THE LAST FRONTIER

Sometime this fall, if all goes well, a revolutionary new undersea vessel will be lowered gently into the waters of Monterey Bay for its maiden voyage. Named Deep Flight I, the 14 ft long, 2900 lb vehicle is shaped like a chubby, winged torpedo but flies like an underwater bird. Compared with the hard-to-maneuver submersibles that now haul deep-sea explorers sluggishly around the oceans, Deep Flight is an aquatic F-16 fighter. It can perform barrel rolls, race a fast-moving pod of whales or leap vertically right out of the sea. With a touch on the controls, a skilled pilot - who lies prone in a body harness, his or her head protruding into the craft's hemispherical glass nose - can skim just below the ocean's surface or plunge thousands of feet below.

But Deep Flight I is just a pale prototype of what's to come. Back in their Point Rich-
PROBING THE ABYSS

mond. California, workshop, the craft's designers have already drawn blueprints for its successor, Deep Flight II, an industrial-strength submersible capable of diving not just a few thousand feet but as far as seven miles straight down, to the Mariana Trench—the equivalent of Mount Everest or the South Pole or the moon.

More than 35 years after the bathyscaphe Trieste took two men, for the first and last time, 35,800 ft down to the deepest spot in the world—the Mariana Trench's Challenger Deep just off Guam in the western Pacific—undersea adventurers are preparing to go back. Last March a Japanese robot scouted a tiny section of the bottom of the 1.584-mile-long crevasse and sent back the first real-time video images of deepest-sea life. And in laboratories around the world, engineers are hard at work on an armada of sophisticated craft designed to explore—and in some cases exploit—the one great unconquered place on earth: the bottom of the sea.

The irony of 20th century scientists venturing out to explore waters that have been navigated for thousands of years is not lost on oceanographers. More than 100 expeditions have reached Everest, the 29,028-ft. pinnacle of the Himalayas; manned voyages to space have become commonplace and robot probes have ventured to the outer reaches of the solar system. But only now are the deepest parts of the ocean coming within reach. "I think there's a perception that we have already explored the sea," says marine biologist Sylvia Earle, a former chief scientist at the National Oceanographic and Atmospheric Administration and a co-founder of Deep Ocean Engineering, the San Leandro, California, company where construction of Deep Flight I began: "The reality is we know more about Mars than we know about the ocean."

That goes not only for the sea's utter-

most depths but also for the still mysterious middle waters three or four miles down, and even for the "shallows" a few hundred feet deep. For while the push to reach the very bottom of the sea has fired the imagination of some of the world's most daring explorers, it is just the most visible part of a broad international effort to probe the oceans' depths. It's a high-sea adventure fraught with danger, and—because of the expense—with controversy as well.

But the rewards could be enormous: oil and mineral wealth to rival Alaska's North Slope and California's Gold Rush; scientific discoveries that could change our view of how the planet—and the life-forms on it—evolved; natural substances that could yield new medicines and whole new classes of industrial chemicals. Beyond those practical benefits there is the intangible but real satisfaction that comes from exploring earth's last great frontier.

There's a lot to explore. Oceans cover nearly three-quarters of the planet's surface—336 million cu. mi. of water that reaches an average depth of 2.3 miles. The sea's intricate food webs support more life by weight and a greater diversity of animals than any other ecosystem, from sulfur-eating bacteria clustered around deep-sea vents to fish that light up like Times Square billboards to lure their prey. Somewhere below there even lurks the last certified sea monster left from pre-scientific times: the 64-ft.-long giant squid.

The sea's economic potential is equally enormous. Majestically swirling ocean currents influence much of the world's weather patterns: figuring out how they operate could save trillions of dollars in weather-related disasters. The oceans also have vast re-

FROM LEFT TO RIGHT: CHARLES NICOLIN IMAGES, UNLIMITED, BRUCE ROBINSON, MARTY SHENDYEROWA, FOR THE ROBERT BALLARD AND DARRAH DRIVE TO THE AUGUST GLOBUS EXTENDED TRIP TO THE MARINA, NAKAGO FOR TIMES, BRUCE ROBINSON, NAKAGO. THE SHIPS PROJECT FILE, NICOLIN MINDEN PICTURES.
A two-stage robot that is tethered to the surface was explored by the Challenger Deep last March, it stopped at 35,798 ft., an arm's length short of the Trieste's record.

