THE ENDLESS VOYAGE

"Beneath the Surface" Episode 108

The stratification controls where the nutrients are, where they can be brought up, so that they can combine with sunlight to make primitive life.

If you want to ask the question, "Is the whole North Pacific warming up or cooling down?" Again, this is a very difficult thing to do using other instruments. With sound, you can literally transmit over thousands of kilometers and in a few minutes get a measure of the average temperature of between here and Hawaii, say.

The surface layer of the ocean, or the photic zone, and particularly the euphotic zone, is probably the most important place on our planet, because that's where photosynthesis occurs, that's where half the oxygen in our atmosphere is produced.

NARRATOR:
TO THE CASUAL OBSERVER, THE OCEAN IS SOMETHING OF A SPRAWLING, LIQUID MONOLITH, A MASSIVE, UNIFORM BODY OF WATER DISTINGUISHABLE FROM PLACE TO PLACE ONLY BY THE LANDFORMS AROUND IT. BUT A LOOK BENEATH THE SURFACE REVEALS AN INTRICATE SYSTEM OF UNEXPECTED DIVERSITY, LAID OUT IN DISCRETE ZONES AND LAYERS ACCORDING TO A HIGHLY STRUCTURED MARINE BLUEPRINT.

SEAN CHAMBERLIN, Ph.D., Fullerton College:
One of the things that I think surprises most people about the ocean is its structure. We don't normally think of the ocean as having a structure to it in the same way that a forest has an obvious structure. It has the canopy overhead and the mid-story, where you have the leaves and animals living, and then the under-story. But in fact, because of the property of the ocean itself—its temperature, salinity, light—it has a very real structure to it, and it's this structure, really, it's this environment, that really allows organisms to adapt to different types of environments, and really gives the oceans its diversity in a sense.

PETER RHINES, Ph.D., University of Washington:
The two dominant physical properties of the ocean, in my eyes, are the rotation of the planet which it's sitting on, and also the fact that the oceans are layered. They have dense water at great depth and then, as you proceed up towards the ocean surface, the water gets less and less dense, becomes possibly warmer, possibly fresher, lower salinity.

NARRATOR:
THE HORIZONTAL LAYERS OF THE OCEAN PROVIDE A CONVENIENT FRAMEWORK WITHIN WHICH TO ANALYZE OCEAN STRUCTURE.

CHAMBERLIN:
The surface layer of the ocean, where we have light penetrating—and the open ocean down to about 200 meters—is known as the epipelagic zone. It's the zone to which light penetrates in the very surface of the waters. Here is where you find phytoplankton and zooplankton, you find oceanic food webs that depend on those phytoplankton in this upper layer. The layer below that is known as the mesopelagic zone. This has been affectionately called "the twilight zone," it's sorta that quasi-lighted environment full of denizens of the deep. And it's an area of active interest right now, particularly with carbon cycling, because of the processing of particles that goes on with organic matter that goes on in this mesopelagic zone, which extends from about 200 meters down to about 1,000 meters.

NARRATOR:
1,000 METERS DOWN MARKS THE APPROXIMATE DEPTH OF THE PERMANENT, OR MAIN, THERMOCLINE, A ZONE OF THE OCEAN IN WHICH TEMPERATURE DECREASES RAPIDLY WITH DEPTH.

LIBE WASHBURN, Ph.D., University of California, Santa Barbara:
There are two thermoclines that we talk about. One is called the main thermocline, and this is at great depth in the ocean. And it reflects the fact that at the surface, the ocean is approximately the temperature of the atmosphere. But as we go deeper into the ocean, the water gets much, much colder and gets down to just a few degreed Centigrade at great depths. The other thermocline that is important is the seasonal thermocline, and this forms right near the surface and is a consequence of heat transfer with the atmosphere and storm activity. The thermocline is maintained by heating at the surface from the sun, and the tendency to cool the waters at depth as polar water masses move along the ocean bottom and bring cool water into the depths of the ocean.

