of the Bismarck Sea called the eastern Manus Basin. We were not seeking to discover exploitable mineral deposits but rather to find a natural laboratory where we could examine how this type of massive sulfide ore forms. Our ultimate goal was to facilitate the search on land for such deposits, which can be found buried within slices of former seafloor that had long ago thrust onto the continents.

At the beginning of this expedition, our strategy was to dredge pieces from various submarine volcanoes and pick out those samples that best matched the rocks hosting such ores on land. We also towed an underwater video camera over the sea bottom at many sites and lowered special instruments in hopes of detecting the plumes of cloudy water emitted from black smokers. We scrutinized hours and hours of video recordings, searching for the characteristic shape of hot spring chimneys or for concentrations of sea life known to form biological halos around deep-sea vents.

The first video sighting of volcanic chimneys in the eastern Manus Basin occurred about 170 kilometers east of the Vienna Woods. The view lasted only a few seconds, but it was unmistakable. People mumbled words like "El Dorado" as excitement spread through the ship, galvanizing both scientists and crew for the four days of dredging and deep-sea photography remaining in our tight schedule.

In the time allowed us, we mapped deposits scattered over several kilometers and named the site PACMANUS, after the nations involved in the expedition (Papua New Guinea, Australia and Canada) and the Manus Basin. Our attempts at dredging failed, but we managed to recover a few grams of these massive sulfides before our expedition came to an end. And the re-

AUSTRALIAN RESEARCH VESSEL *Franklin* (*left*) carried investigators to the Bismarck Sea. A system for detecting and sampling plumes of hot, particulate-rich water (*center*) helped them home in on the deposits, as did their underwater video camera (*right*).

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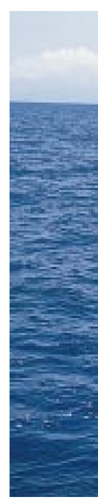
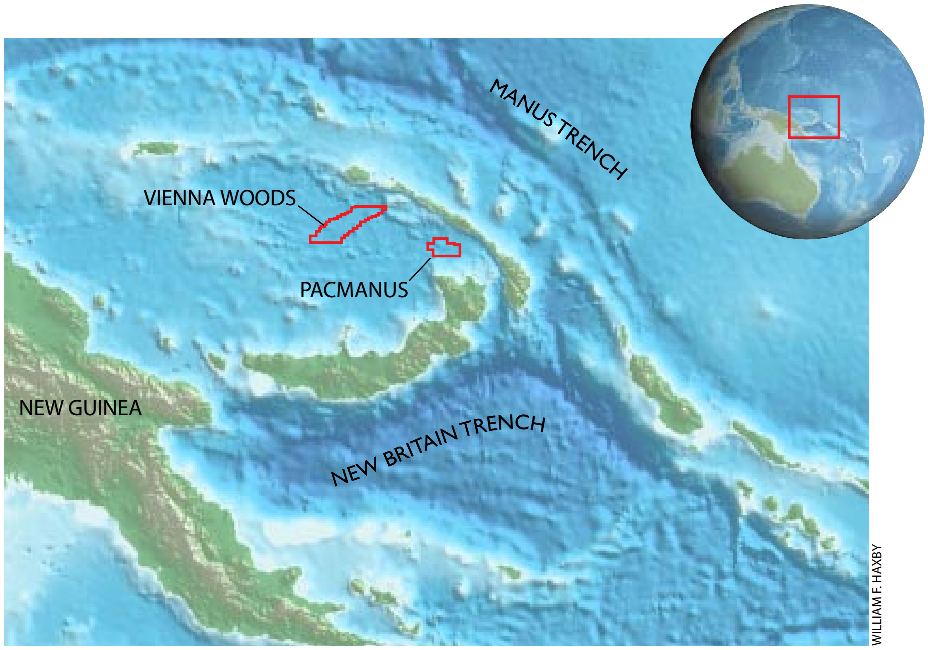




