THE ENDLESS VOYAGE

"It's in the Water" Episode 107

The Earth is unique with having a lot of water on its surface, at least in our solar system.

We would be terribly different creatures, if we would be creatures at all, in absence of water. One of the primary chemical features of water is its polar structure.

One of the biggest miracles in the universe is the oxygen molecule and its bond angle that it forms with hydrogen.

NARRATOR:
FOR CENTURIES, SCIENTISTS HAVE PONDERED TO WHAT EXTENT LIQUID WATER EXISTS IN THE SOLAR SYSTEM ON PLANETS OTHER THAN THIS ONE. WHILE IT IS FOUND IN PLENTIFUL AMOUNTS ON EARTH, IN SOLID AND GAS FORM, AS WELL AS LIQUID, THE PRESENCE OF ABUNDANT LIQUID WATER ELSEWHERE REMAINS IN QUESTION. BUT ONE THING NO ONE QUESTIONS IS THAT, WHEREVER IT EXISTS, WATER IS INDEED UNIQUE. IN LARGE PART DUE TO ITS CHEMICAL STRUCTURE.

STEVEN EMERSON, Ph.D., University of Washington.
Water is an unusual molecule. It's bent. It's got a hydrogen here and oxygen here. And there's 105 degrees between those. And that tends to make it have a polar character.

KATHERINE BARBEAU, Ph.D., Scripps Institution of Oceanography, UCSD:
The centers of the positive and negative charge don't cancel each other out and so you get sort of a positive section of the molecule and a negative section of the molecule where the oxygen is.

KENNETH COALE, Ph.D., Moss Landing Marine Laboratories, CSU:
This charged separation is known as a dipole—two poles, positive and negative. As such, it has inherent properties. It sticks together with other water molecules in ways. For instance, the negative part of the oxygen molecule is attracted to the positive part of another hydrogen atom, on another water molecule. And those weak, electrostatic interactions are known as hydrogen bonds. That shapes all life on Earth.

WILLIAM JENKINS, Ph.D., Woods Hole Oceanographic Institution:
One analogy might be to think of a room full of dancers. And if you have a room full of dancers, they tend to bounce off one another—if you go to the same kind of clubs that I do. And that creates a kind of chaotic motion. But now, if you have actually put Velcro on the backs of the dancers, they tend to occasionally stick to one another. Thus is the interaction associated with the polarity of the water molecule. And that creates a kind of

clustering or clumping. And that clustering or clumping in water is actually an organization.

NARRATOR:
THIS TENDENCY OF WATER MOLECULES TO CLUSTER OR STICK TOGETHER HAS SIGNIFICANT RAMIFICATIONS.

PETER RHINES, Ph.D., University of Washington:
Electrically neutral molecule—or at least one without a dipole moment—the water has a higher boiling point and a higher freezing point than it should based on its size so to speak.

JENKINS:
If you look at the kind of typical patterns of behavior of different elements in the elemental table, you'll find that the expected boiling point of water would be something like 150 degrees Fahrenheit below zero. It isn't, and it's because of this structure, this behavior that's going on in the system driven by the dipole characteristics of water molecules that raises that melting and boiling temperatures so high. And that's what makes the Earth very hospitable to life as we know it.

NARRATOR:
WATER'S UNIQUE CHEMICAL STRUCTURE ALSO GIVES IT EXCEPTIONAL ABILITIES TO DISSOLVE OTHER SUBSTANCES.

ELLEN DRUFFEL, Ph.D., University of California, Irvine:
The fact that water is polar makes it able to go in and dissolve almost all ionic bonds. Because of this negative side of the water molecule, it will attach itself onto the positive sodium, for example. And the positive side of the water will attach itself onto the negative chloride. And it will work very quickly and dissolve the whole crystal of sodium chloride. And that's what makes it a good dissolving agent.

JEFF BADA, Ph.D., Scripps Institution of Oceanography, UCSD:
Everything to some degree is soluble in water. So that means that things dissolve and get transported from one part of the planet to another. And this is important for living systems because, for example, nutrients, which are required to maintain the very basic process of biology on the Earth, photosynthesis, can be transported from one part of the ocean to another, and this enriches part of the ocean in nutrients to allow organisms to survive and grow.

NARRATOR:
AND FINALLY, ICE, WATER IN SOLID FORM, IS ABLE TO FLOAT ON TOP OF WATER IN ITS LIQUID STATE.