NARRATOR:
CONTINUING DOWNWARD THROUGH THE WATER COLUMN, THE NEXT MAJOR LAYER ALONG THE WAY IS A REGION KNOWN AS THE BATHYPELAGIC ZONE.

CHAMBERLIN:
This is the zone of complete dark, and probably when we think of monsters of the deep, we're thinking of organisms in this particular zone. And that extends from about 1,000 meters to about 4,000 meters, which is about the depth at which we also find the deeper waters—the waters that are coming from polar environments' water masses—about make their mark at about the 4,000 meter mark. But we have all sorts of bizarre bioluminescent creatures, and fish with fanged teeth and all sorts of interesting—all the interesting animals living in this zone.

NARRATOR:
THE NEXT AREA DOWN, AT ABOUT 4,000 METERS, IS THE ABYSSOPELAGIC ZONE, A REALM CHARACTERIZED BY HIGH PRESSURE AND VERY COLD AND SALTY WATER.

Below that we can define what's known as the hadolpelagic, or the "hadopelagic"—or the hadopelagic zone, in only the very deepest parts of the ocean. This would be submarine trenches, a place like the Marianas Trench, where we have miles' deep water--sort of a unique environment because of its proximity and because it's in a trench.

NARRATOR:
ONE OF THE DEFINING ELEMENTS THAT DISTINGUISHES ONE OCEAN LAYER FROM ANOTHER IS THE PRESENCE OR ABSENCE OF LIGHT. INDEED, THE IMPACT OF LIGHT IN THE MARINE ENVIRONMENT IS SIGNIFICANT.

Light, as it comes towards our planet, can be subject to various processes that either remove it and absorb it, or that scatter it and send it in a different direction. And that process really is ubiquitous whether you're underwater or on land as well. As light penetrates the sea surface, a couple different things start to happen. The first thing that happens is that it begins to diminish in intensity very quickly as light is absorbed by the water itself and by the particles and dissolved substances in that water.

MICHAEL LATZ, Ph.D., Scripps Institution of Oceanography, UCSD:
Unlike land, where essentially there's no absorption—preferential absorption of sunlight—water strongly absorbs and scatters sunlight. And so the color and the brightness of sunlight changes as you descend to deeper depths.

NARRATOR:
THE THIN LAYER OF LIGHTED WATER AT THE TOP OF THE OCEAN IS KNOWN AS THE PHOTIC ZONE.

It's a funny thing, as we go deeper down, the light decreases in intensity to where we actually just almost have single photons of light. So we actually kind of divide up the photic zone into two parts—the photic zone where photosynthesis can occur, where there's enough light for plants to grow, is known as the euphotic zone. That's an area where there's plenty of light sufficient to activate photosynthesis. Below that is what's known as the disphotic zone—not enough light for photosynthesis, but just kind of that twilight. So enough to see, and enough that organisms living in the water column can kind of see shadows and kind of get around a little bit. But it's a very dim sort of lighted view.

The limit of sunlight in the ocean is about 1,000 meters or so in the clearest waters, which is a few thousand feet. Below that there is no sunlight, which is important to the animals living there. And so we have a situation where the upper part of the ocean is brightly lit by the sun during the day, and then the middle part of the ocean has dim light, and then the deepest part of the ocean never has any appreciable sunlight, so it's dark.

CHAMBERLIN:
Light acts as a clue or a type of signal for animals that triggers their migration up into surface waters of the ocean or down into the deeper waters. Certain organisms like to

travel up to the surface waters at night to feed. That's where all the sweetest phytoplankton are after a day's photosynthesizing. All the good stuff's up there. So these vertical migrators will come up to the surface at night to feed and go back down before the sun comes up, because in the bright light, they are essentially a visible target for anything that might want to eat them.

NARRATOR:
THE AMOUNT OF LIGHT AVAILABLE NOT ONLY AFFECTS THE BEHAVIOR OF MARINE ANIMALS, IT ALSO HAS AN IMPACT ON THEIR ANATOMY.

