THE ENDLESS VOYAGE

"Over the Edge" Episode 105

Takes two and half hours to get to the bottom. But after about a half an hour, that lovely color blue on the outside goes to deep blue, darker blue, and then black. For about the last two hours of that dive, you're in blackness, in a world that you can only imagine what's surrounding you.

The habitat itself is very harsh. The pressure is high. The temperature is low.

What was very surprising about hydrothermal vents was, it was like this big oasis in this desert of the deep sea.

NARRATOR:
THE WATER'S EDGE—THE FIRST LEG OF AN ODYSSEY THAT EXTENDS FROM THE JUNCTION OF LAND AND SEA TO THE SUBMERGED EDGE OF THE CONTINENTS…AND FINALLY, TO THE BOTTOM OF THE DEEP OCEAN. A JOURNEY REMARKABLE NOT SO MUCH FOR THE DISTANCE COVERED, BUT FOR THE ASTONISHING CHANGES THAT TAKE PLACE ALONG THE WAY.

GARY GREENE, Ph.D., Moss Landing Marine Laboratories, CSU:
Continental margins are probably one of the most interesting geomorphic aspects of the Earth. If you were to travel from, say, the coastline out into the deep abyss, it would be a spectacular ride of some zero to five thousand meters plus in depth.

NARRATOR:
THE BEGINNINGS OF THAT RIDE UNFOLD ACROSS A CONTINENTAL SHELF WHICH MAY BE BROAD AND GENTLY SLOPING, OR NARROW AND THEN QUICKLY VERY STEEP. MOST CONTINENTAL SHELVES ARE GENERALLY MARKED BY HILLS, DEPRESSIONS AND SEDIMENTARY ROCKS. IN BOTH TEXTURE AND COMPOSITION, THEY ARE MORE LIKE THE CONTINENT FROM WHICH THEY EXTEND THAN THE OCEAN FLOOR TO WHICH THEY EVENTUALLY LEAD. IN FACT, SOME OF THE SEDIMENT DEPOSITED ON A CONTINENTAL SHELF MAY CONTAIN VALUABLE RESOURCES SIMILAR TO THOSE ON THE DRY LAND NEARBY.

WOLFGANG BERGER, Ph.D., Scripps Institution of Oceanography, UCSD:
Now these have fairly thick sediment wedges. And in these sediments there are locked-up petroleum resources—oil and gas. And that is being increasingly explored and also exploited.

DEBORAH KELLEY, Ph.D., University of Washington:
So that's one kind of mineral deposit. The other kind of mineral deposit—or economic deposit—that occurs and is probably a place that will be much more important to many

countries is that when sediments are accreted onto the margin, the sediments become compacted. They have lots of organic material associated with them, and they produce—there's microbial communities that actually live in the sediments and produce large amounts of methane. Given the right pressure and temperature, that methane can actually form a solid compound—solid ice compound called methane clathrate or methane hydrates. And probably in the near future that will be an incredibly important resource for many countries. It's a very clean burning fuel.

NARRATOR:
CONTINENTAL SHELVES ARE SHAPED PRIMARILY DURING PERIODS WHEN SEA LEVEL IS AT ITS LOWEST.

GARY GREENE:
There are flat, wave eroded and sometimes severely eroded shelf…where the continental slopes are primarily sedimentation. They are an area where sediments that eroded from the continents then drape the continental slope.

KELLEY:
In places where subduction is occurring, the continental slopes themselves are typically much more tectonically active. There's lot of earthquakes that are associated with them, and they're much steeper environments, much more rugged in general. In contrast, if you go to the eastern part of the United States, that area is a passive margin, which means the mid-Atlantic ridge has been spreading apart, but where it meets the continental margin, there's not a subduction zone there presently. So, in many areas it's a much smoother environment—there's not such steep slopes.

GREENE:
The continental rise forms from both sedimentation traveling down the slopes and also from sediments traveling down through submarine canyons, which are major conduits for sediments that eroded from the continents.