BADA:
And why is this important? Well, if ice didn't float, it would simply sink to the bottom of the ocean and before too long, the whole ocean would fill up with its ice. So, the fact that

we have a solid—ice—that has a lower density than the liquid water, it floats on the surface, where it's exposed to solar radiation and can periodically melt.

NARRATOR:
LIQUID WATER ON EARTH EXISTS IN A GREAT VARIETY OF SETTINGS. CONTRARY TO POPULAR OPINION, HOWEVER, IN NONE OF THESE IS WATER EVER 100% PURE.

COALE:
Although we often think of lakes and streams and rain and glaciers as being fresh, pure water, they're not—they have dissolved gasses in them, they have trace constituents, metals, organic substances. The thing that really distinguishes sea water from these other natural water systems is the amount of salt that's dissolved in it. Sea water represents a soup—a chemical soup comprised of the entire periodic table that has been leached from continental rocks, over ages, eons, millions and billions of years.

Other pathways by which materials can be introduced into sea water include volcanic activity, underwater hydrothermal vents. Also, atmospheric deposition is an important pathway for certain types of substances into sea water. Glaciers introduce substances into sea water in certain environments. Groundwater is an important source to sea water that's being increasingly recognized that there is exchange between sea water and underground aquifers in certain coastal environments. But certainly, riverine deposition and continental weathering is a major source of elements to sea water.

NARRATOR:
WHILE BOTH SEA WATER AND FRESHWATER CONTAIN A WIDE ARRAY OF MINERALS AND OTHER CONSTITUENTS, THE AMOUNT OF SALT IN SEA WATER IS GENERALLY GREATER THAN IN ANY OTHER LARGE BODY OF STANDING WATER.

COALE:
The oceans are billions of years old. And, if you can imagine the water cycle acting on the oceans, evaporating water from the surface, raining down on the surface of the ocean, but also on the continents. And every time it rains on the continents, it scavenges salts from many, many square miles of watershed, leaching minerals from these watersheds, depositing them into the ocean where the water leaves but the salts don't. And so the residence time of those mineral phases is long with respect to the ocean. In lakes, that's not necessarily the case. Water rains down, leaches a smaller watershed, water comes in, salts pour out with the discharge. In land-locked lakes such as Mono Lake or Great Salt Lake, for instance, where there is no discharge, those lakes do get salty. So, in that way, they are similar to the oceans. But in most freshwater systems, there's an inlet and an outlet and the residence time of salts in those freshwater systems is short. The residence time of salts in the oceans is very long.

NARRATOR:
JUST ARE THERE ARE MEANS BY WHICH SALT IS ADDED TO SEA WATER, SO, TOO, ARE THERE WAYS BY WHICH IT IS REMOVED. THESE ARE COLLECTIVELY KNOWN AS SINKS.

BARBEAU:
In terms of the sinks, salts in sea water, primarily salts are taken out by being converted into particulate form, and then sequestered in the sediments.

If you can think of sediments at the bottom of the ocean, in between the fine interstices of sediment grains, there's water that moves with the sediments. And as the sediments are subducted under continental plates, those sea water salts are removed with it.

Interaction of sea water with hot rocks, hot basalt at sites of volcanic activity at the mid-ocean ridges can also be an important sink for some elements.

DRUFFEL:
These hydrothermal vent systems have large amounts of water percolating through, and the chemistry of the water changes.

The discovery of hydrothermal vents changed our notion of ocean chemistry in some very fundamental ways. Not only did we discover new sources of minerals to the oceans, but we found that circulation through these hydrothermal vent systems actually removed some elements.

NARRATOR:
EFFORTS TO MEASURE SALINITY HAVE LONG BEEN A FUNDAMENTAL PART OF CHEMICAL OCEANOGRAPHY.

BARBEAU:
In early days, salinity was defined as the mass of salts in a given mass of sea water. But it was very difficult, it's not practical to evaporate all the sea water and then weigh the salts because, if you heat the salts up enough to drive up all the water, you get changes in their chemistry, and so that's not really very practical.

Salts won't dry out all the way and it's always been a pain. You get a big old cake of stuff in the bottom of your beaker when you try it anyway. Don't do this at home.

