Light in the Ocean's Midwaters

Beneath the surface of the ocean, sunlight is gradually extinguished, but the resulting darkness yields to a host of bioluminescent creatures

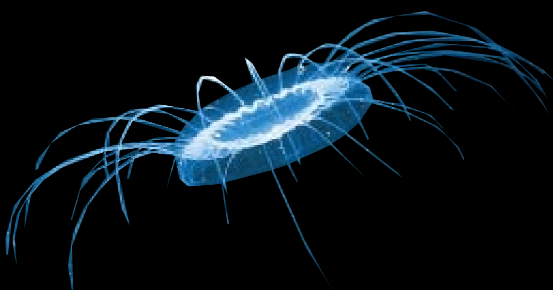
by Bruce H. Robison

HATCHETFISH
Sternoptyx diaphana
(2.5 to 9.0 centimeters)

FANGTOOTH
Anoplogaster cornuta
(15 centimeters)

JELLYFISH
Catablema sp.
(Bell diameter: 4 centimeters)

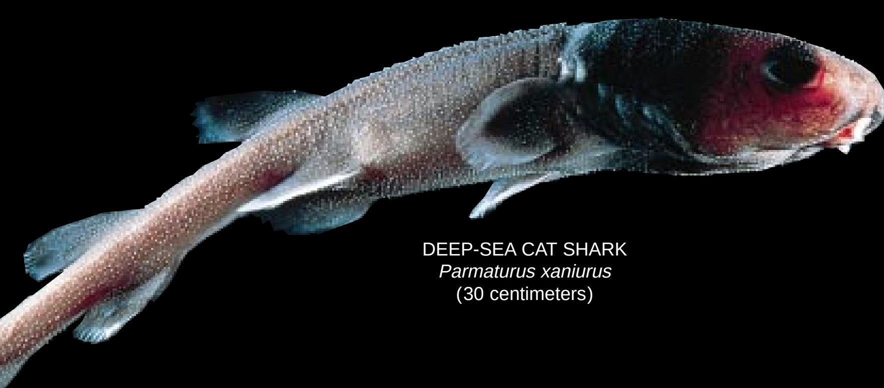
Vampyroteuthis infernalis
(25 centimeters; inverted configuration at right)



NARCOMEDUSA
Solmissus marshalli
(Bell diameter: 15 centimeters)

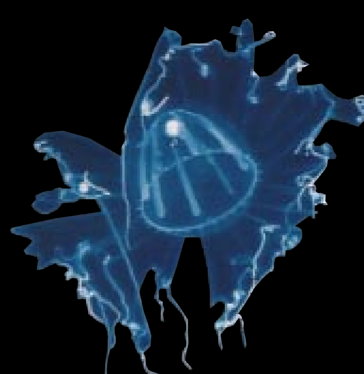
SNIPE EEL
Nemichthys scolopaceus
(1 meter)

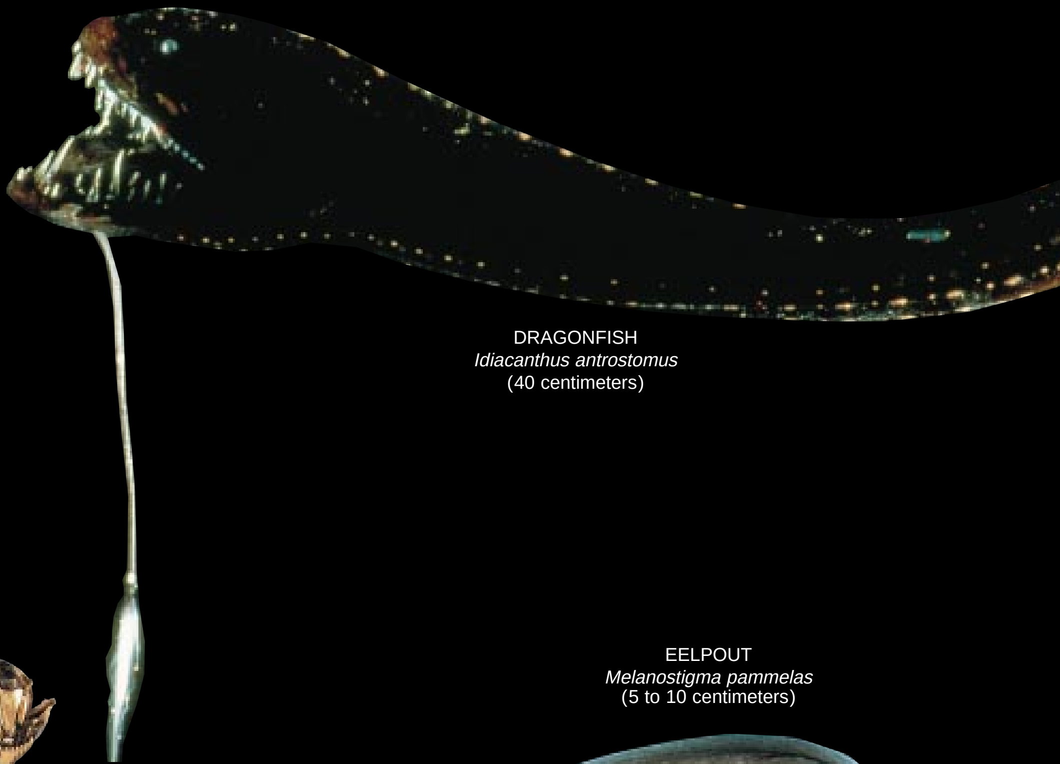
Periphylla periphylla
(Bell diameter: 7 centimeters)