Proof that there is life at the very bottom of the sea. This 2-in. crustacean was found 36,700 ft. down in the Marianas Trench. Colonies of these mollusks grow near life-sustaining hydrothermal vents. The deepest known population of clams was recently found off Japan at a depth of 20,886 ft.

These superheated structures form in regions where the sea floor is spreading. At depths of 2,600 ft. to 70,000 ft., these potato-size nuggets are rich in iron copper cobalt manganese and nickel.

Commonly found at depths of 14,000 ft. to 17,000 ft., these bottom-dwelling organisms have no mouths. They get their energy from bacteria that live in their stalks.

From bacteria that live in their stalks.

The world's deepest diving mammal is the Pacific Ocean at an average depth of 7.300 ft. These 8-in. long organisms have no mouths. They get their energy from bacteria that live in their stalks.

These fish, found only near vents in the Pacific Ocean at an average depth of 7,300 ft., these 8-in.-long organisms have no mouths. They get their energy from bacteria that live in their stalks.

From bacteria that live in their stalks.

Believed to grow up to 64 ft. long and live as deep as 3,300 ft., these eyes and an enlarged dorsal fin that acts like a sensory antenna.

Sponges divers in ancient Greece breathed from air-filled kettles: bulky- helmeted diving suits linked by hose to the surface first appeared in the 1960s. But it wasn't until scuba came along that humans, breathing compressed air, were able to move about freely underwater at depths of more than 100 ft.

The most experienced scuba divers rarely venture below 150 ft.. However, owing to increasingly crushing pressure and the laborious decompression process required to purge the blood of nitrogen (which can form bubbles as a diver returns to the surface and cause the excruciating and sometimes fatal condition known as the bends). And pressurized diving suits make it possible for humans to descend only to 1,440 ft.—far short of the deepest reaches of the oceans.

Underwater vehicles date back at least to 1620. But it wasn't until Barton's bathy- sphere came along that scientists could descend to any respectable depth. The Bathysphere eventually took Barton and zoologist William Beebe to a record 3,028 ft., off Bermuda. But it wasn't at all maneuverable: it could only go straight down and straight back up again. Swiss engineer Auguste Piccard solved the mobility problem with the first true submersible, a dirigible-like vessel called a bathyscaphe, which consisted of a spherical watertight cabin suspended below a buoyant gasoline-filled pontoon. (A submersible is simply a small, mobile underwater vessel used for science.)

The Trieste, which took U.S. Navy Lieut. Don Walsh and Piccard's son Jacques into the Challenger Deep, was only the third bathy- scape ever built, and unlike modern submersibles—which bristle with advanced underwater cameras, grabbers, collection baskets and manipulator arms—it carried nothing but its passengers. Its mission was to test whether humans could reach the abyss, the first step...
SEAMONSTERS
Creatures that live in the harsh conditions far below the surface have evolved bizarre traits to help them survive, including flatter, crushproof forms; glow-in-the-dark skin; translucent bodies and built-in fishing lures.

In the wake of Trieste's successful dive, the number of submersibles expanded dramatically. The Woods Hole Oceanographic Institution's workhorse, the three-person Alvin (still in operation), was launched in 1964. And the first robots, robot-on-a-tether—the so-called remotely operated vehicles, or ROVs—were developed several years later. The Soviet Union, France and Japan began building their own submersibles, either for military or scientific reasons, and for the first time scientists could systematically collect animals, plants, rocks and water samples rather than study whatever they could dredge up in collection baskets lowered from the surface.

Thus began a remarkable period of undersea discovery that transformed biology, geology and oceanography. Scientists have started to understand, for example, how year-to-year changes in wind patterns and ocean currents that lead to phenomena like the Pacific's El Niño can not only devastate populations of commercially valuable fish but also trigger dramatic shifts in weather patterns. Oceanic fluctuations over much longer time scales, combined with major currents like the Gulf Stream, may start (and bring to an end) planet-wide climatic changes like the Ice Ages.

