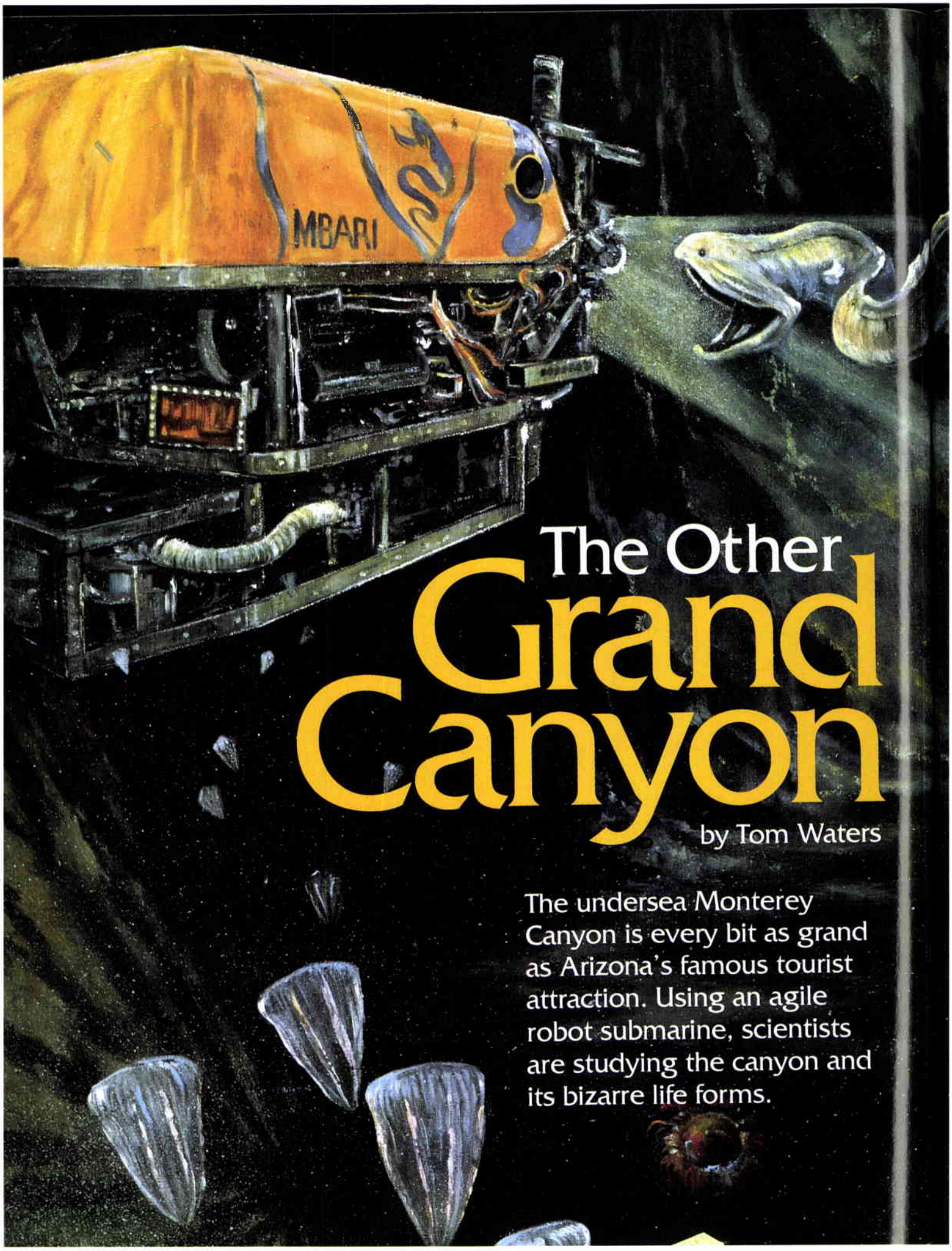
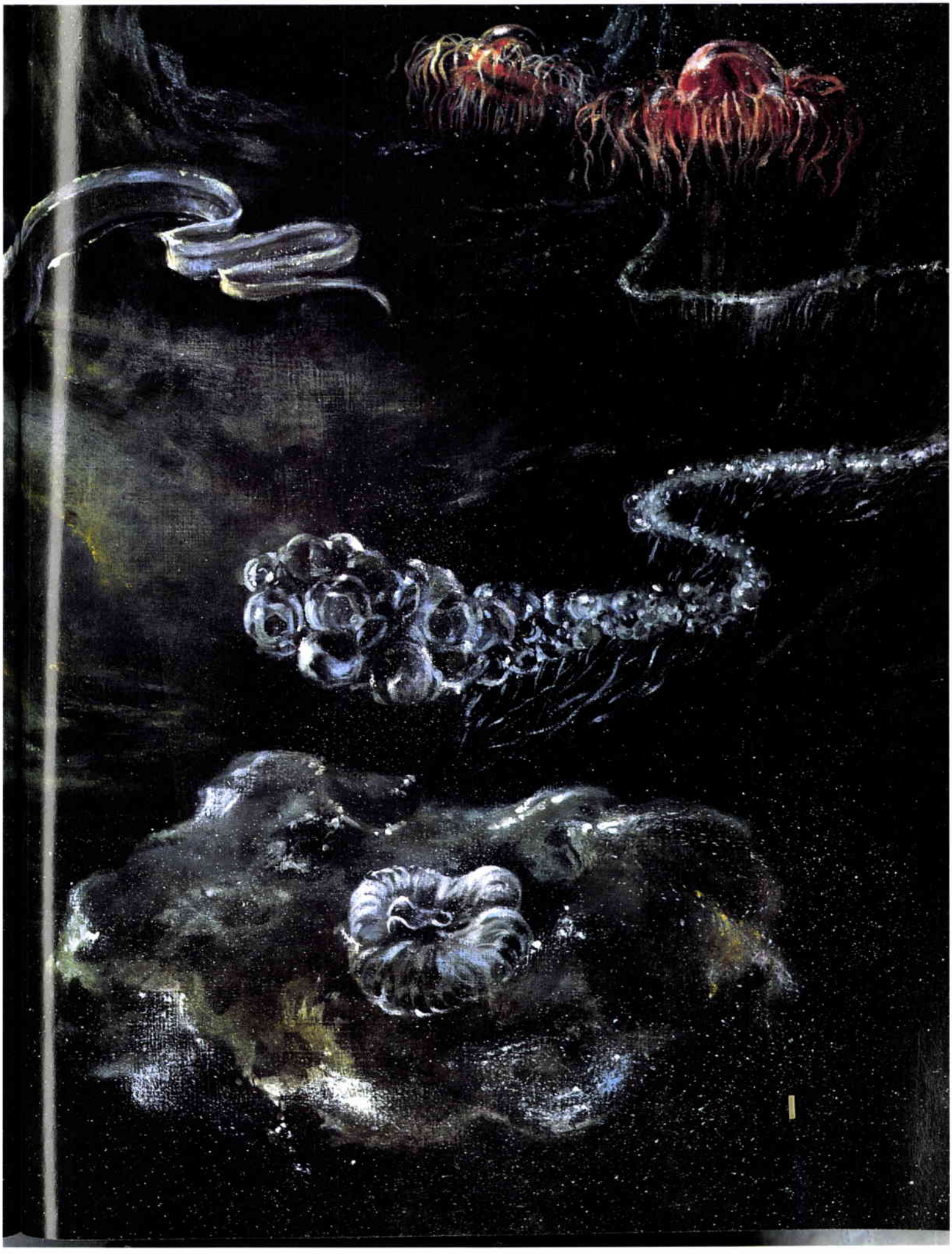
