By Kevin Hardy and Ian Koblick

Following the theme of undersea habitats in the Journal of Diving History, starting with the 50th Anniversaries of SEALAB I *then* SEALAB II, *this series of reports continues with an adaptation of Dr. Joseph MacInnis's informative March 1966* Scientific American *article "Living under the Sea."*

Living under the Sea

By Dr. Joseph B. MacInnis

Adapted from
SCIENTIFIC AMERICAN,
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It is one thing to glimpse a new world and quite another to establish permanent outposts in it, to explore it and to work and live in it. Now, however, men are beginning to try to live underwater- to remain on the bottom exposed to the ocean's pressure for long periods and to move about and work there as free divers. The submerged domain potentially available to man for firsthand investigation and eventual exploitation can be regarded as a new continent with an area of about 11,500,000 square miles the size of Africa. It comprises the gently sloping shoulders of the continents, the continental shelves that rim the ocean basins. The shelves range up to several hundred miles in width and are generally covered by 600 feet of water or less. That they are submerged at all is an accident of this epoch's sea level: the ocean basins are filled to overflowing and the sea has spilled over, making ocean floor of what is really a seaward extension of the coastal topography. Geologically the shelf belongs more to the continents than to the oceans. Its basement rock is continental granite rather than oceanic basalt and is covered largely with continental sediments rather than abyssal ooze.

Not surprisingly, mineral deposits similar to those under dry land lie under the shelf. Oil and natural gas are the foremost examples. But there are other reasons direct undersea investigations. One is the increasing interest in all aspects of oceanography, including geological, chemical, biological and meteorological. Likewise salvage and submarine rescue will benefit from manned bottom outposts.

The reasons for going underwater are balanced by an impressive list of potential hazards. Most of them stem from the effects of pressure, which increases at the rate of one atmosphere (14.7 pounds per square

FIGURE 1: CONTINENTAL SHELF (lightest areas) off part of North America is shown. It is less a part of the ocean basin than it is an extension of the continental land mass. As in most parts of the world, the shelf slopes gently to about 600 feet below sea level; then the continental slope plunges toward the floor of the ocean basin. On this map, based on charts of the International Hydrographic Bureau, the contour intervals are in meters rather than feet. The lightest tone shows the bottom from sea level down to 200 meters (655 feet); successively darker blacks indicate bottom from 200 to 1,000, 1,000 to 3,000 and deeper than 3,000 meters.

inch, or 760 millimeters of mercury) with every 33 feet (10 m) of depth in seawater.

The best-known hazard and one of the most dangerous is decompression sickness, the "bends." Under pressure the inert gas in a breathing mixture (nitrogen or helium) diffuses into the blood and other tissues. If the pressure is relieved too quickly, bubbles form in the tissues much as they do in a bottle of carbonated water when it is opened. Sudden decompression from a long, deep dive can be fatal; even a slight miscalculation of decompression requirements can cause serious injury to the joints or the central nervous system. A diver must therefore be decompressed slowly, according to a careful schedule, so that the inert gas can be washed out of the tissues by the blood and then exhaled by the lungs. Whereas the demands of decompression become more stringent with *depth*, with *time* they increase only up to a point.

After about 24 hours at a given depth the tissues become essentially saturated with inert gas at a pressure equivalent to the depth; they do not take up significantly more gas no matter how long the diver stays at that level. Therefore if a diver must descend to a certain depth to accomplish a time-consuming underwater task, it is far more efficient for him to stay there than to return to the surface repeatedly, spending hours in decompression each time. Although this "saturation diving" is efficient, it imposes an extra technical burden, because the schedules for the ultimate decompression must be calculated and controlled with particular care.