The submarine canyons are an integral part of the shelf and the slope in the sense that they are major features—they're much steeper—the terrain is much steeper than the surrounding shelf itself or slope. They basically act as funnels for the sediment to get down into the abyssal plains.

NARRATOR:
THE SEDIMENT THAT'S SWEPT ALONG THROUGH A SUBMARINE CANYON SOMETIMES TAKES THE FORM OF A TURBIDITY CURRENT.

GREENE:
It's a density current that travels down slope at a very rapid rate, approaching 50, 60 miles per hour in some cases. And it carries a tremendous amount of material with it. This is a primary mechanism for eroding submarine canyons. It's also the primary mechanism of getting very coarse grain material out into the deep ocean regions, such as the abyssal plain.

NARRATOR:
UNLIKE CONTINENTAL MARGINS, WHICH ARE IN MANY WAYS SIMILAR TO THE ADJACENT CONTINENT, THE DEEP OCEAN FLOOR IS MUCH DIFFERENT, BOTH IN COMPOSITION AND ORIGIN. ALTHOUGH IT COMPRISES MORE THAN HALF OF EARTH'S SURFACE AREA, UNTIL FAIRLY RECENTLY THE DEEP OCEAN WAS A REGION OF NEAR TOTAL MYSTERY. EVEN NOW, EFFORTS TO MAP OCEAN BASINS ARE IN THEIR INFANCY. WHAT IS KNOWN IS THAT THESE AREAS CONSIST MAINLY OF OCEANIC RIDGE SYSTEMS AND SEDIMENT-COVERED PLAINS, INTERRUPTED BY ISLANDS, HILLS AND VOLCANOES.

DAVID SANDWELL, Ph.D., Scripps Institution of Oceanography, UCSD:
The abyssal plains are fractures in the crust that are elongated in the direction of the seafloor spreading, and they form sort of the fabric of the ocean floor.

They're an area where sediments accumulate on the deepest parts of the ocean, and they are generally formed from material being carried down submarine canyons or down along a submarine slope.

NARRATOR:
PERHAPS THE MOST STRIKING FEATURE THAT CHARACTERIZES THE DEEP OCEAN FLOOR IS THE VAST OCEANIC RIDGE SYSTEM THAT ENCIRCLES EARTH ALONG TECTONIC PLATE BOUNDARIES.

PAUL JOHNSON, Ph.D., University of Washington:
A mid-ocean ridge is the place where ocean crust is formed. If you can imagine two rigid blocks, like North America and Europe and Africa, for instance, and you take these two rigid blocks, and you pull them apart—that's plate tectonics. The place where there is some give to this is called the mid-ocean ridge. You have to form new crust between these plates as you pull them apart. Plate tectonics now requires—because they're rigid plates—requires this to be a very thin zone of formation. That thin zone of formation is very hot and therefore elevated, and forms a ridge in the middle of an ocean. And that's mid-ocean ridge. It's a long, linear, active volcanic chain where ocean crust is formed.

The crest of the oceanic ridge is where the plates are moving apart. It's a very fine crack between two plates. This is where 90% of all the Earth volcanism occurs. And there are basically two styles of seafloor spreading ridges. If you went to the mid-Atlantic ridge, you'd find that the crack forms a trough, a deep trench. And this is where the plates are spreading apart. There's hills on either side of the spreading ridge. If you go to the Pacific Ocean, where the spreading rates are higher, you'll find a completely different style of seafloor spreading ridge. There you have a slight bump at the ridge axis, a lot of extra volcanism that spills out onto the flanks of the ridge axis.

NARRATOR:
THEY MAY BE UNIQUELY DRAMATIC, BUT OCEANIC RIDGES ARE NOT THE ONLY GEOLOGIC FEATURES THAT BREAK UP THE FLAT, SEDIMENT-RICH PLAINS COMPRISING MUCH OF THE DEEP-OCEAN BASIN. SEAMOUNTS DO MUCH THE SAME THING.