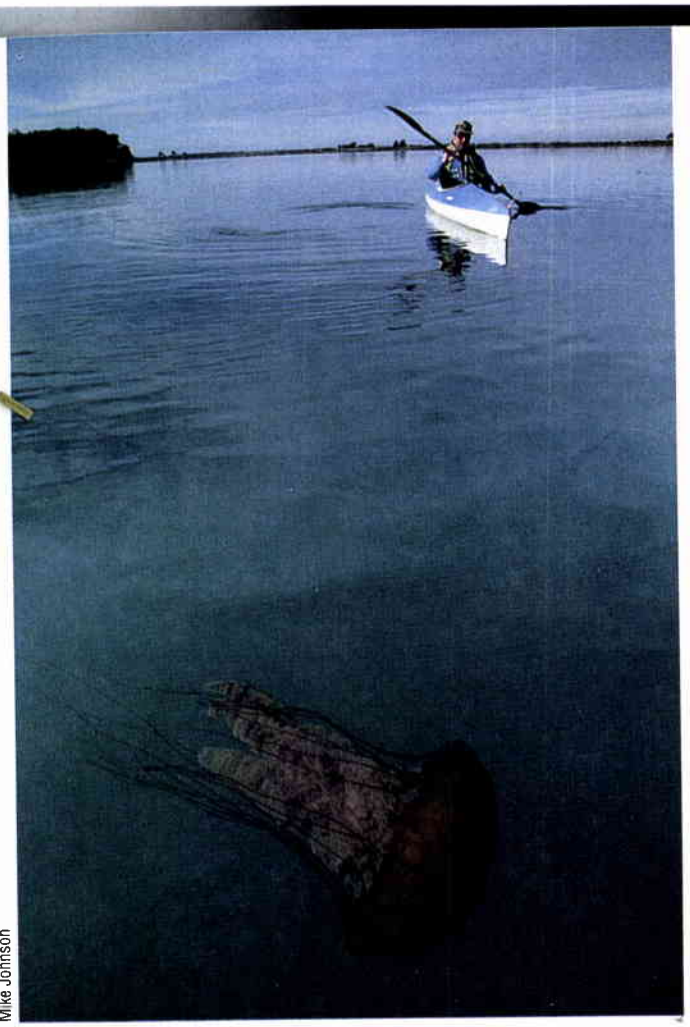