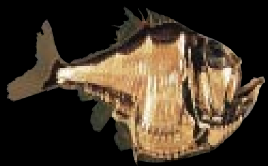
DEEP-SEA CAT SHARK
Parmaturus xaniurus
(30 centimeters)

Colobonema sericeum
(Bell diameter: 2.5 centimeters)





DRAGONFISH
Idiacanthus antrostomus
(40 centimeters)

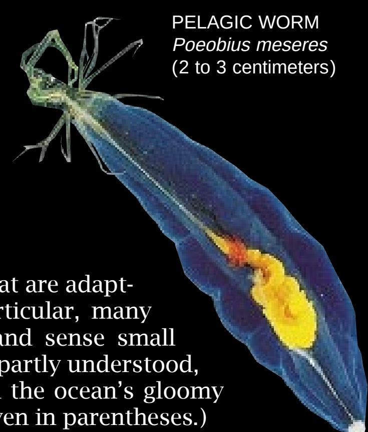


HATCHETFISH
Argyropelecus pacificus
(3 to 9 centimeters)

EELPOUT
Melanostigma pammelas
(5 to 10 centimeters)

CTENOPHORE
Beröe
(5 to 12 centimeters)

PELAGIC WORM
Poeobius meseres
(2 to 3 centimeters)



CREATURES OF THE MIDWATERS take diverse forms that are adapted to their environment in a variety of ways. In particular, many fishes, squids and gelatinous animals can produce and sense small amounts of light. The role of such illumination is only partly understood, and for many animals it remains a mystery hidden in the ocean's gloomy depths. (Approximate sizes of those shown here are given in parentheses.)

BRUCE H. ROBISON; SEA STUDIOS (jellyfish, pelagic worm, ctenophore); KIM REISENBICHLER (*Vampyroteuthis*)

The most expansive animal habitat on the earth lies between the sea surface and the floor of the deep ocean basins. Within this enormous volume live the largest and perhaps most remarkable biological communities anywhere. Yet because this region is so foreign to the world of normal human experience, we still know extraordinarily little about its fauna. But the quest to understand the nature and behavior of these unfamiliar organisms has been making steady progress. Over the past few years my colleagues and I at the Monterey Bay Aquarium Research Institute in northern California have been able to explore the ocean below the sunny surface waters and to examine local ecology from the novel perspective that modern oceanographic technology affords. And, as is often the case when one gets to view something from an entirely new vantage point, that undersea world looks very different from what we had imagined.

My studies of the biology of the ocean's midwaters—a zone that reaches from about 100 meters to a few kilometers below the surface—have benefited enormously from countless hours spent on board *Deep Rover,* a one-person research submarine. Less adventurously but just as effectively, my work has also taken advantage of a remotely operated vehicle (or ROV) named *Ventana,* a maneuverable, computerized platform about the size of a small car that is fitted with an arsenal of cameras, instruments, sensors and samplers.

These two underwater vehicles boast capabilities that far surpass the relatively crude tools that supported previous midwater research. During the 1950s, for example, the marine biologist Eric G. Barham of Stanford University also examined the ocean near Monterey Bay, but at that time he was limited to using sonar and trawl nets towed behind a ship to identify and track the movements of midwater fauna. In the course of his pioneering studies he uncovered a rather limited set of animals—shrimps, lanternfish, squids and arrow worms—and determined the broad patterns of their vertical migrations, from depths of around 300 meters during the day, up to the surface layers at night.