GARY GREENE, Ph.D., Moss Landing Marine Laboratories, CSU:
Seamounts are generally volcanic edifices that either formed in association with spreading centers or what we call off-axis volcanoes.

They're basically individual volcanoes that have—most of them form away from a ridge axis—not right on the ridge axis where you have your main volcanic activity. They form on the ridge flanks.

DEBORAH KELLEY, Ph.D., University of Washington:
As they rise up above sea level—eventually, similar to Iceland or Hawaii—the basalts are extruded down the flanks of the volcanoes, and they actually form very gentle slopes. They're usually much larger than continental volcanoes, with slopes of maybe about 30 degrees or so, but several thousand feet tall.

A guyot in contrast to a seamount is a flat-topped seamount, and it can be formed in several ways. One way is through erosion—that it was subjected to wave erosion at one time, which flattened its top.

KELLEY:
Basically, what happens is as they rise up to sea level, they become a wave-cut platform. Some of the guyots have fairly flat tops because of that wave action.

NARRATOR:
IN SOME CASES, VOLCANIC ISLANDS RISE FROM THE DEEP OCEAN FLOOR IN CURVING CHAINS KNOWN AS ISLAND ARCS.

GREENE:
In island arcs…you have one plate carrying materials—it might be sedimentary materials, it could be oceanic materials as part of the plate—deeper into the lithosphere, where it's heating up and forming a magma chamber, and eventually, then, that magma chamber breaks its way up to the surface where it starts then, building up volcanic edifices, such as volcanic arcs and mountains.

NARRATOR:
AMONG THE MORE INTRIGUING FEATURES ON THE SEAFLOOR, ALSO OCCURRING AS A RESULT OF TECTONIC ACTIVITY, ARE TRENCHES.

KELLEY:
As the oceanic crust is being transported away from the spreading center and it meets up with that down-going convection cell, that piece of oceanic crust is pulled down into the

mantle material. And, when that happens, there is a deep trench that forms. The deepest parts that we know about on our planet occur at these oceanic trenches, where the subduction zones occur. For instance, the Marianas Trench is the deepest place that we know of on Earth right now.

NARRATOR:
THE DEEP OCEAN BOASTS SOME OF THE MOST EXTRAORDINARY FEATURES FOUND ANYWHERE ON EARTH. HUGE MOUNTAIN CHAINS, TOWERING VOLCANIC STRUCTURES, TRENCHES THAT ARE UNIMAGINABLY DEEP. BUT THERE IS SOMETHING ELSE IN THIS VAST AND MYSTERIOUS WORLD BENEATH THE SEA, SOMETHING UNDISCOVERED UNTIL 1977 THAT HAS IGNITED THE CURIOSITY OF OCEANOGRAPHERS AND OTHER SCIENTISTS PERHAPS MORE THAN ANYTHING ELSE. THIS IS A HYDROTHERMAL VENT, A KIND OF DEEP OCEAN HOT SPRING, FOUND AT A DEPTH OF NEARLY 10,000 FEET. WHILE THE WATER TEMPERATURE OF DEEP OCEAN BASINS GENERALLY AVERAGES ABOUT THREE TO FOUR DEGREES CENTIGRADE, THE TEMPERATURE OF WATER IN THE VICINITY OF HYDROTHERMAL VENTS CAN BE AS HOT AS 350 DEGREES CELSIUS, OR 650 DEGREES FAHRENHEIT. BUT THAT'S JUST PART OF THE STORY.

DONAL MANAHAN, Ph.D., University of Southern California:
In the 20th century, one of the big discoveries was the discovery of hydrothermal vents in the late 1970s. This was an enormous revolution. Nobody had predicted that there would be this entire new ecosystem, basically driven by geochemical energy from the center of the Earth, as opposed to the traditional models of driving from photosynthesis on the surface of the Earth. So, when hydrothermal vents were discovered, it came as an enormous surprise to the first geologists who spotted the animals, to the biologists who made the first dives on Alvin to go down and take these samples. And I think that 20 years later, we're still fascinated by some of the diversity issues of these vents.