Pressure also has significant effects on a diver's breathing requirements. For one thing, hyperoxia (too much oxygen) becomes almost as dangerous as hypoxia (too little). Acute hyperoxia can affect the central nervous system, causing localized muscular twitching and convulsions; chronic hyperoxia impairs the process of gas exchange in the alveoli, or air sacs, of the lung. Optimum oxygen levels are still under investigation; they vary with the duration, depth and phase of the dive and the muscular effort required of the diver. It is clear, however, that the "partial pressure" of oxygen should be kept at a constant 150 and 400 millimeters of mercury during the at-depth phase of a long saturation dive. The partial pressure of oxygen in the air we breathe at sea level is 160 millimeters of mercury (21 percent of 760). If oxygen is kept at 21 percent of the mixture, however, its partial pressure increases with depth, rising to 1,127 millimeters 200 feet down, for example. As a result, the proportion of oxygen in the air or other breathing mixture must be cut back sharply from 21 percent. The band of permissible percentages narrows rapidly with depth calling for increasing accuracy in the systems that analyze and control the gas mixture.

Nitrogen, which is physiologically inert at sea level, has an anesthetic effect under pressure. At depths greater than 100 feet it begins to produce "nitrogen narcosis," that can impairment a diver's judgment and motor ability. Helium has been found to be much less narcotic and currently replaces nitrogen in almost all deep-sea dives. Being less dense, it also offers less breathing resistance under pressure; important to a working diver. Helium has two disadvantages, however. Because its thermal conductivity is almost six times as great as nitrogen's, it accelerates the loss of body heat and makes a diver uncomfortably cold even at temperatures of 70 or 80 degrees. Helium also distorts the resonance of a diver's voice, making his speech almost unintelligible and thus giving rise to a serious communication problem.

In any confined environment the buildup of exhaled CO_2 (carbon dioxide) must be monitored carefully.

In diving experiments at Ocean Systems, Inc., we kept the partial pressure of CO_2 below 7mm of mercury (compared with the sea-level pressure in fresh air of 0.3 millimeter), while at the U.S. Naval Medical Research Laboratory in New London, Conn., Karl E. Schaefer has found that at sea level slightly higher levels are tolerable for several weeks. In any case, CO_2 accumulates rapidly in a small space and soon reaches a toxic level, causing dizziness, headache and an increase in the rate of breathing. It must therefore be continuously "scrubbed" out of the diver's atmosphere, usually by being passed through a chemical with which it will react. Other gases, such as CO (carbon monoxide) and certain volatile hydrocarbons, can also reach toxic levels quickly if they are allowed to concentrate in the diver's breathing mixture.

There are sometimes other obstacles to casual access to the ocean floor: a demoralizing lack of visibility, strong currents, and uncertain bottom profiles. There are also dangerous marine animals, ranging in size from a unicellular infective fungus to the widely feared great white shark. Finally, the water of the continental shelf is cold. Temperatures average between 40 and 60 degrees, and without protective clothing a diver soon becomes totally ineffective.