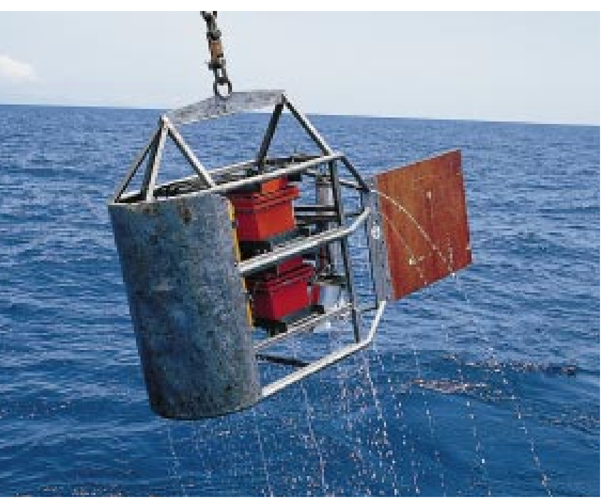
WILLIAM F. HAXBY

EXPLORATION RIGHTS have been granted to Nautilus Minerals Corporation in two locales (*red*) within the national waters of Papua New Guinea. The New Britain Trench marks the site of ongoing subduction, whereas the Manus Trench has long been inactive.

sults of that initial foray prompted us to go back. In the course of six more research cruises, including two that employed piloted submersibles, we—along with an expanded group of colleagues from France, Germany and Japan—have been able to inspect these remarkably rich deposits at close range and to collect numerous samples containing high concentrations of copper, zinc, silver and gold.

After mapping the area in detail with the help of many other investigators, we now know that these accumulations of metallic minerals extend for 13 kilometers along the top of a volcanic ridge made of dacite, a type of lava that is rare on the ocean floor. The greatest concentration occurs within a two-kilometer part of the ridge, where several fields of active chimneys dot the bottom. The people involved in their discovery have given them playful nicknames such as "Roman Ruins" (where fallen chimneys are especially common), "Satanic Mills" (where the chimneys belch out particularly thick clouds of black particles) and "Snowcap" (where a white bacterial mat coats a small hill). To those fortunate enough to see them, the diversity of sights in the Manus Basin is indeed tremendous.

In 1996 we participated in the discovery of yet another accumulation of massive sulfides, 50 kilometers east of our previous find and not far from the port of Rabaul, Papua New Guinea. Having improved our techniques for finding black smokers, we rapidly homed in on the site by tracking a large plume of sulfide particles emanating from the twin peaks of an undersea volcano named Su-Su. (This apt if unoriginal moniker means "breasts" in Melanesian Pidgin.) Densely packed chimneys cover a 200-meter-long strip of seafloor on the flanks of one summit. These massive sulfides proved to be more richly endowed with precious metals than any we had sampled before at PACMANUS.


C. TAYLOR CSIRO

Money Matters

Current evaluations suggest that each cubic meter of rock in these deposits is worth about $2,000, which almost certainly means that ore could be extracted, raised to the surface and processed at a tidy profit. But Nautilus Minerals Corporation (based in Port Moresby, Papua New Guinea, and Sydney, Australia), which obtained the licenses to explore for minerals on the floor of the Bismarck Sea, has much work to do before it can begin deep-sea mining operations. We and our co-workers at the Commonwealth Scientific and Industrial Research Organization in Australia are now doing studies under contract from Nautilus to help the company face the many challenges ahead.

First, Nautilus must carry out a thorough examination of the area to determine the extent of the massive sulfides and to estimate the amount and grade of ore available at each deposit. This work will initially involve dredging samples from the bottom with high precision in many places and perhaps drilling into the seafloor at selected spots. Geologists hired by the company will have to study the ore carefully to evaluate the density, porosity, abrasiveness and mechanical properties of this sulfide-rich rock. Mining engineers can then begin the task of developing special methods for excavating, hoisting and processing the ore.

Remotely operated equipment like that used to dig trenches or shovel ore in an open pit mine presumably offers the most straightforward means for scooping up the minerals. Hoisting ore to the surface by cable would work but might be prohibitively time-consuming and expensive, given the 1,000 tons or so of rock the company would probably want to raise each day. Perhaps the engineers will favor a scheme similar to the one used in 1978 on board the *Glomar Explorer,* which successfully deployed a series of buckets on huge conveyors to retrieve metal-rich nodules from the floor of the Pacific. Lifting a slurry of crushed ore with pumps might also be a workable tactic.