But with the primitive technology then available, Barham's early research missed a tremendous amount of detail in the ocean simply because he could not view it directly. With *Deep Rover* and *Ventana* my colleagues and I have found that the ocean's midwaters contain a far greater variety of organisms than Barham could possibly have caught in his nets: some forms of sea life are simply too fragile to be extracted from

Exploring the Midwaters with Camera and Robot

The submersible *Deep Rover* can carry a single occupant to depths in the ocean as great as one kilometer for up to eight hours at a time. The vehicle's transparent passenger housing—constructed from a massive acrylic sphere 160 centimeters in diameter and 13 centimeters thick—offers the pilot panoramic views of the surrounding waters. The pods underneath the sphere contain banks of lead-acid storage batteries that power the vehicle's lights, electric thrusters and hydraulic manipulator arms, as well as its many other pieces of scientific, navigational and life-support equipment.

In contrast to submersibles such as *Deep Rover, Ventana*—a remotely operated vehicle (ROV)—carries no pilot on board. Instead controllers communicate with the underwater robot through a cable attached to *Ventana*'s support ship. Electric power for lights, thrusters and other equipment passes continuously downward through copper conductors within the umbilical tether, and data and video images travel upward, encoded on optical fibers at the core of the cable. Keeping vigil at the monitors of a shipboard console, scientists and pilots control *Ventana*'s movements and can, if need be, maintain the vehicle's subsurface research tasks around the clock.

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***DEEP ROVER* submersible vehicle hovers inches above the surface—just before its deployment.**

***VENTANA* rises from the sea, lifted by a crane on the support ship (*left*). The front of *Ventana*'s frame supports cameras, sensors, samplers and a mechanical arm (*bottom center*). Pilot and scientist operate the vehicle together from a control room on board the ship (*bottom right*).**

their supportive, watery environment. In many respects, we now think of this delicate marine life as *forming* much of that midwater environment.

Among the larger pieces of biological substratum pervading this region are the bodies of gelatinous animals, along with their extended feeding structures and discarded body parts. The most striking contributions of this kind in Monterey Bay are generated by the elongate siphonophores, linear assemblages that can stretch as much as 40 meters—making them some of the longest creatures on the earth. Whether these animals should be regarded as organized colonies of individuals or as a single, complex superorganism remains unclear. I think of them as living drift nets.

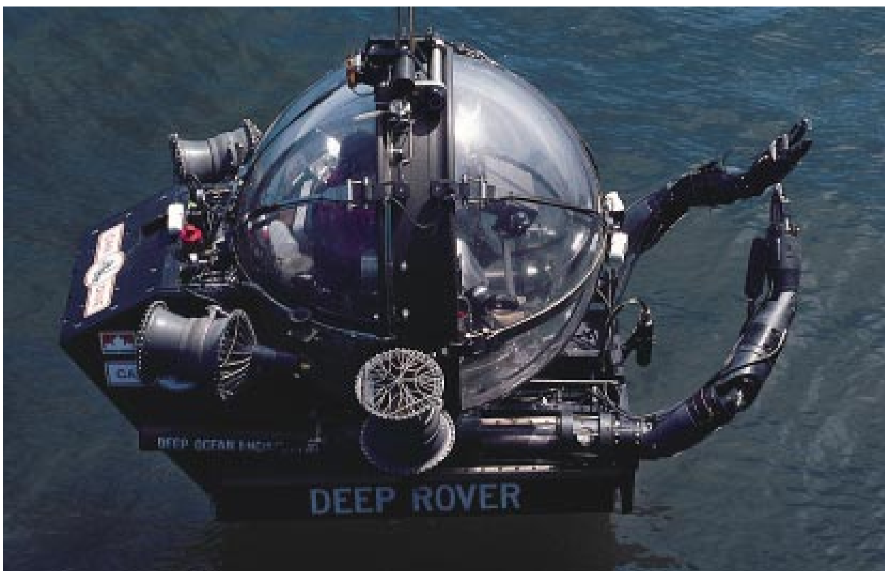
Another part of the biological backdrop common in midwater is composed of the balloonlike feeding filters of animals called appendicularians. The most prominent examples are those produced by the giant form, *Bathochordaeus,* an animal that secretes sheets of mucus that look to an underwater observer like floating islands. Because a multitude of midwater animals regularly cast off feeding structures and other body parts, at times the water can become thick with them.