The Other Grand Canyon

by Tom Waters

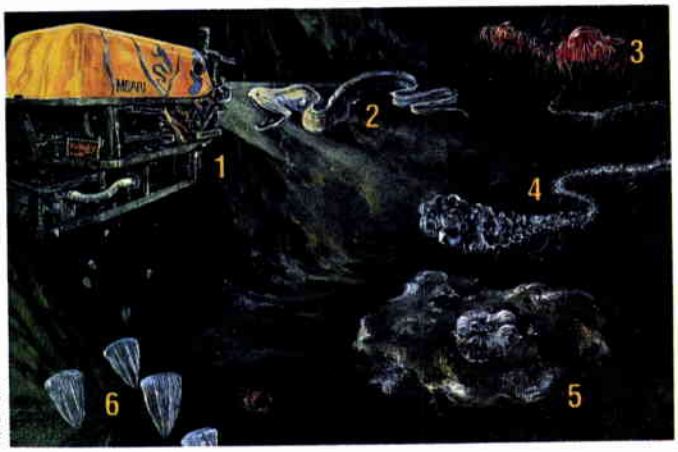
The undersea Monterey Canyon is every bit as grand as Arizona's famous tourist attraction. Using an agile robot submarine, scientists are studying the canyon and its bizarre life forms.





Mike Johnson

A lone kayaker watches as a jellyfish drifts by in Elkhorn Slough, which empties into Monterey Bay. Just a few miles west of these sluggish waters, a grand undersea canyon plunges to depths of nearly 8,000 feet, where jellyfish like this one and a host of other elusive midwater creatures inhabit a dark world that scientists have just begun to explore.



Karen Carr

1. The tethered submersible Ventana, exploring one of Monterey Bay's side canyons. 2. A gulper eel, caught in one of the Ventana's headlights. 3. Jellyfish feed on marine snow (white specks) and on other creatures in the middle depths. 4. A siphonophore, a chainlike predator composed of many individual animals. 5. A larvacean, which builds a mucus "house" around itself to strain food from the water. 6. Ctenophores, one of the many kinds of life forms that haunt Monterey Canyon.

Almost every working day, the research vessel Point Lobos heads out into Monterey Bay, a clamshell-shaped cutout in the California coast 65 miles south of San Francisco. When the ship reaches open water, the scientists and crew on board find themselves amidst several of the state's geological splendors: to the north, the mountains of the Santa Cruz Range; to the east, the high sand dunes on the bay's shore; and to the south, the jagged granite cliffs of the Monterey Peninsula.

Beneath the surface of the bay lies another splendor seen only by a lucky few: Monterey Canyon. Hidden from view by thousands of feet of water, this submarine chasm is as grand as Arizona's famous tourist attraction, possessing steep, rocky precipices and a series of curving meanders inhabited by strange and elusive marine life. West of the Monterey Peninsula, the canyon walls gradually drop an incredible 7,360 feet (2,300 meters) — a quarter mile more than the highest cliff of the Grand Canyon.