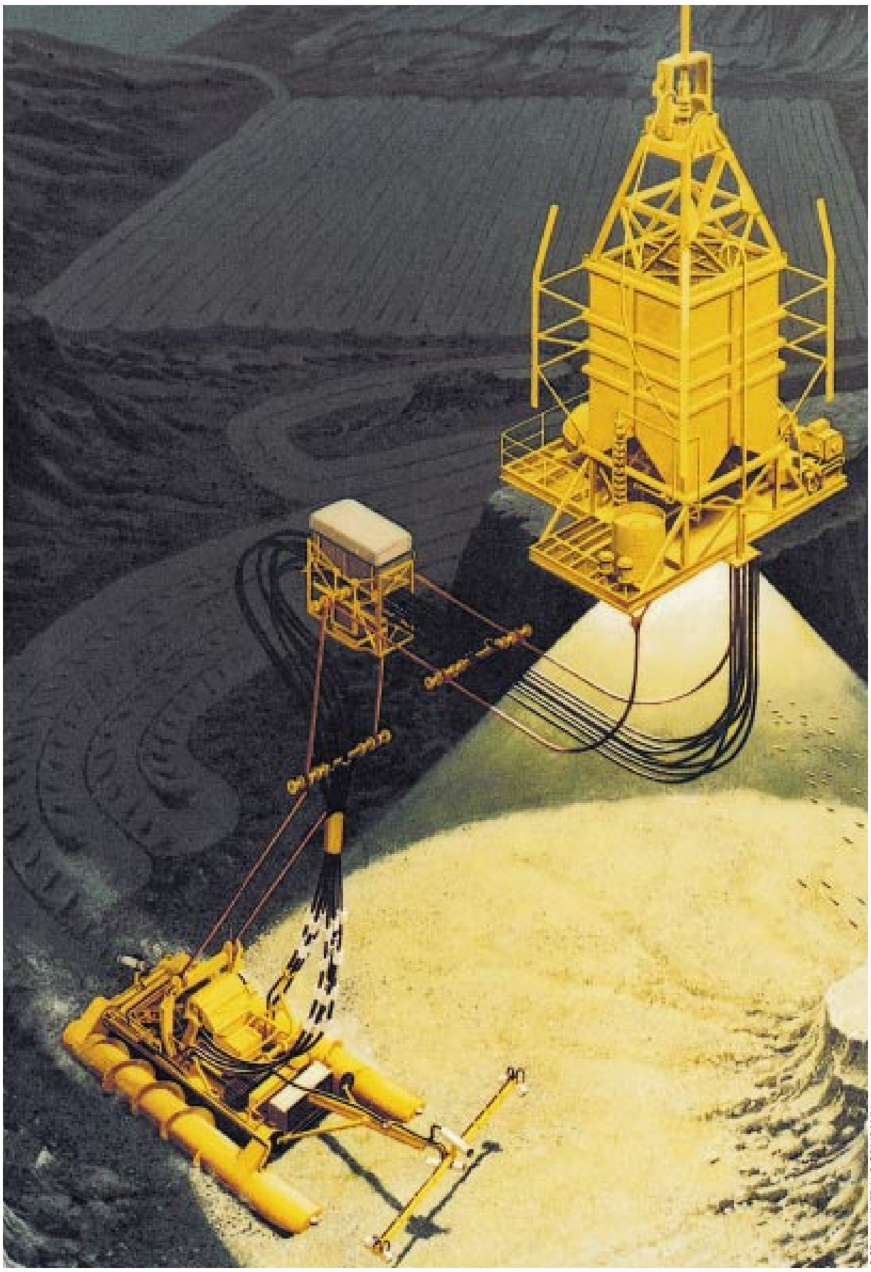
Siemag Transplan, a German firm, has in fact developed just such a system. It can lift particles of rock or coal from deep in a mine using a U-shaped tube, with water pumped down one leg and a wet slurry of ore rising up the other. Similar devices might perform even better under the sea, because the pressure at the bottom of the pipe could be adjusted to match that of the seafloor. If the velocity of water in the pipe is maintained at several meters per second, the upward force would be sufficient to lift small chunks of rock that are a few centimeters across. But whatever method proves best, before seeking approval from the government of Papua New Guinea, Nautilus must first show that the mining it plans to do will not harm the biota living in this unusual seafloor environment.

