W. C. TUTTLE – SHOTGUN WORK FOR SHORTY

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Adventure

MAR.

"BENDS" AND "SQUEEZES"
by
COMMANDER EDWARD ELLSBERG

SHARK!

by **CAPTAIN JEAN ELLRICH**, *SHARKOLOGIST*

Adventure

(Registered U. S. Patent Office)

Vol. 94, No. 5 for March, 1936 Published Once A Month

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"Seex men," Chico told Shorty, "say Johnny Wayne keel Telford. But I am jus' like a clem. An' a clem ees a feesh w'ich ees so damn see-crit that w'en hees shut hees mouth, you can't even see hees feet."

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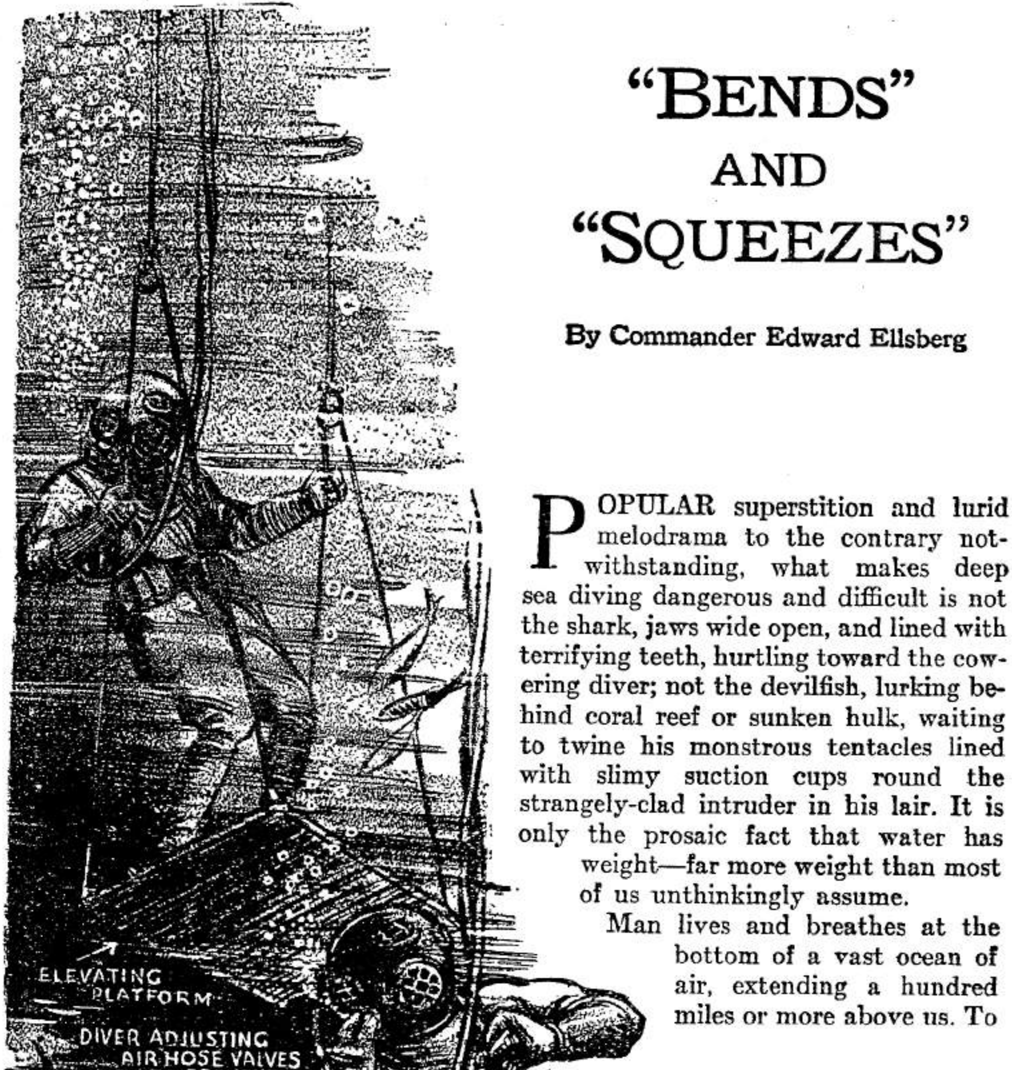
"BENDS" AND "SQUEEZES"