The best way to visualize the midwater environment might be to imagine a dim, weightless world filled with ragged, three-dimensional spiderwebs. Although my colleagues and I have made a host of surprising discoveries about this wispy realm during our explorations, perhaps the most intriguing result to emerge from these efforts to probe the ocean's darkness has been an appreciation for the role of light.

Life in the Twilight Zone

Marine biologists had for decades believed that sunlight could penetrate perhaps 300 to 400 meters below the surface of the sea before it became too weak to support vision—a belief they held despite their knowledge that fishes and squids with large, highly developed eyes lived at depths below these levels. But now that we have been able to observe denizens of supposedly dark parts of the ocean, it is becoming clear that these animals are in fact influenced by the tiny amount of sunlight that does filter down to their abode.

Not until I was able peer directly into this world could I begin to appreciate what the midwater habitat is really like. Submerged alone in *Deep Rover* more than half a kilometer below the surface, I have often switched off the lights of the submarine and looked out at the blackness that surrounds the vehicle's transparent passenger sphere. After letting my eyes fully adjust, I can perceive only that looking up is somewhat less dark than looking down. Yet it has become clear to marine biologists that a variety of animals must utilize this subtle difference. Moreover, we have be-



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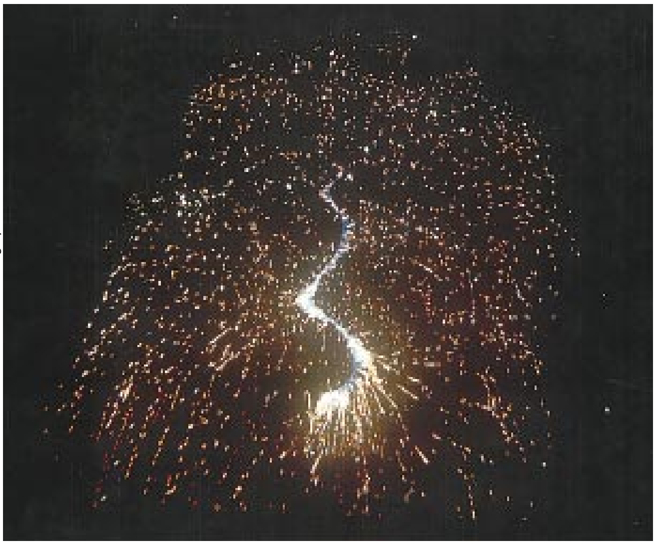
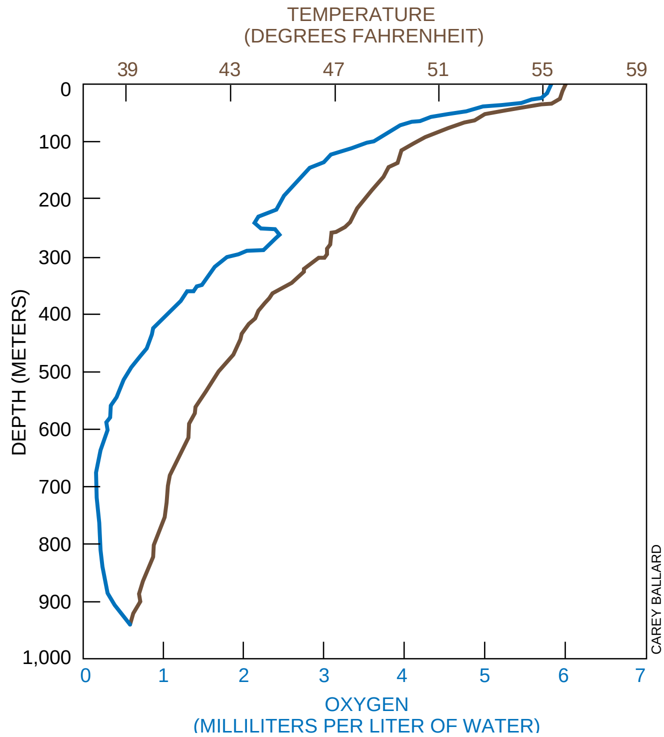
The ROV carries both a black-and-white and a broadcast-quality color video camera. In addition to the two cameras and the powerful video lights, shipboard controllers can employ a scanning sonar system to "peer" into the vehicle's surroundings using high-frequency sound waves. Guided by these devices, scientists are able to make measurements and perform experiments using a variety of special-purpose hardware. These instruments include dye injectors (to track subtle currents), a transmissometer (to measure optical clarity) and a structured light array (to map the density of particulates). The ROV's operators can also capture and recover objects of interest with several types of apparatus. Four detritus samplers, for example, easily encase small but delicate specimens, and a suction sampler is able to draw extended gelatinous animals into the vehicle.