Monterey Canyon is part of a much larger geologic feature, the Monterey Canyon System, comparable in size to the 278-mile-long Grand Canyon. The 60-mile-long gorge empties into the gently sloping Monterey Sea Valley. The valley continues out into the Pacific Ocean for an additional 180 miles until it reaches the flat abyssal plain of the Pacific Ocean.

Even so, Monterey Canyon is not the world's largest undersea chasm. But to marine researchers, it is surely the most convenient. At the port of Moss Landing, where the Point Lobos is berthed, the head of the canyon is within yards of the coast. From here, the floor of the canyon begins its gradual descent to a depth of nearly 8,000 feet.

Cold, nutrient-rich water that flows into the bay from the north sustains kelp forests, fisheries and thriving colonies of seals and other marine mammals. The bay's richness also helps sustain five research institutes, including the Monterey Bay Aquarium Research Institute, a private organization founded in 1987 by David Packard, cofounder of the Hewlett-Packard Company.

MBARI operates the Point Lobos and its most important (and expensive) passenger: a tethered robot submersible called Ventana, Spanish for "window." The Ventana — referred to routinely as the ROV, or "remotely operated vehicle" — enables scientists from the Institute and other research institutions to study Monterey Canyon's geology and inhabitants without having to go there in person.

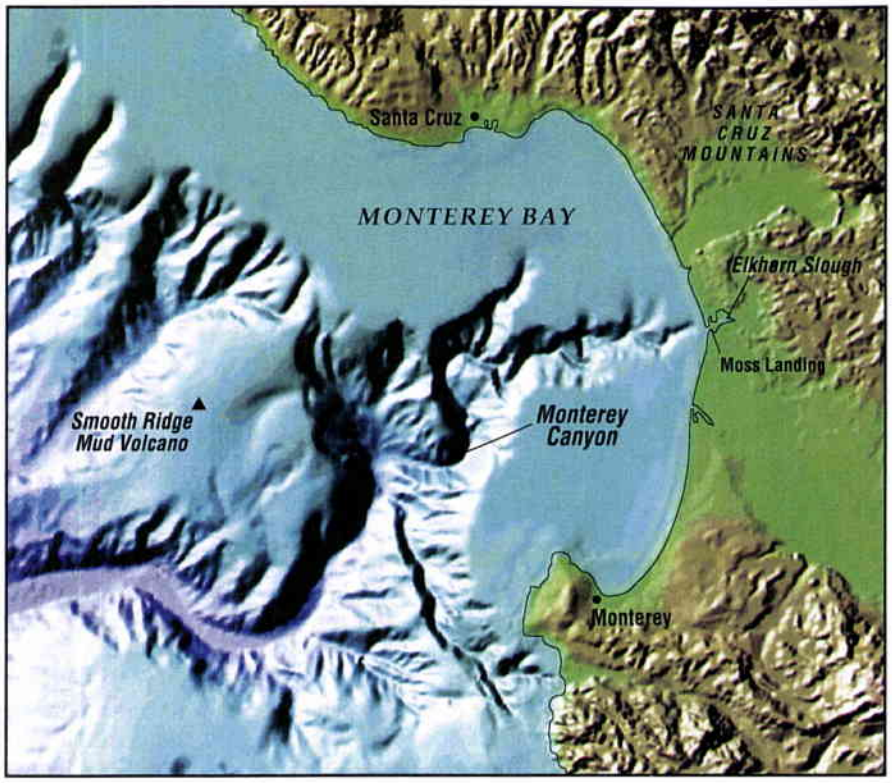
There's plenty of territory for these scientists to cover. In the bay's sunless middle depths, otherworldly creatures drift through the darkness, feeding on the blizzard of organic material, or "marine snow," from above. In the canyon itself and its various side branches, dense colonies of clams, tube worms and bacteria feed on chemical-rich fluids oozing from underwater springs called cold seeps.

Monterey Canyon's geology, too, is a focus of intense study. Although its geologic history is understood in its essentials, the details of how it was carved

out of the continental shelf are not yet completely known.

A more practical concern for the geologists who study the canyon is the hazards posed by the earthquake faults that slice through the bay's solid foundation. The faults are known to be active, but it is not as clear just how often they can be expected to slip and unleash significant earthquakes on the nearby cities of Monterey and Santa Cruz.

To the scientists who work in the bay, these unanswered questions represent a chance to do original research in a little understood place. According to Bruce Robison, a marine biologist at MBARI, doing research in the depths of Monterey Canyon is reminiscent of natural history's heroic age, when naturalists traveled to the remotest corners of the globe in search of new plants, animals and geological wonders. "We're like nineteenth-century explorers who get to use twentieth-century technology," Robison says, "and that's pretty rare."