Hydrothermal vents are found in many different places in the ocean. Primarily, hydrothermal vents bring up hot water from deep in the Earth. They are loaded with various minerals, such as sulfide, metallic—poly-metallic sulfide minerals, the like. And they form very intricate and spectacular features called chimneys. These features are generally found in areas where the seafloor is spreading apart, such as mid-oceanic ridges.

JOHNSON:
It's a visually spectacular process when you see it. It's like looking at—bigger than Yellowstone on the seafloor in an environment that is normally almost a desert, very few things on the seafloor, and on ridge flanks, but you come up to a mid-ocean ridge and all of a sudden there are these enormous biological communities and bacterial mats.

KELLEY:
They're very similar to geysers, similar to what you would see in Yellowstone, but they occur at much deeper depths. And because they're at much deeper depths, the fluids can

get much hotter. Many areas of the seafloor are underlain by active volcanoes, and those volcanoes supply heat, and those volcanoes cool down. When they cool down the surface and, to some depth, the rocks crack—the basaltic rocks, similar to what you would see in Hawaii. As those cracks develop, seawater—cold seawater—can percolate down through those cracks. It gets near the hot rocks, the cooling volcanoes becomes buoyant and rises to the seafloor at temperatures up to 700, 800 degrees Fahrenheit.

JOHNSON:
Hydrothermal circulation is a really very complex process where you're heating seawater above the boiling point. It's a physical process associated with the cracking of rocks. It's a chemical process. It's a process that extracts magnesium from seawater.

So it extracts elements, like iron and sulfur, most of the metals—it actually leaches out of the rocks, and so the fluids that are emitted onto the seafloor are much hotter than what the normal background ocean water temperatures are. And they're laden with—they're enriched in a lot of chemical species. When they hit the seafloor—very cold seawater—those minerals fall out of solution. They precipitate and form these black smoker chimneys which most of them are made out of metal deposits.

NARRATOR:
THE INTERACTION BETWEEN SEAWATER, ROCKS AND MINERALS THAT IS AT THE CORE OF HYDROTHERMAL CIRCULATION HAS PROFOUND IMPLICATIONS FOR THE MARINE ENVIRONMENT.

PAUL JOHNSON, Ph.D., University of Washington:
Most seawater will have, in one or two hundred thousand years, will have actually passed through one of these hydrothermal systems. In a hydrothermal circulation cell, you're taking normal seawater, you are drawing it down into the crustal rocks, you are re-heating it to very high temperatures on the ridge axis, even very intermediate temperatures on the ridge flank, and you're exposing it to rock that has a lot of chemicals that want to react with it. There's a lot of iron. Iron is given off from the rocks into the seawater. Magnesium is absorbed from the seawater into the rocks. Calcium is given off. It's forming this chemical balance at very high temperatures. The fluid that actually comes out of a hydrothermal vent is chemically much different than the fluid that went in, the seawater that went in. So it is changing its chemistry.

STACY KIM, Ph.D., Moss Landing Marine Laboratories, CSU:
Some of the chemicals that are in high concentrations in this hydrothermal fluid are hydrogen sulfide, and that's one of the chemicals that's very important for the life that exists at hydrothermal vents. The hydrogen sulfide is an energy source. It's comparable to sunlight. Plants on the surface of the Earth use sunlight as an energy source to create compounds, and the microbes in bacteria that live at hydrothermal vents use hydrogen sulfide as an energy source to build carbohydrates. And these bacteria at hydrothermal vents are the base of the food web there.

NARRATOR:
WHAT IS PERHAPS MOST SPECTACULAR ABOUT HYDROTHERMAL VENTS ARE THE EXCEPTIONALLY STRANGE ORGANISMS THAT HAVE SOMEHOW ADAPTED TO AND APPARENTLY THRIVE IN THIS UNIQUE REGION OF THE DEEP OCEAN.

MANAHAN:
By some estimates, in hydrothermal vents there are hundreds of species that are unique to that, not found anywhere else on Planet Earth. Hydrothermal vent tubeworms are an example. Lots of arthropods. Just a very large number of species that are unique to these vent sites.