By Commander Edward Ellsberg



POPULAR superstition and lurid melodrama to the contrary notwithstanding, what makes deep sea diving dangerous and difficult is not the shark, jaws wide open, and lined with terrifying teeth, hurtling toward the cowering diver; not the devilfish, lurking behind coral reef or sunken hulk, waiting to twine his monstrous tentacles lined with slimy suction cups round the strangely-clad intruder in his lair. It is only the prosaic fact that water has weight—far more weight than most of us unthinkingly assume.

Man lives and breathes at the bottom of a vast ocean of air, extending a hundred miles or more above us. To the pressure existing at the bottom of this gaseous ocean, our bodies and our lungs are tuned. On atmosphere this pressure is about fifteen pounds to the square inch, the cumulative weight of a column of air resting on us at sea level, rising (but always thinning out) above our highest mountains into the stratosphere and far beyond.

To decrease this pressure half an atmosphere, it is necessary to rise considerably, approximately to the top of Pike's Peak, fifteen thousand feet. To many people who have ascended the peak, that reduction in pressure of seven pounds per square inch is quite a strain, something to write home about.

To the diver, such a change in pressure is trifling. He can hardly get his feet wet without undergoing greater changes. For water is heavy. A cubic foot of sea water weighs sixty-four pounds and exerts a pressure of .445 pounds over each square inch of its base. The weight of a column of water only thirty-three feet deep equals one atmosphere, enough to balance the weight of all the air from sea level up to the outer most limits of the air blanketing this earth.

A diver, simply by going down fifteen feet, has therefore increased the pressure on his body seven pounds to each square inch, quite as great a change as he could get by rising three miles in the air. But instead of going down only fifteen feet, he may dive one hundred feet, two hundred feet, where the pressure changes are vastly greater. What happens when he does it?

To dive, to stay below some time, and to accomplish some real work on the bottom, requires a diving rig in which a man can both breathe and work. The conventional diving dress, a flexible, canvas-covered, rubber suit joined watertight to a rigid copper helmet, represents so far the only combination which permits both breathing and working. There are two other possibilities—naked diving and completely armored, rigid suits. The naked diver is quite free to move naturally but he can't breathe effectively, so his dive is always brief; the armored suit diver is quite free to breathe naturally but he can't move effectively, so his dive is practically useless.

However, in the regulation diving rig, in spite of its handicaps, down to three hundred feet something can be done and so far, practically all the work ever done below the sea has been done in this dress. But in doing it, the diver has had to stand a lot.

To start with, there is the pressure of the sea. The average man's body has an area of some two thousand square inches; for every foot he descends, an increased load of water of about nine hundred pounds comes on him, nearly half a ton added with each foot. At three hundred feet down, this water pressure is two hundred and seventy thousand pounds—one hundred and thirty-five tons, the weight of a husky locomotive. And the weight is real; there is nothing theoretical about it. It is there on the diver just as much as if he were stretched out on an anvil and that whole locomotive weight somehow concentrated on his body.

Why doesn't it crush him?

Air is the answer—compressed air. As he goes deeper, the diver is fed compressed air through a hose at a pressure which must always slightly exceed the increasing pressure of water. Primarily the air is there for him to breathe, but its purpose is far wider than that. The air under pressure enters his helmet, under the same pressure goes to his lungs. And there in the lungs the pressure of the air is communicated to the blood and by it spread instantly to every part of the body, inflating the body to a pressure high enough to balance off the sea and carry the load, exactly as the air pressure inside a pneumatic tire inflates it and keeps it round, in spite of the load of the car above pressing down on it.