LATZ:
The animals living in the deep sea, where there is no sunlight, have very well-developed eyes. They are large, they have well-developed retina. They can be very sensitive in detecting low levels of light. The question is, what light are they detecting if there's no sunlight in the deep sea? Well, they are detecting not sunlight, but bioluminescence. In the deep sea, bioluminescence—the light produced from living organisms—is a very important form of optical communication. And so the animals living in the deep ocean have well-developed eyes to see bioluminescence.

NARRATOR:
TWO PRINCIPAL FACTORS AFFECT THE ABSORPTION OF LIGHT IN OCEAN WATER.

SEAN CHAMBERLIN, Ph.D., Fullerton College:
One is, the water itself is a very strong absorber of sunlight, and it will absorb, selectively absorb different wavelengths of light, blue light being the color of light that it absorbs the least. That's why we see the bright blue ocean when we're out in the very clearest waters.

And so the color and the brightness of sunlight changes as you descend to deeper depths. What happens is that the red colors of the spectrum are absorbed and the violet colors are scattered. And so as you go deeper into the ocean, the primary color of light that remains is blue—blue-green. And so we find that the visual systems of animals living in the deeper part of the ocean is adapted to blue light, not only sensing the blue color of the light, but also being very sensitive to low levels, because the sunlight brightness decreases exponentially with depth.

The other element that absorbs in oceanic waters are the things that are suspended in the water. The sediments and the plankton themselves, and the bacteria themselves, will also absorb—selectively absorb different wavelengths of light, the phytoplankton in the water column are one of the primary means by which the ocean really changes its color. Phytoplankton containing the pigment chlorophyll, which is the green pigment that we find in all plants, makes the water appear green, because those are the colors that the plants reflect.

NARRATOR:
JUST AS SEAWATER HAS A SIGNIFICANT IMPACT ON LIGHT IN THE OCEAN, SO TOO DOES IT AFFECT SOUND.

PETER WORCESTER, Ph.D., Scripps Institution of Oceanography, UCSD:
With not a very loud source, a couple hundred watts—you can actually send sound literally thousands of kilometers using the proper techniques. This happens because of the way the ocean is structured. Sound speed depends on temperature and salinity and pressure. The two dominant things are temperature and pressure. And in the ocean, temperature decreases from being very warm near the surface and it drops through what's called the main thermocline till it reaches a temperature of maybe…three or four degrees Centigrade at a depth of about 1,000 meters. Then it's almost constant to the bottom. And what this means is that sound speed decreases as you go from the surface down to about 1,000 meters. Below that, though, temperature is almost constant and the pressure effect dominates. So as you go to greater pressures, sound speed again increases, and so it makes the sound speed increase as you go deeper. So it's really a reflection of the basic way in which the ocean's stratified.

NARRATOR:
WHILE SOUND IN THE OCEAN TRAVELS ABOUT FIVE TIMES AS FAST AS IT DOES IN THE ATMOSPHERE, SOUND WAVES IN FRESH WATER TRAVEL FASTER STILL. AS WITH LIGHT, ABSORPTION PLAYS A MAJOR ROLE.

WALTER MUNK, Ph.D., Scripps Institution of Oceanography, UCSD:
It turns out that sound in seawater is absorbed much more rapidly than in laboratories, fresh water. And that came as a surprise during World War II, that transmission in the ocean didn't go nearly as far as it would in a lake. And it is due to very small amounts of magnesium sulfate. Magnesium sulfate has that curious property that the acoustic vibrations can go into molecular energy and eat up the energy, instead of permitting the soundwave to continue. And that was a discovery that was quite unexpected.

NARRATOR:
STILL ANOTHER PROPERTY OF ACOUSTIC PHYSICS IS A PHENOMENON KNOWN AS SPREADING.

WORCESTER:
That's something I think everyone's used to. If you drop a rock in a pond and you see the ripples spread out, the same thing happens to sound in the ocean. If you have a source of sound, sound spreads out from it in all directions. And if it spreads out, it gets weaker.