Some Like It Hot

The active chimneys on the floor of the Bismarck Sea are teeming with marine life of extraordinary and stunning variety. At these depths, no sunlight penetrates, so photosynthesis of the kind that sustains life near the surface is impossible. The energy source for the communities living around the chimneys is chemical.

These and most other deep-sea hydrothermal vents emit hydrogen sulfide, which nourishes specialized bacteria living around them. The microbes form the bottom link of a strange food chain coupling them to bacterial-mat grazers, symbiotic organisms, carnivores and scavengers. Such deep-sea vent communities were first recognized in 1977 and 1979, when *Alvin* descended to hot springs west of Ecuador on the Galápagos Ridge and the nearby East Pacific Rise. The scientists found heat-resistant microbes, such as *Pyrolobus fumarii* and other so-called hyperthermophiles, growing in the walls of these vents and thriving at searing temperatures of about 105 degrees Celsius (221 degrees Fahrenheit).

DEEP-SEA MINING METHODS being considered by Nautilus Minerals Corporation include a scheme worked out two decades ago by Ocean Minerals Company for harvesting manganese nodules from the bottom of the sea (*artist's conception shown below*).



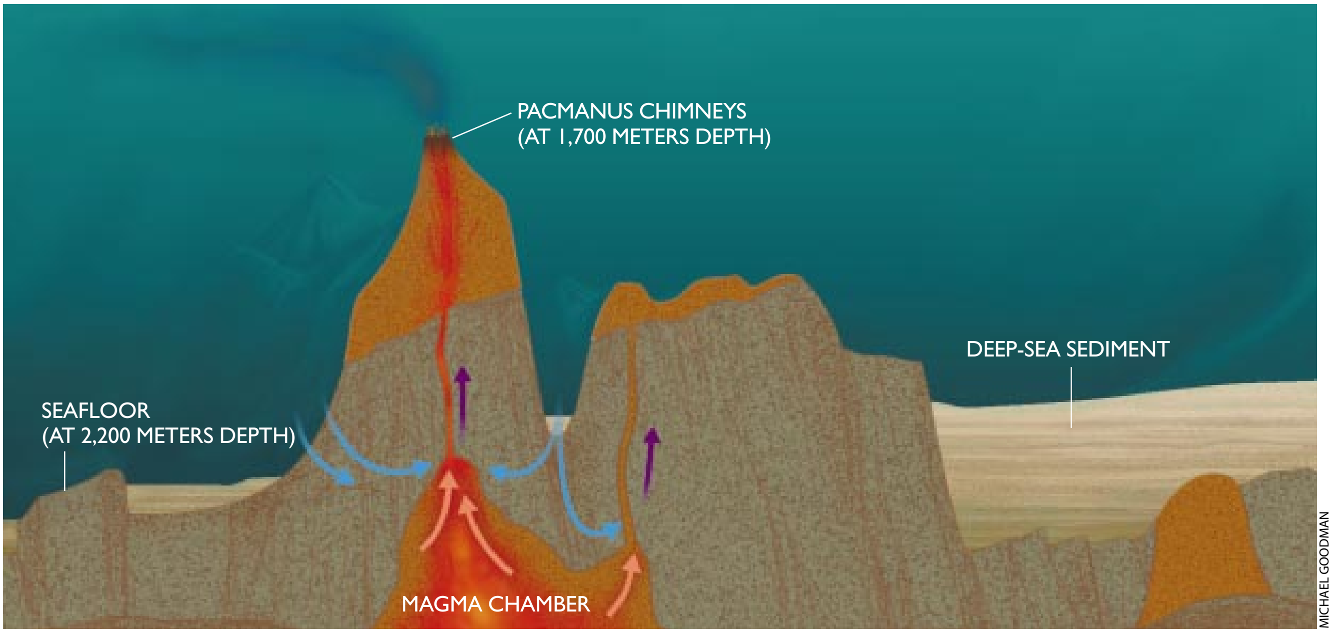
OCEAN MINERALS COMPANY

Of the more than 300 species of organisms since recognized at such sites, the vast majority proved to be new to science. Although tube worms and clams predominate at the hydrothermal vents of the east Pacific and mid-Atlantic, the dominant animals around the active chimneys of the Bismarck Sea are gastropods (snails). On the outside of some chimneys, a square meter of surface can be covered by as many as 400 gastropods, accompanied by bresiliid shrimp, carnivorous bythograeid crabs, scavenging zoarcid fish and galatheid crabs. On the cooler fringes of the hot springs, there are mussels, several newly recognized kinds of anemones and long-necked barnacles, which until recently were thought to have died out with the dinosaurs at the end of the Mesozoic era, 65 million years ago. At Vienna Woods, Russian biologists have measured as many as 5,000 animals packed onto a single square meter of chimney wall.

Clearly, mining these sites would be unacceptable if it threatened this unique biological assemblage. The diversity of these organisms and their potential value to biomedical research or as a source of pharmaceuticals remain largely unknown. But a number of observations suggest that the environmental effects of mining this habitat may not be especially worrisome.

The fauna in question normally tolerate highly acidic waters containing sulfur, thallium, arsenic and mercury. So the release of these substances from mining into the surrounding water should not harm the local biota. Indeed, when the venting of hot water carrying these seemingly toxic elements ceases, the colonies either die or migrate to a more active site. What is more, these vent creatures live quite happily in conditions in which the seawater is thick with particulate smoke as well as clouds of dead and partly mineralized bacteria. And they are perfectly capable of surviving the strong earthquakes that repeatedly disrupt these volcanic fields, snapping tall chimneys like matchsticks and raising tons of sediment into suspension.