Here then, compressed air saves the diver, makes it possible for him to breathe and to exist under an otherwise crushing load of water. But for all this there is a price to pay, and compressed air exacts it relentlessly.

Man was never made to breathe air under pressure; queer and unnatural things happen when he does. Many a diver has paid with his life the price of treading the deep ocean floor.

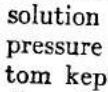
Air has two main constituents. Oxygen, the active ingredient which we must have to sustain life, makes up one-fifth of it. Nitrogen, the inert component, forms practically all the other four-fifths, doing nothing except diluting the air so we do not get too much oxygen with each breath. When we breathe ordinarily, the hemoglobin in the blood, (the red corpuscles) takes up oxygen from the lungs and carries it through the blood stream to the tissues. There it is converted into carbon dioxide, which as a waste product is carried back to be exhaled from the lungs. Nitrogen, the inactive air component, takes no part in these physiological reactions.

But as the diver goes down and the pressure on his lungs goes up, things change. Under the increasing pressure, more and more of the inert nitrogen is forced to dissolve in the blood and is carried by it throughout the body, where the nitrogen is soaked up in varying amounts and at varying rates by the different body tissues. Fat has a great affinity for nitrogen. For that reason fat men make poor divers. Fat will hold five times as much nitrogen as ordinary flesh and gives it up more slowly. The speed and degree of this saturation of the body tissues with nitrogen depend, of course, on the pressure on the diver (the depth at which he is) and the length of time he stays under that pressure. The deeper he goes, the faster he saturates; the longer he stays at any depth, the more nitrogen his tissues soak up.

But this absorption the diver never feels. Other symptoms, due to other causes—dizziness, difficulty in breathing, oxygen exhilaration—may be very marked, but never while he is under pressure will the degree of nitrogen saturation come to his notice or bother him.

But when the time comes to rise and the pressure of the sea comes off, it comes to his notice fast enough. The heavy air pressure required to balance off the pressure of the sea, has forced unnatural quantities of nitrogen into solution in the blood and the tissues; pressure while the diver was on the bottom kept it in solution. Now that the diver has ascended to the surface and the pressure is gone, what are the results?

To the earlier divers, lured into the depths by the hope of fabulous wealth, the results were startling. Convulsions seized the diver, twisted him in a knot. Agonized contortions ensued, the "bends," the expressive term long ago given to this disease. Where exposure had been long and the depth great, death or paralysis ensued; in lesser cases, severe and recurring pains in the joints remained to plague the victim.



THE cause and cure? Not till engineering necessities in caisson work directed medical attention that way, was it solved. The cause is simple and easily demonstrated. A bottle of beer, preferably somewhat warm, best illustrates it. Held up to the light, the unopened bottle is full of a clear amber liquid. There is, however, a gas, carbon dioxide, dissolved under pressure in considerable quantity in that clear liquid—but so long as the bottle cap is in place and the pressure kept on, the observer is as unaware of the presence of that gas as is the diver on the bottom of the nitrogen in his blood.

But once the bottle cap is pulled, conditions change swiftly. With the cap gone, the pressure on the beer is released. The dissolved gas, no longer held by pressure in solution, comes bubbling out, and in a moment under the action of the escaping gas, the beer is frothing and foaming from the neck of the bottle.

In the same way and for the same reason, the identical thing happens in the diver's blood. With the pressure gone, the nitrogen in the blood and tissues comes out of solution and forms bubbles in the blood. If the reduction of pressure is quick enough, as after an immediate ascent from a lengthy dive at considerable depth, the amount of air liberated may be great enough to fill the right side of the heart and cause immediate death, or in certain other cases, to have large bubbles form in the brain or in the spinal column, causing paralysis. In lesser cases, the diver is tortured by bubbles which have lodged at various spots in his anatomy, usually the joints.