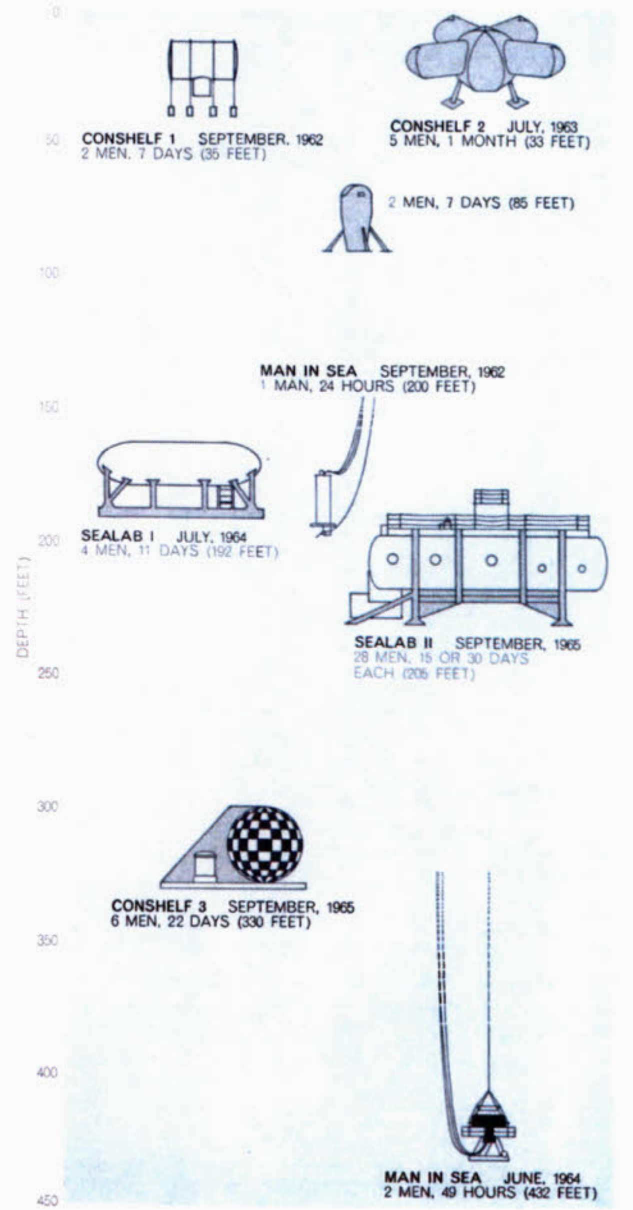


Figure 2: SATURATION DIVING, in which the divers stay down for prolonged periods, is made possible by underwater shelters. The chart gives data for seven such dives. "Man in Sea" is the Link project, "Conshelf" is Jacques-Yves Cousteau's, and "SEALAB" is the U.S. Navy's.

Faced with these difficulties commercial divers and undersea investigators found it impossible to spend time and do useful work on the continental shelf. Those who went down in pressurized suits and thick-hulled submersible vehicles were held prisoner by their protective armor. Free divers, on the other hand, could not go very deep or stay very long.

Before open-sea experiments were possible some preliminary research was necessary.

How deep could a man go as a free diver? How long could he stay down? What would be the acute and the long-term medical effects of the pressure itself and of the synthetic atmosphere? What would be the response to the cold, the confinement and the psychological hazards of deep submergence? Some early and significant answers were provided by Captain George F. Bond, a U.S. Navy physician who in 1957 conceived and carried out a series of simulated dives in a compression chamber on land at the Naval Medical Research Laboratory. Bond's group first exposed small animals, including some primates, to a pressure equivalent to a depth of 200 feet. Volunteer Navy divers then lived in the chamber under precisely controlled conditions of pressure, temperature and humidity. These experiments showed, among other things, that men could breathe helium instead of nitrogen for long periods without ill effects and encouraged Link and others to move ahead.

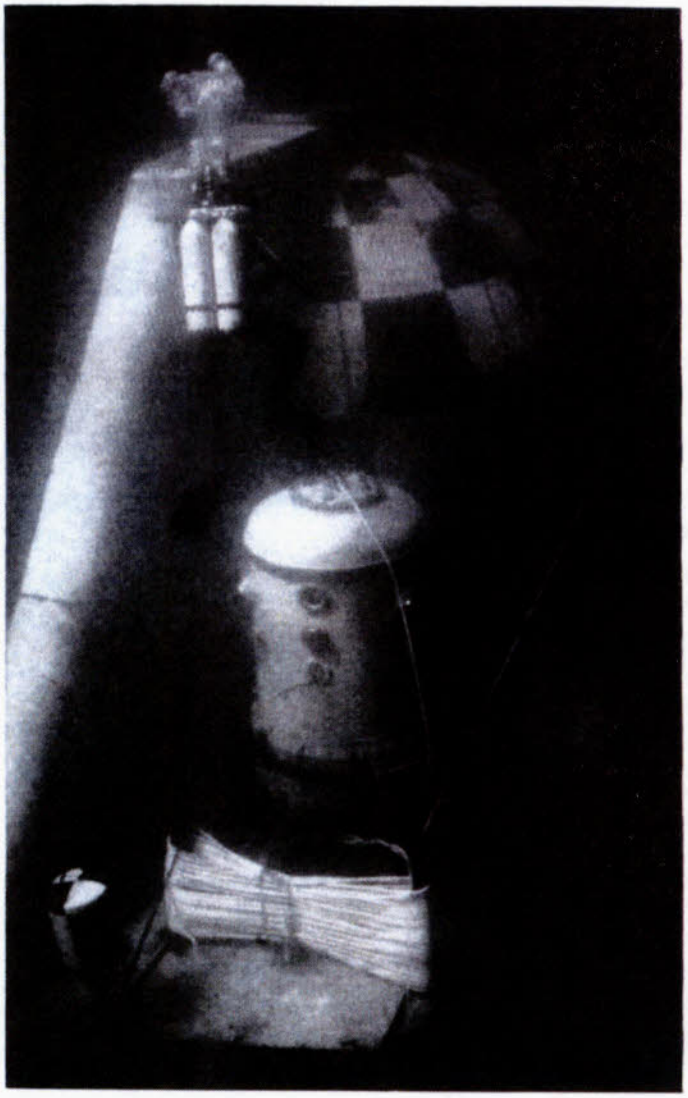
Figure 3: An UNDERWATER DWELLING called the SPID (for "submerged, portable, inflatable dwelling") was designed by Edwin A. Link as a base of operations for long dives to the continental shelf, here undergoing a pressure test at 70 feet. In the summer of 1964 two divers occupied the SPID for two days at 432 feet below the surface.