The reason that I'm louder when I'm 10 feet away from you than when I'm 100 feet away from you is mainly because the acoustic wave has spread. That's very familiar to all people. The closer you are, the louder you are. That is not peculiar in any way to the oceans.

NARRATOR:
THE RATE AT WHICH SOUND SPREADS OUT IS AFFECTED BY SCATTERING, WHICH OFTEN OCCURS WHEN SOUNDWAVES HIT BOUNDARIES LIKE THE SEA FLOOR OR THE OCEAN SURFACE.

And what happens there as the sound hits either one, it's scattered by the small-scale variability and the surface and the bottom. So instead of traveling in a straight line, it gets scattered in all directions. So if you're some distance away, some of the sound that you would've heard has been scattered into other directions.

MUNK:
I mean the simplest thing would be that you have an object like a solid buoy in the way, and the sound hitting the buoy would be reflected in all possible directions. To have a reflection, you need an object which has a different characteristic than the water itself. And the important scattering in the ocean actually has to do with inhomogeneities in temperature itself—small-scale temperature changes, which act like foreign objects and scatter the sound, eventually become limiting to how far you can go.

And then, finally, actually in the interior of the ocean, there's small-scale variability due to turbulence—what are called internal waves, which are small-scale waves that happen in the ocean interior. And that also scatters sound and reduces its intensity as you go out of range.

NARRATOR:
WHEN SOUNDWAVES SCATTER, THEY MAY CAUSE THE FORMATION OF A SHADOW ZONE.

MUNK:
If you have an object that scatters sound in all directions, then behind that object you will have less sound. Some of it will, the word is "diffract," around, so it won't be 100% quiet, but it will be much more quiet than on the forward edge. And these shadow zones appear in curious manifestations. They do not only appear as a result of scattering objects, but they also appear as a result of refraction. Refraction is what bends the path of sound waves. And near the surface, you have sound being bent downward by the warm water, and that can create shadow zones in which it is much more difficult to hear objects than it is in other zones.

WORCESTER:
The simplest example is probably if you have a surface ship, say a destroyer, looking for a submarine some distance down in the ocean, and it sends out a pulse of sound—a sonar pulse, looking for reflections back. Well, as that sound travels out, the surface of the ocean's very warm. It's colder deeper, which means the sound speed's lower as you go deeper. This means the sound that the ship sends out gets bent down. And so, as it's bent down—if the submarine's out past where it's being bent down, the sound will never reach it. You won't—you won't be able to get reflections back from it because it's in a shadow zone that's created by the way the sound bends.

And that became a primary issue again, in connection with anti-submarine warfare during World War II. It's especially bothersome in the early afternoon, when the surface waters are heated.

WORCESTER:
In the early days of sonar, there's a thing called the afternoon effect, where trying to track submarines—and in the morning it would work very well. It would be able to detect them out to reasonable ranges and everything seemed to be working fine. Then, after lunch, the detection ranges would get much, much shorter.

At one time the Navy thought—the Navy officers—that it was due to acoustic chief petty officers having had too much of a lunch and being sleepy after lunch.

But actually what was happening is the surface of the ocean was warming up, making the sound bend down at much shorter ranges, so it never reached the submarines.

NARRATOR:
MILITARY APPLICATIONS WERE AMONG THE FIRST WAYS IN WHICH SOUND AND ITS PROPERTIES WERE USED IN THE MARINE ENVIRONMENT. ONE SUCH APPLICATION WAS BASED ON THE DISCOVERY OF THE SOFAR CHANNEL.

PETER WORCESTER, Ph.D., Scripps Institution of Oceanography, UCSD:
The sound speed minimum, the sound speed channel, this duct, is called a SOFAR Channel. It stands for "Sound Fixing and Ranging." The fact that this minimum existed was actually discovered shortly after the end of World War II, really independently by the Russians and by the U.S. And one of its initial uses, once people realized that sound could propagate long distances in it, was to track down fliers. They had little explosives, so that if they were down, they would drop—these would sink in the ocean down to a depth of, say, 1,000 meters—3,000 feet—and then detonate, and then this sound would travel out to receivers that the Navy had installed. And you could basically triangulate to figure out where the flier was. That's where the name SOFAR came from—"Sound Fixing and Ranging."