BARBEAU:
For many years, salinity was defined in terms of the chlorinity of sea water. The concentration of chlorides, which was determined by titration with silver nitrate. The concentration of chloride could be determined very accurately and there's a definite ration—a mathematical relationship between the chlorinity and the salinity of sea water.

That was how they used to calculate salinity. We don't do that much anymore. It's expensive, silver's toxic and it's difficult to do at sea. But we can take advantage of the fact that the presence of dissolved ions in solution increased the electrical conductivity of the water. And so we can measure with a probe the conductivity of a solution and then calculate salinity from that. Now that's been a tremendous benefit to oceanographers. This means that we can make robust salinity detectors, salinometers, if you will, or conductivity cells that can be deployed on robots, that can be deployed on instrument packages from the side of the ship, that can be put on buoys or autonomous devices.

RAYMOND W. SCHMITT JR., Ph.D., Woods Hole Oceanographic Institution:
For years we've been able to get ocean temperatures from satellites. However, there's not yet a satellite available to tell us the ocean salinity. So, oceanographers are working very hard to do a better job measuring salinity. And the only way we know how to do this is by putting instruments in the water. One of the key elements of our improved capabilities is a system called the Argo Float. This is a program to deploy 3,000 profiling floats. These profiling floats would act like weather balloons, drifting around the global ocean at a depth of 2,000 meters, surfacing every 10 days by inflating a small bladder at the bottom of the float. As they rise through a water column, they measure the temperature and salinity.

STEPHEN RISER, Ph.D., University of Washington:
Then, while it's on the surface, it will transmit this data to a satellite. The satellite then will transmit the data back to our lab or to some central data facility. And the data are available in nearly real time.

KENNETH COALE, Ph.D., Moss Landing Marine Laboratories, CSU:
Now salinity is one of the easiest things for us to measure in sea water, and we can measure it to a great degree of precision.

NARRATOR:
OBTAINING ACCURATE SALINITY MEASUREMENTS IS VITALLY IMPORTANT BECAUSE SALT, ALONG WITH TEMPERATURE, HAS A SIGNIFICANT IMPACT ON THE DENSITY OF SEA WATER AND THIS, IN TURN, GREATLY AFFECTS OCEAN STRUCTURE AND CIRCULATION.

KATHERINE BARBEAU, Ph.D., Scripps Institution of Oceanography, UCSD:
Density is measured in terms of mass per unit volume and the presence of salts will certainly increase the mass per unit volume of sea water and its density.

LIHINI ALUWIHARE, Ph.D., Scripps Institution of Oceanography, UCSD:
One of the really interesting things about having salts in sea water is actually how it controls the temperature at which sea water can boil or freeze. So usually we think of freshwater freezing at about zero degrees Celsius, but with saltwater, around the North Pole and around the South Pole, you can have water that can go down to temperatures of about minus 1.8 degrees Celsius without freezing, and that's because the presence of salt actually decreased the freezing point of water.

NARRATOR:
BECAUSE COLD WATER IS MORE DENSE AND THEREFORE TENDS TO SINK, THE ULTIMATE IMPACT OF TEMPERATURE AND SALINITY ON SEA WATER IS EXTRAORDINARILY IMPORTANT.

WILLIAM JENKINS, Ph.D., Woods Hole Oceanographic Institution:
And one of the most important aspects of that is that when you think about how oceans work on a global scale the oceans are density stratified. What I mean by that is that heavy water sinks to the bottom because it's heavy, relatively speaking. It's denser. And light water sits at the ocean surface. Now, the net result of that is that, in fact, in the polar regions of the Earth, you actually tend to cool water and make it more dense. That water, because it's more dense, will tend to sink below lighter waters. That sets up a convection cell, an overturning cell, where you have cold, dense water in the Polar Regions which tends to sink down to the bottom of the ocean. That's replaced by warm, surface water from the warmer portions of the globe—the equatorial regions, for example—and that overturning cell actually tends to set up a transport. That transport, on a global scale—and it's quite remarkable when you think about it—tends to transport a significant fraction of the heat that's delivered to the surface of the Earth in the tropical regions. And, in fact, at various latitudes in the ocean, it transports up to about half of the total heat transport that goes on. In other words, half of the heat from the tropical regions is carried to the Polar Regions by the atmosphere. And the other half by the ocean.