When the cause of the "bends" was found, the cure was indicated. Obviously it lay in bringing the diver up slowly from the depths to avoid any sharp decrease of pressure with a resultant liberation of free nitrogen in dangerous quantities; and if trouble showed up nevertheless, in getting the diver back under pressure, either by putting him in a suit and sending him down again, or preferably shoving him inside a tank or "recompression chamber" where he can be put under air pressure to recompress the bubbles, and then properly decompressed afterward.

It was only as recently as 1907 that J. S. Haldane, a scientist working on the problem for the British Admiralty, finally determined the major factors in the "bends," or in medical terms, caisson disease, and worked out the present theory of stage decompression. He observed that at depths of thirty-three feet or less, divers, regardless of length of dive or how quickly they rose, were never bothered by the "bends," though obviously their bodies ultimately must have become saturated with nitrogen under that added pressure of one atmosphere while they worked on the bottom. He deduced from this that, perhaps because blood is a thicker liquid than beer or water, the human body could stand a reduction of pressure of one half without ever allowing nitrogen bubbles large enough to cause trouble to form anywhere in blood or tissue.

Proceeding from that conclusion, he reasoned that regardless of depth of dive, a diver could immediately be brought up to the point where the absolute pressure on him was halved without danger. For instance, a man at three hundred feet (one hundred and forty-eight pounds absolute) could be brought at once to one hundred and thirty-three feet (seventy-four pounds absolute) without danger of "bends."

Working from this principle, he built up a "decompression table" showing the stages and the length of time to be spent at each stage, so that for every depth and for dives of varying periods at that depth, the diver might be brought up by intermittent stages so spaced and timed that he would be properly desaturated at each stage before rising to the lower pressure of the next.

The beauty of Haldane's theory was that by these intermittent rises, a sufficient drop in pressure was realized at each stop so that the gas tended to come out of solution quickly and escape (always of course within safe limits), thus facilitating decompression and shortening it appreciably. But if anyone thinks decompression from deep water is rapid even now, the following excerpts from the United States Navy decompression table is quoted:

Haldane's tables, modified slightly,

Depth in feet	Length of dive, min.	Stops at different depths, in minutes at each depth of water noted below										T'tl time of rise in min.
		100	90	80	70	60	50	40	30	20	10 feet	
0—36	No limit	Immediate rise without decompression										2 min.
66	60 min.									3	10 min.	15 min.
	180 min.									10	30 min.	42 min.
250	15 min.		2	3	5	7	10	10	15	20	30 min.	106 min.
	60 min.	10	15	20	25	30	30	35	40	40	40 min.	289 min.

have made deep diving possible and when everything goes well, have practically eliminated the "bends." But everything does not always go well and there are yet other troubles

In spite of decompression tables, heavy pressure effects claim their victims. Men are different, and even the same man reacts to decompression differently on different days. On the *S-51* salvage job, carried out in one hundred and thirty-five feet of cold seawater, minor cases of the "bends" started to incapacitate the divers; and to bolster up the force, some less experienced men were used.

One of these, dazed perhaps when the bottom pressure hit him, started to wander away from the sub. Found by another diver, he was started up. For his length of time on the bottom, he was given more than full decompression. When hauled in over the side and undressed, except for the fact that he was unusually happy with an "oxygen jag" on, he seemed okay. Nevertheless, a few minutes later at the mess table he collapsed.

Promptly his shipmates rushed him up on deck and into the recompression tank where, unconscious, he was put back under the pressure he had faced on the bottom. His abdomen was a mass of blotches from innumerable small burst blood vessels. The doctor worked on him all night as the pressure was released. At 3 A.M., he was still unconscious. Recompression and decompression had done everything possible for him; but paralysis still had him. To save his life, we cut our mooring hawsers and steamed in from sea to land him in a hospital, where for the next few months he hovered between life and death, wasting from a one hundred and sixty pound man down to a seventy pound skeleton before finally after seven months, the turn came and he recovered. Paralyzed intestines was what the "bends" gave him. With less adequate attendance and treatment, he would never have survived the first night. But why didn't his decompression save him from the "bends?" None of us could ever figure that out.