In the U.S., Link and Bond were designing pressure experiments and engineering diving systems that would enable free divers to reach greater depths safely. From late 1963 until March 1964, a series of simulated saturation dives-the first such dives deeper than 200 feet-were carried out under the technical direction of Captain R. D. Workman at the Navy's Experimental Diving Unit in Washington DC. The tests showed that divers suffered no harmful effects when exposed to depths of 300 and 400 feet for 24 hours and that they could be decompressed successfully on a linear decompression schedule.

In addition to Link's Man-in-Sea "Submerged Portable Inflatable Swelling" (SPID), (the subject of an upcoming *JoDH* article, 2016, Vol 24, Issue 86) there have been a number of other recent saturation diving experiments, two of them conducted by Bond's Navy group. The first, "SEALAB I," took place off Bermuda later in July, 1964 (the subject of the *JoDH* Volume 22, Number 79). Four men lived for 10 days in a large cylindrical chamber 192 feet below the surface. Last summer the Navy conducted "SEALAB II," a massive 45-day effort involving three teams of 10 men, each of which spent 15 days underwater (the subject of the *JoDH* Volume 23, Number 84). The base of operations was a cabin 57 by 12 feet in size submerged in 205 feet of water near the Scripps Institution of Oceanography at La Jolla, Calif. The SEALAB "aquanauts" salvaged an airplane hulk, did biological and oceanographic research and conducted psychological and physiological tests. Electrically heated suits made it possible for them to work comfortably in the 55-degree water.

In the Mediterranean off Cap Ferrat, Cousteau's group last fall made another significant advance in underwater living. Six men lived for almost 22 days in Conshelf III, a spherical dwelling 330 feet below the surface, linked to the surface by only an electrical and communications cable. Cousteau's "oceanauts" concentrated on difficult underwater work, including the successful emplacement and operation at 370 feet of a five-ton oil-well head in which oil under pressure was simulated by compressed air.

As men go deeper and stay longer the hazards increase and safety margins narrow, new questions arise. At what depth will even helium become too narcotic or too dense to breathe? Can hydrogen serve as an acceptable substitute? At what depth will pressure effects