Although the vent communities appear quite resilient, great care is still warranted. One cautious strategy would be to mine progressively up-current, selecting sites where the flow would carry clouds of fine particles and other mining debris away from the intact deposit. In this way, if only part of the area is mined, the rest of the deposit and its fauna will remain undis-



MASSIVE SULFIDES of the PACMANUS fields form above a buried magma chamber (*orange*). Cold seawater (*blue arrows*) percolates deep into the crust, where it warms and mixes with fluids from the magma (*pink arrows*). The combination (*purple arrows*) then rises carrying dissolved metals, which drop out of solution at the seafloor, forming sulfide chimneys and particle-laden plumes.

turbed. The creatures living there could then recolonize nearby mined-out areas that were still actively venting.

Hidden Treasures

Even if it were deemed desirable to preserve the vent communities in their entirety, it may still be possible to extract valuable minerals from formerly active chimneys that are now largely devoid of life. The challenge is finding such sites. We have learned how to home in on active hot springs quite readily by following their plumes with special detectors. Yet this method will not lead us to dormant vents. Nor will detailed photographic surveys of the seafloor necessarily reveal older deposits: many of these extinct chimneys are completely covered by the ooze that is forever settling on the bottom.

Fortunately, a variety of geophysical techniques routinely employed to hunt for concealed ore deposits on land can be adapted for use on the seafloor. Gravimetric mapping should detect the larger deposits, and magnetic or electromagnetic techniques could pinpoint smaller accumulations of massive sulfides. Measurements of the resistivity of crust might also delineate buried sulfides (assuming that engineers can find a way to inject electric currents into the seafloor for such surveys). And the natural radioactivity of potassium, uranium and thorium in exposed but inactive chimneys might be sufficient to signal their presence to prospectors towing sophisticated sensors over the seafloor. This technique could provide an easy way to find dormant chimneys without having to conduct laborious video or photographic surveys of the bottom.

Although we are optimistic that the necessary procedures can be worked out so that the vent communities of the Bismarck Sea will not be endangered, we believe mining should not proceed on the basis of what some might call hopeful speculation. Instead a rigorous program of research and testing should precede any decision to move forward with mining, even in a limited way.

At this early stage, as with most ambitious new endeavors, the proposition of mining deep-sea hydrothermal vents is fraught with questions. Yet plucking valuable metals from the bed of the ocean is a tantalizing concept, one that intrigues us immensely. Sizing up the threat to the biota and the true economic potential of these deposits will require an immense effort—but it may ultimately yield immense rewards. SA

The Authors

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Further Reading

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