EARTH: Steven G. Davis. Canyon topography by Norman Maher/MBARI

Monterey Canyon and the many chasms that empty into it have been carved out of the edge of the continent during the past 20 million to 25 million years.

Monterey Canyon was carved out of the continental shelf over the past 20 million to 25 million years. That's the easy part of the story. But if you want to understand the canyon's complex history, you go to Gary Greene. Formerly with the U.S. Geological Survey, Greene has studied the canyon for some 30 years; in fact, he was the first scientist to explore its depths in a manned submersible. He now heads Moss Landing Marine Laboratories and works closely with geologists from the Institute.

When submarine canyons were first discovered, geologists assumed that they actually started out as canyons on dry land at a time when sea level was lower. Then, the theory went, the canyons were submerged by a rise in sea level. But there was one problem, Greene says: Not all undersea canyons lie near a river old and energetic enough to have carved such chasms. A bigger, older knife was needed.

In the 1930s, geologists found a mechanism that could, given enough time, cut even the grandest undersea canyons: turbidity currents. These are enormously powerful underwater debris flows, a dense slurry of sea water, rock debris of various sizes and fine sediments. They cascade down underwater slopes at high speed, scouring away rock and sediment. Over millions of years, most geologist now believe, turbidity currents have carved undersea canyons as surely as the Colorado River has cut the Grand Canyon.

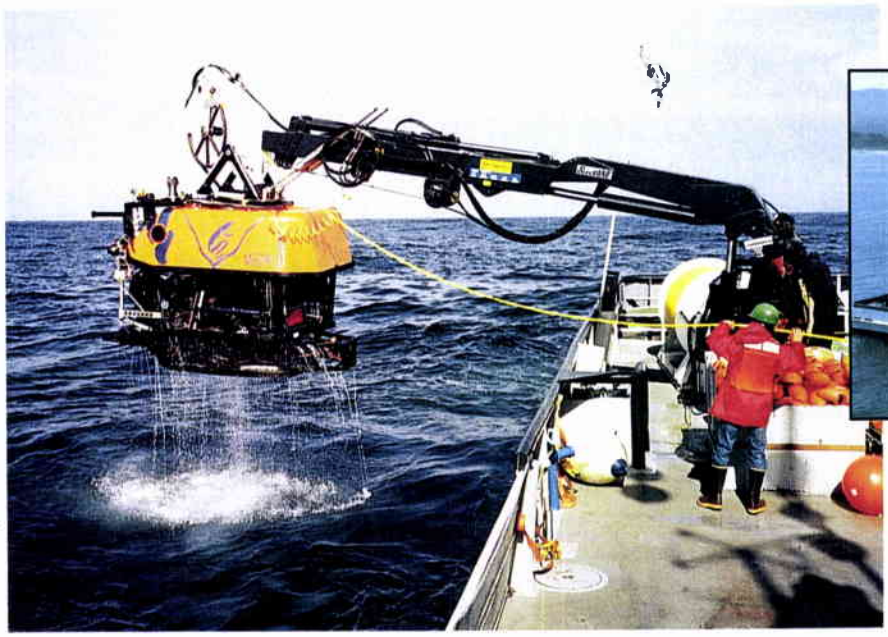
In the 1960s, Greene took on the challenge of explaining Monterey Canyon's history. By then, it was clear that turbidity currents had excavated the world's undersea canyons. Subsequently, Greene discovered evidence that they had carved Monterey Canyon along an ancient fault that once ran east to west across the bay. Turbidity currents eroded the weakened rock along this fracture, cutting a groove that channeled subsequent turbidity currents. With each new debris flow that cascaded down the fault zone, the canyon got slightly deeper.

But turbidity currents alone fail to explain the canyon's particular shape, including its several sharply curving meanders. Other undersea canyons are more or less straight, resembling the gullies eroded in bare hillsides during a heavy rain. Why is Monterey Canyon crooked? Once again, Greene found an answer in the network of faults that run through the bay.

Many of these faults run north by northwest to south by southeast. Greene reasoned that as blocks of crust slipped by each other along the north-south faults, offsets were introduced into the roughly east-west course of the canyon (akin to the way slippage along California's San Andreas Fault has, over many years, offset streams, fence lines and roads that cut across it). Turbidity currents gradually bridged the offsets, resulting in meanders.