NARRATOR:
TODAY, SOUND IN THE MARINE ENVIRONMENT IS USED IN A NUMBER OF WAYS THAT EXTEND WELL BEYOND THE ORIGINAL MILITARY APPLICATIONS.

STEPHEN RISER, Ph.D., University of Washington:
The atmosphere is transparent to electromagnetic energy. That's light and heat and that's how we communicate in the atmosphere. Electromagnetic energy does not propagate very well in the ocean, but acoustic energy does very well. So one can send acoustic energy over very long distances in the ocean. And you can use the properties of acoustic

energy in the ocean, propagation paths and things like that, to actually measure the flow of the ocean current.

My research is really focused on developing the use of sound as a way to study the ocean interior. It's really kind of a remote sensing of the ocean interior, if you will. And the basic ideas behind it are very simple, because sound speed depends on temperature and salinity and pressure, but mostly temperature. If you send a pulse of sound between a source and receiver, measure that travel time very accurately as basically a measure of the temperature between the source and the receiver, you can really use that information to draw a map of the temperature structure of a chunk of ocean that's several hundred kilometers on a side or 1,000 kilometers on a side, and really map the interior structure. This is interesting because the ocean has "weather"—"weather" in quotes, just the way the atmosphere does. If you tried to do this in an area that's, say, 1,000 kilometers on a side, using instruments lowered from a ship, it would take weeks to a couple months, maybe. By the time you got done measuring it, it all would've changed. With sound you can do all this in the space of a few minutes, and you can do it again an hour later, if you want. So it really lets you map things. I think the applications of that are fairly obvious. As we change the temperature of our planet due to release of greenhouse gasses, the ocean warming up, cooling down, how's it changing? How are we affecting the ocean?

NARRATOR:
THE UTILIZATION OF SOUND IN THE MARINE ENVIRONMENT EXTENDS BEYOND HUMAN APPLICATIONS.

WORCESTER:
Marine mammals use sound in the ocean for, really, all the same purposes that animals on land use their sight, to some extent, their hearing. Basically, it's the only way of detecting things at a distance. So one of the well-known uses is for tracking objects. So you have the toothed whales, the odontoceti, that send out very high frequency pings that reflect off prey or other objects—come back to them so they can track their prey just the way a destroyer would track a submarine, or a bat would use its sonar in air to track objects.

NARRATOR:
FOR THOSE WHO STUDY THE OCEAN, THERE IS NOTHING MORE FUNDAMENTAL OR IMPORTANT THAN SEAWATER ITSELF. ITS PHYSICAL PROPERTIES, ITS STRUCTURE IN THE OCEAN, ALL PLAY A ROLE IN DEFINING WHAT IS PERHAPS THE MOST IMPORTANT, IF LEAST UNDERSTOOD, REALM ON PLANET EARTH.

WILLIAM JENKINS, Ph.D., Woods Hole Oceanographic Institution:
One of the big problems is separating chemistry from biology and from physics. The oceans are an extraordinary place, where you have a mixture of all those three disciplines interlinked—and, in fact, the fourth one being geology—that we can't separate them in some sense. And so chemical oceanography, marine chemistry, is actually a very unique discipline, in the sense that it overlaps substantially with all of the disciplines of

oceanography in a fundamental way. We use chemical oceanography as a means of tracing ocean circulation. We use chemical oceanography as a means of understanding the rates of biological processes in the ocean. Biological processes fundamentally affect the chemistry of the oceans. Physical circulation fundamentally affects the distribution of chemicals in the ocean. So they're so interlinked and interwoven that it's difficult to separate one out from the other. But I think clearly there's a lot of areas where we're continuing to try to seek solutions and understandings of processes that are occurring. And how those physical processes affect chemistry is still a very challenging problem. We're leaning the mathematical and analytical tools still to this day.