Scientists have also learned that far from being a flat, featureless plain, the sea floor is rent and wrinkled with a topography that puts dry land to shame. Not only do the seas hold canyons deep enough to hide the Himalayas, but they are also the setting for what is by far the largest geological feature on the planet: a single, globe-circling 31,000-mile-long mountain range that makes its way continuously through the Atlantic, Pacific, Indian and Arctic oceans.

When geologists first visited the midocean range in the late 1970s, they were convinced that it supported the then new theory of plate tectonics. According to this theory, the surface of the earth is not a single, rocky shell but a series of hard "plates," perhaps 30 miles thick and up to thousands of miles across, floating on a bed of partly molten rock. The mid-ocean ridges, geologists argued, were likely locations for planetary crust to be created: the new plate material would be pushed upward by forces from below before it settled back down to form the sea floor.

Rock samples from the Atlantic section of the range—which, when examined closely, proved to be newly formed—provided striking evidence that the theory is correct. But an even more dramatic confirmation came from the Pacific, where black clouds of superheated, mineral-rich water were discovered seeping from chimney-like mounds on the sea bottom—evidence that the rocks below still carried tremendous heat from their relatively recent formation.

These hot gushers, long known as hydrothermal vents, have since been found in many parts of the world, and because they occur at average depths of about 7,300 ft., oceanographers have been able to visit and study a dozen of them. The vents are essentially underwater geysers that work much the same way Old Faithful does. Sea-
water percolates down through cracks in the crust, getting progressively hotter. It doesn’t boil, despite temperatures reaching up to 750°F, because it is under terrific pressure. Finally, the hot water gushes back up in murky clouds that cool rapidly, dumping dissolved minerals, including zinc, copper, iron, sulfur compounds and silica, onto the ocean floor. The material hardens into chimneys, known as “black smokers” (one, nicknamed Godzilla, towers 148 ft. above the bottom).

The chemistry of the vents has provided answers to questions that have perplexed scientists for years. For example, marine geochemists could never understand why the amount of magnesium in seawater remained relatively constant, even though the element is continually eroding into the oceans from dry land. Now they know that magnesium is completely stripped from seawater as it passes through the hot rock—something all the water in the oceans will do every 10 million years.

While academics think of the vents as fascinating natural chemistry labs, capitalists view them as mini-refineries, bringing valuable metals up from the planet’s interior and concentrating them in convenient locations. Oceanographers have long known that parts of the Pacific sea floor at depths between 14,000 ft. and 17,000 ft. are carpeted with so-called manganese nodules, potato-size chunks of manganese mixed with iron, nickel, cobalt and other useful metals. In the 1970s, Howard Hughes used the search for nodules as a cover for building the ship Glomar Explorer, which was used to salvage a sunken Soviet sub. Now several mining companies are drawing up plans to do with more up-to-date equipment what Hughes only pretended to do.

If the discovery of the vents was a major surprise, scientists were astonished to learn that at least some of these submerged geysers—whose hot, sulfurous environs bear more than a passing resemblance to hell—are actually bursting with life. Nobody had invited biologists along to study the vents because nobody imagined there would be anything to interest them. But on a dive off the Galapagos in 1977, researchers found the water around a vent teeming with bacteria and surrounded for dozens of feet in all directions with peculiar, 3-in.-long tube-shaped worms, clams the size of dinner plates, mussels and at least one specimen of a strange pink-skinned, blue-eyed fish.

Recalls biologist Holger Jannasch...
Woods Hole in Massachusetts. "I got a call through the radio operator at Woods Hole from the chief scientist ... who said he had discovered big clams and tube worms, and I simply didn't believe it. He was a geologist, after all." Disbelief was quickly replaced by intense curiosity. What were these animals feeding on in the absence of any detectable food supply? How were they surviving without light? The answer, surprisingly, had been found by a Russian scientist more than 100 years earlier. He had shown that an underwater bacterium, *Beggiatoa*, lived on hydrogen sulfide, a substance that is highly toxic to most forms of life. The bacterium was chemosynthetic—as opposed to photosynthetic—getting its energy from chemicals rather than from the sun.