Today, most geologists agree that turbidity currents played the greatest role in carving the canyon. But there's also circumstantial evidence that another process, called freshwater sapping, has cut some of Monterey's side canyons and may have helped shape parts of the main canyon as well.

Greene says there's evidence that at times in the



Courtesy MBARI/Jenny Paduan

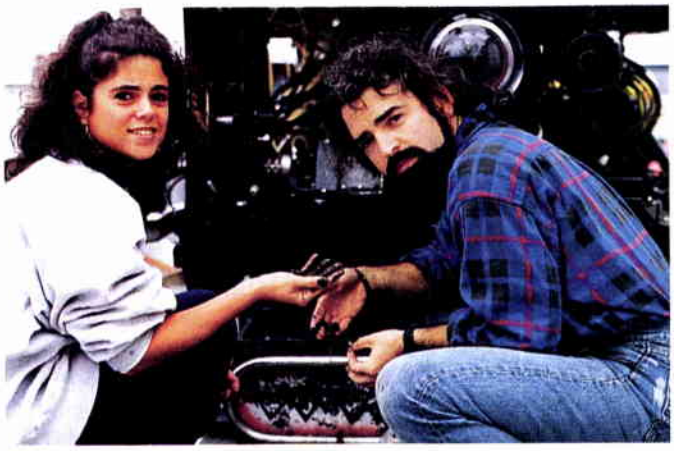
Courtesy MBARI

The Ventana (above), a robot submersible operated by the Monterey Bay Aquarium Research Institute, is winched onto its support ship, the Point Lobos (right) after a mission. Trailing a 7,000-foot fiber-optic tether, the Ventana can dive to depths of 6,000 feet.

past when the climate was wetter, huge amounts of water from the Santa Cruz Mountains flowed into the canyon through tilted aquifers. The water bubbled out of the canyon walls, which cut across part of the sandstone layer that forms the aquifer. This undermined the slopes of the canyon, triggering landslides.

Greene believes that freshwater sapping may have sculpted the canyon's slopes here and there, playing second fiddle to turbidity currents. But his younger colleague, MBARI geologist Dan Orange has some doubts about that. In fact, in speculative moments he wonders if freshwater sapping could have played a much larger role. As water seeped up through the bay's ancient east-west fault zone, could it have cut the initial groove that, tens of millions of years later, evolved into the vast Monterey canyon?

At the moment, too little is known about Monterey Canyon's plumbing system — the network of cracks and faults in the bay's foundations — to allow Orange to transform his speculations into a testable scientific idea. The answers to his questions lie on the canyon floor, beyond the reach of human divers. That's where the Ventana comes in.



Courtesy MBARI/Patricia Parisi

Graduate student Leslie Kahn and Institute geologist Dan Orange sift through cold-seep clams brought up from the depths of Monterey Canyon by the Ventana.

It's 7 a.m. on a typical work day for the scientists and crew on the Point Lobos. Today, with the help of two skilled pilots, Orange will take the Ventana down more than 3,000 feet to a wart of marine sediment called the Smooth Ridge Mud Volcano. No Mount Fuji, this volcano is just a shallow dome about 1,000 feet across and six feet high.

Orange and Greene suspect that the volcano formed when a buoyant mixture of water and gas erupted through the floor of the bay from a layer of oil-producing rock several miles below. This layer, called the Monterey Formation, contains ancient marine sediments rich in organic material. The eruption opened a channel to the surface, terminating at a spongy path of sediment on the volcano's slightly flattened peak. This patch marks the location of one of the canyon's dozen known cold seeps.

Marine biologists who work at the Institute are fascinated by the cold seeps because of the colonies of clams and tube worms they nourish. Indeed, one of the most active areas of research is the ecology of the cold-seep animals. But Orange focuses on their place in the plumbing system of the bay, the collection of channels, faults and aquifers that pipe water from various sources to the cold seeps scattered throughout the canyon. "I call myself a crustal Roto-Rooter man," Orange says. "I'm interested in where the cold-seep fluids come from and what controls the flow."

Figuring that out could have some pretty important implications. Shifts in Earth's crust prior to earthquakes are known to affect the flow or chemistry of subterranean fluids, chiefly groundwater. Orange says it's conceivable that by monitoring similar changes in Monterey Canyon's plumbing it might be possible to