What is particularly interesting is to look at the evolution of these life forms to see where do they come from. Did they evolve there? Did they evolve somewhere else and then migrate there in evolutionary time? Those are some of the interesting questions in the evolutionary biology of animal life forms at the moment.

NARRATOR:
FOR MANY SCIENTISTS, THE LURE OF HYDROTHERMAL VENTS EXTENDS BEYOND THE VENT REGION ITSELF.

DEBORAH KELLEY, Ph.D., University of Washington:
I think the reasons that hydrothermal vents are of such interest is that they embody a lot of the processes that make our planet what it is. The other reason is is that there's interest through NASA, in the sense that if we want to look for other places in our solar system where life can exist, maybe microbial life, then what we'd like to know is how does life develop on a planet? What processes physically sustain life? By looking at the volcanoes and the life they support here on our own planet, perhaps we can gain guidance to the search for life on other planets as well.

NARRATOR:
HYDROTHERMAL VENTS WEREN'T DISCOVERED UNTIL THE LATE 1970s, PRIMARILY BECAUSE THERE SIMPLY WASN'T ANY SAFE WAY TO CONDUCT RESEARCH AT THAT DEPTH.

JOHNSON:
When I started studying mid-ocean ridge processing in 1974, we were limited to what we could see from the surface ship, which was basically going out with an echo locator, dragging a steel bucket over the seafloor with a cable. In 1974, we just started the first dives on the mid-Atlantic ridge using the submersible Alvin. Hydrothermal circulation was not believed in. It was not a concept that had any credibility at that time. People were thinking, "Well, we should look around and see whether or not there is any fluid coming out of the rocks." We didn't find any at that time in the mid-Atlantic ridge. We didn't know where we were. It's very difficult to do science when you really don't know where you are. You are limited to an occasional satellite fix every five or six hours, you would organize your experiments around. You'd look at a table, it would tell you, "Yes,

we’re going to have a navigational satellite fix at midnight, and so now we can do an experiment. And we’ll know where we are at that time.” The change in the environment over those 25, 30 years has been incredible.

KELLEY:
One of the ways that we explore for vents—one is by mapping. There’s some very high-end mapping tools now—a system called side-scan sonar that actually gives you an image of what the seafloor looks like. With the side-scan sonar you can cover tens of kilometers in a day. And the second way that we can look for vents now is that we use an instrument that measures conductivity—kind of like salinity in the water—the temperature of the water and the amount of particulates in the water. This instrument package is called a C.D.T., because it measures conductivity, temperature, and also the depth that that instrument’s at.

There are several ways to do research at hydrothermal vents. It takes a large vessel, because hydrothermal vents are generally in the middle of ocean basins, so you have to go well away from shore, and then you can use several sorts of tools to sense and to visit the hydrothermal vent environment. So people who are doing geology can use dredges, they can use drills, they can use sonar and other sound sources to map the particular areas. Then, if you want to get in a little closer, you can use a remote operated vehicle, or an R.O.V., which is a robot attached by a cable to the ship, and driven by pilots who are on the ships. So, if you’re good at video games, you’re probably in line for getting an R.O.V. pilot job. But those allow you to go down and have an eye in the sea and a couple of manipulator arms that allow you to do things on the seafloor. And then we also have a manned submersible, which is called Alvin. Three people can get in that, there’s a pilot and two scientists—and go down and conduct experiments and do manipulations on the seafloor. So there are several different tools that allow us to get into those hydrothermal vent environments and work.

DAVE GALLO, Ph.D., Woods Hole Oceanographic Institution:
Now you’re looking at places—mountains, valleys, things that people have never seen before in their life—and there you are, exploring. And the sub moves across that bottom at about a half a mile an hour, real slow. The lights go out ahead about 30 feet. You never know what’s going to come out of that darkness, or what you’re going to stumble across. So, it’s an amazing thing to do.