The bacteria around the vents, in turn, were living inside the mollusks and worms, breaking down other chemicals into usable food—an ecological niche nobody had suspected they could fill. Many biologists now believe that the very first organisms on earth were chemosynthetic as well, suggesting that the vents may well be the best laboratory available for studying how life on the planet actually began.

Do scientists expect even more surprises as they venture farther below the surface? The question is a crucial one, as both scientists and policymakers debate the finances of deep-sea exploration. Most everyone acknowledges that there is some value in studying the oceans. It's expensive, though, and because of generally tight budgets, even the few existing manned submersibles (which in any case are rated only for depths above 20,000 ft.) often have to sit idle. Building more strikes some as a waste of money.

That includes some scientists. Although he has never been to the very deepest trenches, ocean explorer Robert Ballard of Woods Hole, who is best known for discovering the wreck of the *Titanic* in 1985, is convinced that the action lies in the relative shallows. "I believe that the deep sea has very little to offer," he says. "I've been there. I've spent a career there. I don't see the future there." The French have decided not even to bother trying to break the 20,000-ft. barrier—the range of their deepest-diving submersible, the three-person Nautilus. Says Jean Jarry, director of the Toulon-sur-Mer research center of IFREMER, France's national oceanographic institute. "We think that's a good depth because it covers 97% of the ocean. To go beyond that is not very interesting and is very expensive."

But that attitude is far from universal. Biologist Greg Stone, of the New England Aquarium in Boston, compares reaching the deepest abyss with Christopher
Columbus’ search for the New World. “Why should we care about the deepest 3% of the oceans, and why do we need to reach it?” he asks rhetorically. “For one, we won’t know what it holds until we’ve been there. There will certainly be new creatures. We’ll be able to learn where gases from the atmosphere go in the ocean. We’ll be able to get closest to where the geological action is. We know very little about the details of these processes. And once we’re there, I’m sure studies will open up whole sets of new questions.”

Only the richest countries can afford to explore these questions, of course, and while most expeditions are made up of scientists from many lands, the world’s deep-sea powers—the U.S., France, Japan and, until economic troubles all but ended its program, Russia—are always aware of who’s ahead in the quest for the bottom. At the moment, it’s probably Japan, not least because of the triumphant touchdown in the Challenge Deep last March of its 10.5-ton, $41.5 million ROV called Kaiko. The Japanese got into ocean research well after the French, Americans and Russians. But the country has made up for lost time. Says Brian Taylor, a marine geologist at the University of Hawaii and a sometime visiting scientist at the Japan Marine Science and Technology Center (JAMSTEC): “The Japanese are on the leading edge.”

The Japanese, to be sure, are always interested in new market opportunities. But they have a more compelling need to understand the ocean floor: the southern part of the island nation has the bad luck to sit on the meeting place of three tectonic plates. As these plates grind against each other, they generate about one-tenth of the world’s annual allotment of earthquakes, including plenty of lethal quakes like the one that killed 5,500 people in Kobe in January and the famous 1923 Tokyo temblor in which more than 142,000 perished.

The desperate need to anticipate future quakes is one reason JAMSTEC built the Shinkai 6500 submersible, which can go deeper than any other piloted craft in the world. On its very first series of missions in 1991, Shinkai found unsuspected deep fissures on the edge of the Pacific plate, which presses in on the island nation from the east. The vessel has also discovered the world’s deepest known colony of clams (at a depth of more than 20,000 ft.) and a series of thickly populated hydrothermal vents.

Unlike the French and some Americans, though, the Japanese feel a need to go all the way to the deepest reaches of the ocean. A case in point was Kaiko’s dive to the bottom of the Challenger Deep. JAMSTEC engineers watched

DEEP-SEA ICONOCLAST Though Ballard found the sunken Titanic, he’s now convinced that the deepest part of the ocean isn’t worth visiting
anxiously on a video screen, the robotic craft spent 35 min. at a depth of 35,798 ft.—2 flt. of Trieste’s 1960 record. But during that brief visit, Kaiko saw a sea slug, a worm and a shrimp, proof that even the most inhospitable place on earth is home to a variety of creatures. Next winter Kaiko will return to the deep for to look for more signs of life.