A new ROV called *Tiburon* (Spanish for shark) now under construction at the Monterey Bay Aquarium Research Institute in California should prove even more capable than *Ventana.* Engineers at the institute are also designing and building prototypes of autonomous underwater vehicles. In years to come, these mobile robots will be able to carry out research missions of long duration without the need for a constant human presence—or telepresence—as is now required for operations with *Deep Rover* and *Ventana.*



SIPHONOPHORE deploys an intricate array of tentacles (*above*). If unsuccessful in catching prey, this creature remains in place for only a few minutes before hauling in its elaborate fishing gear and moving to another position. Most animals of the midwaters move effortlessly in three dimensions, but few venture into the anoxic zone near a depth of 700 meters, where oxygen concentration falls to a minimum (*right*).



come keenly aware that most creatures of this twilight world are able to augment the scant sunlight reaching them with another form of natural illumination, bioluminescence.

Although bioluminescence is a relatively rare phenomenon in terrestrial ecosystems, the vast majority of the animals that inhabit the upper kilometer of the ocean are capable of producing light in one way or another. Moreover, much of the particulate matter and biological detritus that floats suspended in these waters will glow after it is physically disturbed. These effects can interrupt the normal blackness of the deep ocean with an eerie light.

Midwater animals employ bioluminescence in myriad ways. Some use it as a burglar alarm, coating an advancing predator with sticky, glowing tissue that makes the would-be attacker vulnerable to other visually cued hunters—like bank robbers marked by exploding dye packets hidden in stolen currency. Others use bioluminescence as camouflage. The glow generated by light-producing organs, called photophores, on the undersides of some fishes and squids acts to countershade them: the weak downward lighting effectively erases the shadow cast when the animal is viewed from below against lighted waters above.

The midwater squids *Chiroteuthis* and *Galiteuthis,* for example, clearly demonstrate this use of bioluminescence. Their bodies are transparent except for their dense eyes and ink gland. Ornate light organs arrayed underneath these opaque structures shine downward to countershade them, whatever the position of the squid—head up, head down, inverted or upright. I have found it a bit unnerving to stare eyeball to eyeball with a creature that can pivot its body around a rigid eye that neither blinks nor changes orientation.

Although marine biologists have been able to understand the usefulness of countershading, other examples of bioluminescence have long eluded our logic. One such enigma is a newly discovered species of tomopterid worm, an active, agile swimmer that has a multitude of paired legs along its tapered body. From specimens caught with nets, biologists have known that some species have structured light organs at the ends of their legs, but only last year James C. Hunt of the University of California at Los Angeles (as well as the Monterey Bay Aquarium Research Institute) and I found a new form of bioluminescent display in a tomopterid that has pigmented pores in roughly the same location as typical leg photophores. This species is a “spewer”: when stimulated, it squirts a bioluminescent fluid from each of its leg pores. The discharge forms a luminous cloud that can completely enshroud the body of the worm or leave a glowing trail as it races away. A thimbleful of the ejected fluid contains hundreds of tiny rods that glow brightly yellow. Other types of spewers are known; their strategy may be to cause a visual distraction. But this species remains puzzling. What is the purpose of the display? Why are the tiny light sources rod-shaped? Why is the light given off colored yellow when most midwater animals have eyes that are sensitive only to blue-green?

Another mysterious application of bioluminescence involves much of the suspended particulate matter and most of the larger gelatinous animals living in midwater: they produce light when stimulated mechanically. “Contact flashing” can happen throughout a large volume of this otherwise dim habitat. Most of the time, the surroundings remain tranquil, with abundant flashers at rest in the dark. But the disturbance of driving *Deep Rover* through these depths of the ocean can trigger a barrage of exploding lights. The scene underwater can quickly begin to resemble something out of a *Star Wars* movie.

The natural movements of animals can also cause the ambient biological lighting to turn itself on, and such bioluminescent responses, when they occur on a large scale, can lead to one of the most remarkable sights in midwaters: a propagated display. This phenomenon starts with local motion triggering contact flashers to fire; these bursts then elicit further flashes like an echo through the adjacent water. Previously poised animals begin moving when the background begins to glow, and their wakes in turn stir up even more light. If contact flashing occurs within a layer of dense particles, the cumulative effect of this bioluminescent