If the "bends," a nitrogen danger, were the only hazard resulting from air pressure, there would be no limit to the depth to which a diver might go, save only his nerve and the capacity of his air compressor to ram the air down to him. But at depths below one hundred and thirty-five feet, (five atmospheres or seventy-five pounds absolute) oxygen itself starts to cause trouble.

Under normal conditions, the air we breathe, with twenty per cent oxygen, has a partial pressure of oxygen (or effective pressure on our lungs) of only one-fifth of an atmosphere. When the diver goes down far enough so the air is compressed to five atmospheres, the partial pressure of the oxygen he breathes is still only one-fifth of that total, but now that one-fifth equals one whole atmosphere, so that the result is the same on his lungs as if he were breathing on the surface one hundred per cent pure oxygen, undiluted with anything.

Now breathing pure oxygen under pressure greater than normal atmosphere is hazardous, increasingly so as the pressure goes up. The major action on the lungs is to induce pneumonia, slowly if the pressure is only a little above normal, very rapidly (in a few minutes) if it is three or four times normal. And in addition, the oxygen has a narcotic effect, tending to produce unconsciousness, the tendency of course varying with the individual.

In mild excess—say at depths between one hundred and thirty and two hundred feet—the oxygen effect on the diver is exhilarating, intoxicating. Some divers come up decidedly happy, inebriated, suffering from an "oxygen jag" indistinguishable in its effects from an alcoholic one. But at greater depths, two hundred and fifty feet and below, the poisoning effect of the oxygen becomes more and more marked; thinking is difficult, and the diver may verge into unconsciousness without warning.

As a result of this situation, no divers have yet gone appreciably beyond three hundred feet (three hundred and six is the existing record, made twenty years ago.) At this depth, the absolute pressure is ten atmospheres, equal to breathing pure oxygen under twice normal pressure. And for the very best divers, the cream of the diving world physically and mentally, the limiting dive at this depth is fifteen minutes to avoid quick pneumonia, unconsciousness with all its perils at that depth, and naturally the dangers from the "bends." Three hundred feet forms our floor for divers. Beyond that, man can not force his fragile body to stand up under pressure.

SO MUCH for "bends," and the physiological effects inside the body of working at the bottom of the deep sea. But the pressure, in spite of what it may do inside, is not yet through with the diver. It has the outside of his body still in its clutch, and what it does to him there comes under the head of "squeezes."

The usual diving rig, as stated before, consists of a flexible rubber suit, canvas-covered, joined watertight to a rigid copper helmet and breastplate. The suit is flexible to permit the diver to use his body to perform useful work. Once beneath the surface, the sea presses the suit tightly in against the body like a second skin.

The helmet and the breastplate to which it is joined are rigid. It provides the air space in which the diver breathes, the frame to hold the faceplates out of which he looks, the shield for his telephone set. It supports his exhaust valve, acts as a small air reservoir in case his air is shut off momentarily. And it is the balance between the buoyancy of the diver's helmet and the lead weights on his shoes and his belt which maintain his equilibrium and permit him to work in any position, erect or lying down.

But the rigidity of the helmet brings in startling dangers. Ordinarily the erect diver under water so adjusts the spring-loaded exhaust valve in his helmet as to give a little air space in the suit over his chest. This gives the same pressure inside and outside his lungs and makes his breathing relatively easy. From chest up, his head inside the helmet is in air; from his chest down, his body encased in his flexible suit is surrounded by water. To get this result, the pressure of air must equal the weight of water at the chest level, and exceed the pressure at the head level by about half a pound.