Japan’s latest success adds fuel to yet another debate about deep-sea exploration. Some scientists insist that remote-controlled, robotic craft are no substitute for having humans on the scene. Says Mabari’s Robison: “Whether you’re a geologist or a biologist, being able to see with your own eyes is vital. That’s a squify-sounding rationalization, but it’s true.” There are other advantages too, he notes. “The human eyes are connected to the best portable computer there is [the brain]. And when things go wrong, a person can often fix them faster, more easily and more efficiently than a robot can. Look at the Hubble Space Telescope repair mission.”

But others argue that robots—whether tethered, like Kaiko or untethered, like the new generation of autonomous underwater vehicles known as AUVs—can do the job just as well. Not only are they much cheaper to build and run than human-operated submersibles, but they can also work for long periods under the most hazardous of conditions. Moreover, remotely operated vehicles such as Kaiko put scientists on the scene, at least in a virtual sense, through video images piped in real time through the fiber-optic cable. Researchers can gather around a monitor and discuss what they are seeing without distractions. “You’re focused,” says Ballard. “You’re not thinking, Is there enough oxygen in here? I’ve got a headache. I just hit my head. I’ve got to go to the bathroom.”

The cheapest way to explore the ocean floor, however, may be with the free-floating AUVs, which can roam the depths without human intervention for months on end. Although they cannot yet provide real-time pictures, they can stay on the bottom as long as a year, patiently accumulating data. Two American AUVs—a government- and university-funded craft called Odyssey and Woods Hole’s Autonomous Benthic Explorer—have just completed tests off the coast of Washington and Oregon. Eventually, fleets of these robots could communicate among themselves to provide information in the most efficient way, periodically surfacing to beam their data to researchers on shore.

Most scientists think the ideal solution would be to use a mix of all three types of vehicles. There is no shortage of designs—but many may never be built. Even Japan’s JAMSTEC, whose constantly growing research budget is reasonably secure for now, has its limitations. In the event of a severe economic slump, says Takeo Tanaka, a planning official for the agency, “we may not be able to get funding for new deep-sea probes.” France has no plans to build more manned company paid IREMÉR for an ultimately unsuccessful attempt to find the sunken airplane of French author and aviator Antoine de Saint-Exupéry.

In the U.S., the most innovative new designs in underwater craft are coming from such private companies as Deep Ocean Engineering. Founded by marine biologist Earle and British engineer Graham Hawkes in 1981 (they married in 1986 but have since divorced), the firm designs and builds underwater exploration vehicles on commission, mostly for the oil and gas industry, various navies, universities and even film crews. The two Deep Flight I vehicles, which Hawkes began with the company but completed independently, were financed by several film and television firms and Scientific Search Project, a marine-archaeology company.

Paradoxically, forcing submersible design into the competitive marketplace may prove to be a boon to underwater research. A new version of Shinkai 6500 would cost perhaps $100 million and require a new surface ship as well. Says Hawkes, who designed Deep Flight and will put it through its initial paces. “That’s so expensive that they’ll only build one, which means it could only be in one place at a time.” Deep Flight, he says, could cut through this impasse. “If we’re successful, it will show that we can access the bottom of the ocean in vehicles costing $5 million. They’re so small and light you can send them anywhere.”

Hawkes’ eventual goal is to give away the plans for Deep Flight I free to anyone who wants them. When Deep Flight II is finished, he hopes, trips to the deepest abyss could become almost routine. Today, the larger craft is still looking for a patron, but Hawkes is un daunted. “We’ll get the funding,” he says confidently. “After all, one Deep Flight cost less than what you need for an America Cup campaign—and the payoff is 10 times a rewarding.”

He is probably right. Despite the budget cuts, despite the inhospitable environment despite the pressing danger, there is little doubt that humans, one way or the other, are headed back to the bottom of the sea. The rewards of exploring the coldest, darkest waters—scientific, economic and psychological—are just too great to pass up. Ultimately, people will go to the abyss for the same reason Sir Edmund Hillary climbed Everest because it’s there. —Reported by Andrea Dorman/San Leandro, Irene M Kunii/Tokyo, Alice Park/Woods Hole and Tat Skari/Paris