JOHNSON:
But the amount of time that you can spend on the bottom is very short. They’re very expensive. It’s very difficult and competitive to get time on Alvin. It’s like a big, large telescope—everybody wants to use it, there’s limited resources. And so we now have evolved to the point where we’re using remotely operated vehicles, like Jason, Robos. They can go down and the scientist can stay up on the surface ship. Instead of being on the bottom for four hours, you’re now on the bottom for four days.

BRUCE ROBISON, Ph.D., Monterey Bay Aquarium Research Institute:
The R.O.V.s, the remotely-operated vehicles, have certain advantages, and the human-occupied or manned submersibles have their advantages. With remotely-operated vehicles, you have, in essence, unlimited power coming down the tether to the vehicle. You can stay down as long as you like, and the payload in general on a remotely-operated vehicle—payload for scientific instruments, for samples you want to collect and things like that—is much greater. Disadvantages of R.O.V.s are that despite the wonderful cameral systems that we have—for example, on MBARI'S R.O.V.s we have highly advanced, even high definition camera systems. Nevertheless, you're looking with one eye through a pipe. You're getting a very small piece of the larger picture. You may have it in very high resolution with perfect color and all of that. Nevertheless, it's just one facet of a much larger overall picture, and you have to keep that in mind when you try to put those little facets together to get an overall picture. With human-occupied vehicles, you can get a panoramic view. You can see things in three dimensions with excellent depth of field. Manipulative tasks are very much more straightforward. There are limitations to human-occupied vehicles in that you've got a person inside whose health and welfare you have to consider. Both systems have real value. In order to get the best science done and the best observations made in the deep sea, you really need both perspectives.

NARRATOR:
STILL ANOTHER PERSPECTIVE IS AVAILABLE HIGH ABOVE PLANET EARTH.

DAVID SANDWELL, Ph.D., Scripps Institution of Oceanography, UCSD:
There's a new technology that we're using to measure the topography of the ocean surface using a radar altimeter. And then we take the topography of the ocean surface, which reflects the gravity field of the Earth, and use that information to invert for the variations in ocean floor depth. For example, if you have a large volcano on the ocean floor, it has an extra bit of gravitational attraction that will attract the water—the ocean surface towards it—pile the water up a little bit, maybe a meter, 50 centimeters. But that pile on the ocean surface water can be measured by a satellite. So, they've revolutionized our view of the ocean basins.

NARRATOR:
EVEN WITH ALL THE NEW TECHNOLOGY THAT'S AVAILABLE, OUR KNOWLEDGE AND UNDERSTANDING OF THE DEEP OCEAN IS FAR FROM COMPLETE. IN FACT, WE KNOW MORE ABOUT THE SURFACE OF MARS THAN WE DO ABOUT MANY PARTS OF THE DEEP SEA.

JOHNSON:
We've now constructed the techniques where we can map the features on the seafloor to this high resolution, but we haven't applied them for very much. We've just gone out, we've developed the instruments and the techniques, and now we've shown that we can do them. Now we need to do them on a larger scale. We've got to understand the system we're looking at like geologists can do on land, where a member of the U.S. Geologic Survey would go out and map their quadrangle, and they'd know where almost every

rock was on the floor, and then they can come back and talk about the scientific processes that formed it. We're not at that level yet. We're trying to get to that level, but that's probably 30 or 40 years down the road. Getting to that means we have to put instruments down on the seafloor to monitor what is going on. We have to map things in a much higher resolution and in much better detail than we do, and we need to extend those areas that we know well, like the Juan de Fuca and a few places in the mid-Atlantic ridge, over the rest of the oceans. We've looked at a very tiny postage stamp of the oceans, and most of it is unexplored.

"THE ENDLESS VOYAGE" IS A 26 PART TELEVISION SERIES ABOUT OCEANOGRAPHY. FOR MORE INFORMATION ABOUT THIS PROGRAM AND ACCOMPANYING MATERIALS, CALL: 1-800-576-2988 OR VISIT US ONLINE AT: WWW.INTELECOM.ORG.