Now if the pressure in the helmet is slowly decreased by bleeding air out through the exhaust valve, a strange sensation results. The diver feels himself hugged by the sea, a close embrace on every inch of his skin, literally squeezing his exposed body everywhere. As more air is released, the grip gets tighter. The initial sensation is not unpleasant—a man indeed may feel that at last he is being caressed by the perfect mistress, lovingly clasped in an all inclusive hug.

But it is well to stop there. What is happening, though as yet only to a slight degree, is that the air pressure is being reduced below what is necessary to balance the sea, and the water is starting to force the blood out of the legs and torso up into the chest cavities, giving an incipient "squeeze."

A real "squeeze," involuntary, of course, so far as the diver is concerned, will kill him instantly and horribly. It comes about when for any reason at all, the air pressure in the helmet fails substantially to match the water pressure. When that happens, the sea comes instantly down on the soft body of the diver and molds it, a bloody mass of jelly, into the rigid helmet.

Why?

The lung pressure always matches the pressure inside the helmet. If that falls a little below the water pressure on the body, the sea promptly "squeezes" the blood out of the body into the lungs, causing hemorrhage. If the helmet pressure falls much below the sea pressure, the sea first "squeezes" the flesh itself solidly into the abdominal and chest cavities, and then starts to push the mangled mass up into the low pressure area inside the rigid helmet. Of course, by then the diver is dead, but the relentless sea nevertheless makes a thorough mess of his remains.

Practically, a "squeeze" comes about in various ways, the simplest being for the diver to fall or be dropped some distance under water. A tender ought never to hold the lifelines slack enough to permit this, but he is sometimes careless. As the diver falls, the water pressure suddenly increases on the diver's body, and unless he can as suddenly build up an equal pressure in his helmet, the sea promptly starts to "squeeze" him up into it.

When the *Empress of Ireland* sank some years ago in the St. Lawrence, drowning some one thousand twenty-four immigrants, the owners of the line felt it advisable to hire divers to salvage the bodies of the dead from the hulk. Engaged in this gruesome task, one of the divers working on the forecastle of the wreck, caught by the tide perhaps, was swept overboard, and dropped some forty feet. He was hauled up dead, killed by the "squeeze."

But it doesn't take deep water to make a "squeeze" dangerous; in fact it is far safer to fall a given distance, say thirty feet, when already in deep water, than to fall the same thirty feet close to the surface. In the first case the added pressure of fourteen pounds will only decrease the volume of air in the helmet to about seven-eighths of its former volume and if the fall is not too sudden, the air coming in during the fall may build up sufficiently to avoid a "squeeze." But near the surface, an increase in pressure of fourteen pounds will cut the volume of air in the helmet in half; the diver will probably be "squeezed" to death before he can get air enough to compensate for that much.

A broken hose is another source of "squeeze." To prevent this a careful tender will always see that his diver has a check valve on his helmet where the hose attaches, so that regardless of what happens to the hose, the air already in the helmet can't blow out through the ruptured hose. But check valves don't always work and tenders sometimes forget to screw them on the helmet before coupling up the hose. The diver pays.

Ten years ago while I was working on salvaging the submarine *S-51* in deep water out in the Atlantic, a very workaday job was underway in the East River in some thirty feet of water wit a couple of divers working from housed-in scow repairing a bulkhead fo a power station. One man was tendin both divers.

The noon whistle blew. The tende signalled both divers to come up. One o them did and entered the deckhouse. few minutes later, the tender, under th impression that both divers were u and inside the scow, proceeded to uncouple the shore ends of their airhose from the compressed air manifold.

That released the pressure on the second diver who unfortunately had no come up. His helmet pressure disappeared, swiftly blowing through th open hose, and the ensuing "squeeze promptly laid him away dead and badl mangled.

All in all, the diver in deep water ha enough to worry about that is real t him. Shark and octopus may be th mainstays for the movie man and th lurid fiction writer when it comes to underwater perils, but for the diver wh has to do the job on the ocean floor, it' the everpresent danger of the things h can't see, the "bends" and "squeezes which make each dive for him a rendezvous with death.