So, together, salinity, density and temperature dramatically affect the way ocean water moves through large ocean basins. Now, if we use the Atlantic Ocean as an example, you can imagine the Gulf Stream, warm, hot sea water rising up past the Eastern Seaboard, evaporating as it goes, reaching Greenland and Newfoundland and cooling. And what happens there is that sea water cools—highly saline sea water cools and sinks. And it sinks and flows down the middle of the Atlantic Ocean. That's one of the places in the world where deep water's actually formed. And it's formed because it's high in salinity and low in temperature. So there's a very dense water mass. The other place where deep sea water is formed is in the Antarctic where temperatures get so cold that sea water freezes leaving behind very cold, highly saline, dense water. And so, there are two places really in the world's ocean where deep water's formed, North Atlantic and all around the southern ocean in the Antarctic. So, in that way, salinity's very important in terms of forcing what we know as thermohaline circulation throughout the world's oceans.

RISER:
Thermohaline circulation is a circulation that is driven by differences in temperature and salinity, as opposed to the circulation that's driven by wind. And when you think about how water—what causes water to move—it can be either some frictional effect, that is the wind is pushing it around, or it can be differences in density.

All these different types of water have different origins and, especially in the southern ocean, it becomes very complicated and it's very important to understand what all these water masses are doing if we A, want to understand the cycling of elements, and B, if we really want to model things in the ocean on long timescales to see what things could happen in the future. We really need to understand how the patterns of water move.

BARBEAU:
These kinds of circulation patterns are very important drivers of climate. Paleoceanographers are studying the way that these circulation patterns have changed over glacial to inter-glacial timescales. And the interaction of deep waters at high latitudes with the atmosphere is really a key factor in terms of how the ocean interacts with CO_2 in the atmosphere, and whether the ocean can take up carbon dioxide effectively.

NARRATOR:
THE EXCHANGE OF GASSES, LIKE CARBON DIOXIDE, IS A CRITICAL ASPECT OF THE ONGOING AND DYNAMIC INTERACTION BETWEEN THE OCEAN AND THE ATMOSPHERE.

JENKINS:
The relationship between the ocean and the atmosphere is extremely important. That's come to public light because of the greenhouse effect and the fact that the oceans are taking up perhaps of order of half of the amount of carbon dioxide that we're producing by fossil fuel burning, or perhaps deforestation.

We're basically concerned with three different reservoirs of carbon on the surface Earth that exchange with each other on timescales that we care about. Thousands of years basically. Most of the carbon in the Earth is tied up in sedimentary rocks. But the residence time of that pool of carbon is millions and millions of years. So in terms of exchangeable pools on the Earth's surface, we have the atmosphere, we have the ocean, and we have the terrestrial biosphere, forests and trees, that kind of thing. And so, out of those three reservoirs, the ocean is by far the largest reservoir of carbon.

Thus, one would argue that in the long term, a very large fraction of the carbon that we are putting into the atmosphere in the form of CO_2 by burning of fossil fuels, will end up in the oceans. The difficulty is what are the rate limiting processes by which this occurs?

BARBEAU:
So, we're very interested in the ocean's ability to absorb the fossil fuel CO_2 that mankind's activities have added to the atmosphere. And that ability of the ocean to absorb CO_2 is mediated primarily in the upper ocean by air-sea gas exchange, across the air-water interface.

Now the oceans play this funny balance with respect to the gaseous composition of the atmosphere. About 18,000 years ago, during the last Ice Age, it appears that marine production was at a maximum. That means that phytoplankton were growing like gangbusters, sucking up atmospheric CO_2, blowing off oxygen, transporting carbon to the deep sea. And this essentially reduced the CO_2 in the atmosphere and the planet cooled. About 6,000 years ago, something changed. Marine productivity decreased and, as a consequence, CO_2 from the oceans outgassed into the atmosphere, the atmosphere trapped more sunlight energy, the planet warmed. And so it appears that ocean productivity and the gaseous exchange between the oceans and the atmosphere is very important in terms of controlling global climate.

NARRATOR:
SOME HAVE SUGGESTED THAT STIMULATING PLANT GROWTH AT THE SEA SURFACE MIGHT BE ONE WAY TO DRAW ADDITIONAL CARBON INTO THE OCEAN. PRESUMABLY, THIS WOULD DECREASE THE CARBON DIOXIDE IN THE ATMOSPHERE, THEREBY LESSENING THE LONG TERM THREAT IT POSES TO GLOBAL CLIMATE. SOME WHO ADVOCATE THIS APPROACH BELIEVE THAT THE MOST EFFECTIVE WAY TO ACCELERATE MARINE PLANT GROWTH IS BY ADDING IRON TO THE SEA WATER.