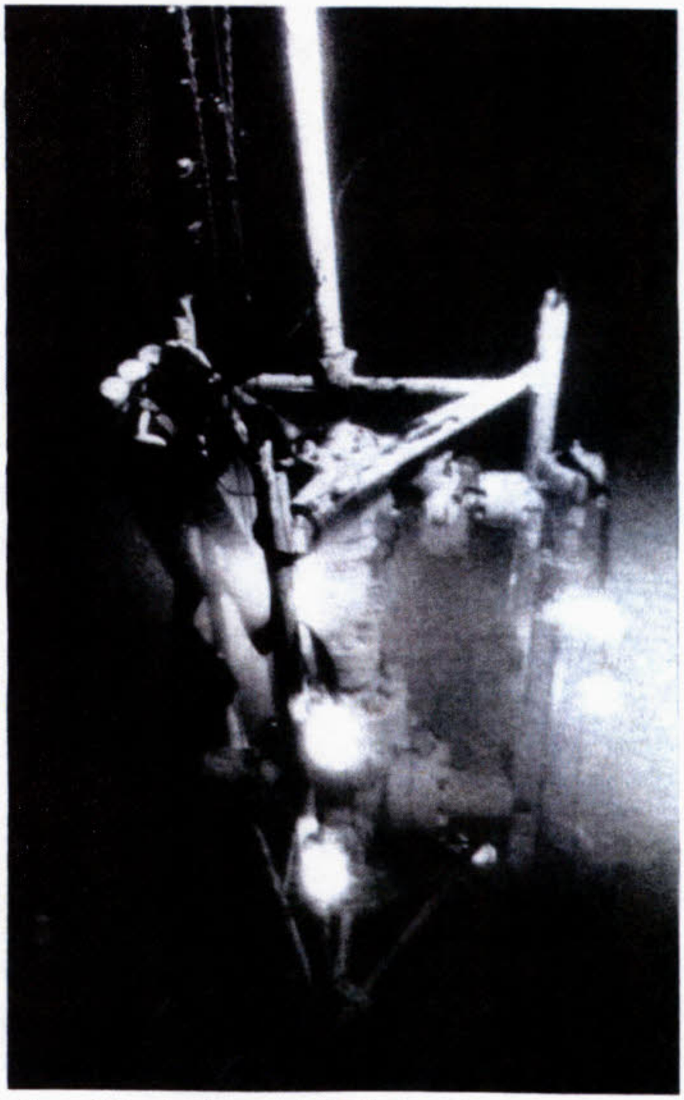


Figure 4: "CONSHELF III" station at 330 feet was occupied by six divers of Cousteau's group last fall. The spherical dwelling in which they lived is shown at the left in a photograph made from Cousteau's diving saucer. The elongated shape (far left) is a fin for stability under tow; the turret· shaped structure is a compression chamber for emergency escape to the surface. The major task accomplished by the divers was the installation and repair of an oil·well head (right). They were able to manipulate repair tools to handle emergency breakdown situations met in actual production. In the photograph a diver is guiding a tool pipe into the wellhead.

cause unacceptable changes in tissue structure? What will be the decompression obligation after saturation at 1,000 feet or more? And what are the residual effects of repeated exposure to great depths?

Again, the answers are beginning to come from dry-land experimentation. Last fall two Ocean Systems divers simulated a dive to 650 feet in our test chamber. They stayed at that pressure for 48 hours, becoming completely saturated with 20 atmospheres of helium. Our results indicated that helium is safe -at least at the depth and for the length of time involved in the test- and suggested that it may be possible to continue with helium as the inert gas even beyond 1,000 feet. We found that breathing an oxygen-neon mixture for 30 minutes at 650 feet caused no measurable narcotic or other detrimental effects and that it markedly improved voice quality. Heart and lung function, exercise tolerance, psychomotor performance and blood and urine characteristics were all within normal limits. I think the most significant result of this longest deep-pressure experiment to date was our impression that divers will be able to perform physical and mental work almost as effectively at 650 feet as at the surface.

There do not, then, seem to be any physiological or psychological barriers that will prevent the occupation of any part of the continental shelf. Nonetheless, it is important to recognize that so far all efforts to live under the sea have been investigations or demonstrations of man's ability to do so. In the last analysis men will live underwater only when specific tasks, with economic or other motivations, present themselves. At this point, however, the gates of the deep shelf have been opened.

Author: Dr. Joesph MacInnis currently studies leadership in lethal environments. He worked on James Cameron's last three deep-sea science expeditions, including the DEEPSEA CHALLENGE Expedition. His latest book, Deep Leadership: Essential Insights From High-Risk Environments, *was published by Random House.*

The full text of MacInnis' original *Scientific American* article is available for a small fee at: <http://www.scientificamerican.com/article/living-under-the-sea/>