KENNETH COALE, Ph.D., Moss Landing Marine Laboratories, CSU:
All life on this planet evolved utilizing iron. Well, as plants in the oceans evolved, they produced oxygen and the world changed. All of a sudden there was oxygen in the atmosphere and iron precipitated. Iron in sea water that was normally abundant vanished. And from that day on, about two billion years ago, the oceans have been limited by the availability of iron. So what's a phytoplankton going to do? It developed evolutionary strategies to deal with an iron-depleted ocean. But every time it got a little bit of iron, the oceans bloomed. And as the oceans bloomed, phytoplankton growth drew down carbon dioxide and the planet cooled. And so, what we find now is that when you add tiny amounts of iron to sea water that has other plant nutrients in it, the plants will grow. They'll bloom. If you don't add iron, they won't. So it seems that iron is key to controlling plant growth in the oceans and thus global warming, climate change.

KATHERINE BARBEAU, Ph.D., Scripps Institution of Oceanography, UCSD:
It took a while for us to be able to measure iron accurately at very low concentrations, as you can imagine, sailing around on a ship that's made of steel, it's very difficult to measure iron that's in the sea water at pico molar concentrations, very low concentrations. And so that's required the development of a lot of special techniques. But now we can accurately measure it. We can conduct experiments where we add iron to sea water on a small scale as well as these large-scale experiments, and we can really see dramatic changes in the phytoplankton community as a result of adding iron in certain areas. So that's why there's so much interest in iron is that it seems to play a key role in mediating productivity in some areas of the ocean.

COALE:
Scientists have conducted several experiments where they've gone forth to the equatorial Pacific, to the southern ocean, to the sub-Arctic Pacific to ask the question, "Are plants limited by iron availability in these major ocean regions?" And in every one of these experiments, small amounts of iron were added to sea water—parts per trillion level of iron were added to sea water, and massive blooms results. This supports the notion that iron is kind of a key that controls ocean productivity and, as a result, may affect the exchange of CO_2 between the atmosphere and the oceans.

NARRATOR:
DESPITE THE FACT THAT IT CAN STIMULATE MARINE PLANT GROWTH, QUESTIONS REMAIN ABOUT IRON'S PRACTICAL VALUE IN THE BATTLE TO COMBAT SURGING ATMOSPHERIC CARBON DIOXIDE.

LIHINI ALUWIHARE, Ph.D., Scripps Institution of Oceanography, UCSD:
People have considered just dumping iron into these oceans where photosynthesis is actually unlimited, increasing photosynthesis thereby drawing CO2 down and then somehow getting it down into the sediments. But increasing photosynthesis alone is not enough, because much of the carbon that's produced by photosynthesis is taken up and degraded very quickly, and this happens in the surface ocean. So what you have is CO2 going to organic carbon, going back to CO2 in the surface ocean and there's this cycle. Only about 1% of the carbon as we know it actually escapes that cycle into the deeper ocean. Most of it's recycled, so not only do we have to increase photosynthesis, we have to find a way of getting that carbon out of surface ocean into the deep ocean. That's sort of where we're stuck. Just increasing photosynthesis is not going to do it for us. We have to actually sequester that carbon in the deep ocean.

NARRATOR:
WHILE THERE'S CONSIDERABLE DEBATE AMONG OCEANOGRAPHERS ABOUT HOW BEST TO SEQUESTER CARBON, THERE'S UNIVERSAL AGREEMENT THAT SEAWATER CHEMISTRY PLAYS A ROLE OF MAJOR PROPORTIONS THROUGHOUT NOT ONLY THE MARINE ENVIRONMENT, BUT ALL OF PLANET EARTH.

WILLIAM JENKINS, Ph.D., Woods Hole Oceanographic Institution:
I think the thing that really concerns me is that the ocean's role in global climate and in regulation of our chemical and biological environment is a dynamic one. And there are an enormous number of feedback loops between the behavior of the ocean and its role in the geosphere as a whole. Problem is that our understanding of those processes is very primitive right now. And the changes that will likely take place as a result of this perturbation that we've placed on the system will be very difficult to predict.

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