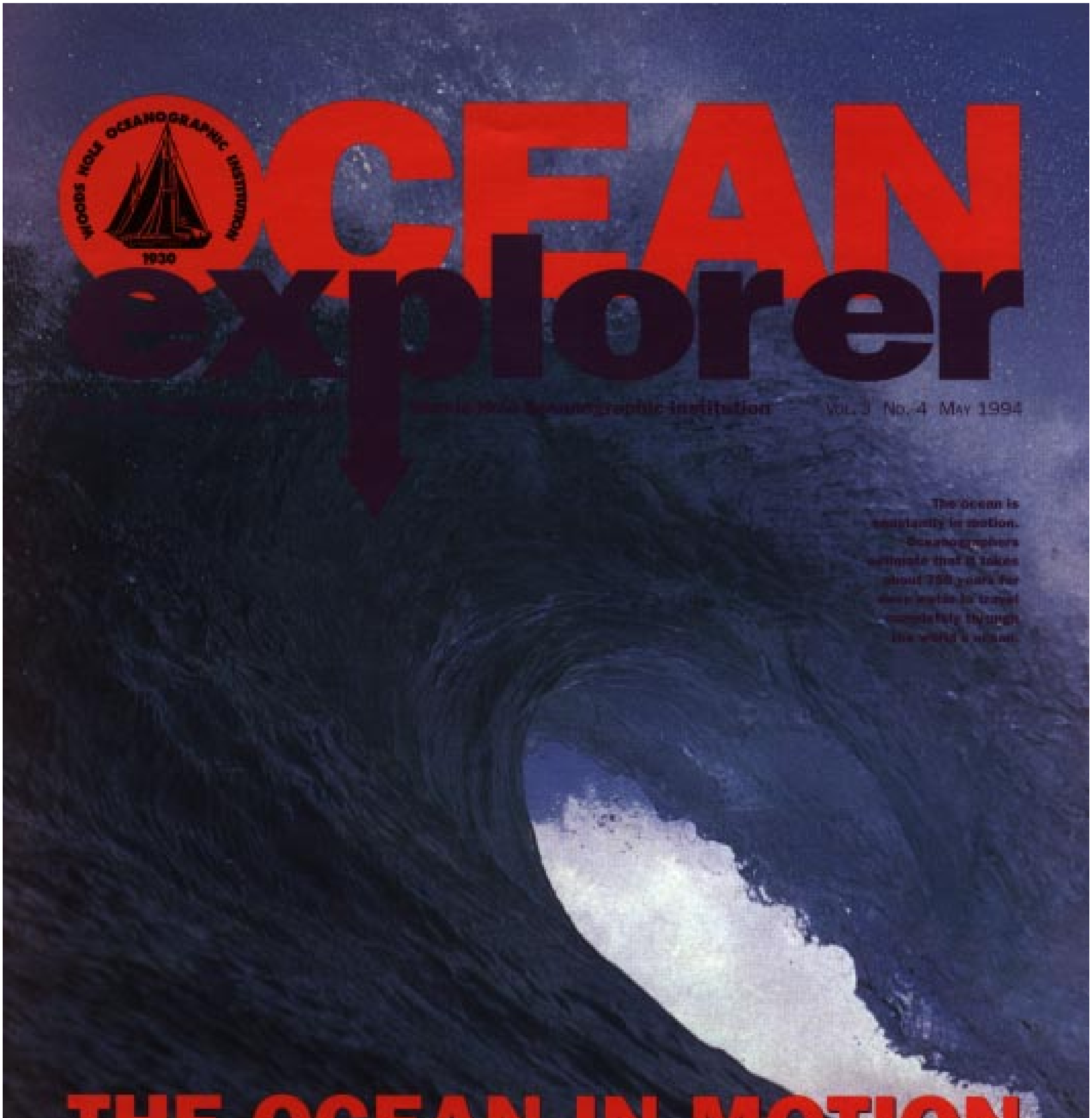


OCEAN explorer

Woods Hole Oceanographic Institution Vol. 3 No. 4 May 1994

The ocean is constantly in motion. Oceanographers estimate that it takes about 750 years for deep water to travel completely through the world's ocean.

THE OCEAN IN MOTION

Off the coast of North America, a spiral of water spins slowly. The spiraling water is considerably warmer than the water surrounding it. Slowly, slowly it spins, traveling towards the northeast. Eventually, it breaks up. Its water moves in many different directions.

Some of that water joins a northbound current that travels toward the Arctic Circle. This water mixes with denser, saltier water. Now heavier, it sinks beneath the surface and eventually turns south, toward the Equator.

In turn, some of that water slips lower and lower in the depths until it mingles with water spewing up from a seafloor hydrothermal vent — a natural chimney that shoots super-hot water and chemicals up from beneath the earth's crust. The plume of vent water carries millions of microscopic larvae that rely on the motion of sea water to carry them to a new home.

Like blood moving through a body, the ocean is constantly in motion. Many oceanographers want to better understand the causes and effects of this motion. In this issue, *Ocean Explorer* talks with a number of physical, chemical and biological oceanographers, who spend their days thinking about the endless motion of the world's ocean.

A RIVER IN THE SEA

The Gulf Stream has been studied for centuries. Yet many questions remain. By Deborah Kovacs

In 1513, the explorer Juan Ponce de Leon commanded a voyage of three ships, sailing north from Puerto Rico to Florida, and then south to the Tortugas islands. The ships met a current so stiff that they could barely sail against it. The explorers didn't know it then, but they had discovered the mighty Gulf Stream. This fast-moving band of water runs up the east coast of the United States and Canada. It acts as a barrier between the warm water of the Sargasso Sea, an oval area near the center of the North Atlantic, and cooler water on the inshore side.

THANK YOU, MR. FRANKLIN

As North America was explored and settled, the Gulf Stream continued to interest many people, including Benjamin Franklin. During his eight round-trips across the ocean, he studied it closely.

In 1769, he asked his cousin, Timothy Folger, a Nantucket whaleman, to sketch the Stream's path. The sketch resulted in the map above, the oldest known picture of the Stream.

Ben's descendents inherited his interest. In 1790, a grandnephew, Jonathan Williams, found "whirlpools" of warm water to the northwest of the Stream. These "whirlpools," now called eddies, or rings, are still studied today.

Ben's great-grandson, A.D. Bache, surveyed the U.S. coastal waters in the 1840s. He thought there might be a "counter-current of cold water from the Pole below the warm current from the Equator." The idea was dismissed at the time. But more than one hundred years later, WHOI physical oceanographer Henry Stommel suggested the idea again. Experiments proved both Bache and Stommel were correct.

HOW DO YOU STUDY MOVING WATER?

The Gulf Stream has been studied closely at WHOI since the Institution was founded in 1930. In recent years, WHOI physical oceanographers Phil Richardson, Larry Pratt, and Nelson Hogg have been among many scientists interested in the Stream.

These days, Phil Richardson mostly studies the Tropical Atlantic. But he studied the Gulf Stream for many years. In 1978, he found the 1769 Franklin-Folger chart, long believed lost. Later, Phil studied many 19th-century pilot charts published by the U.S. Navy. He used the charts to plot the wanderings of derelicts — which are ships abandoned at sea — through the Gulf Stream. By tracing a derelict's path, says Phil, "you could put together a little story." One ship in particular, the *Fannie E. Wolston*, was tracked continually for three years as it made its slow way around the North Atlantic Subtropical Gyre.

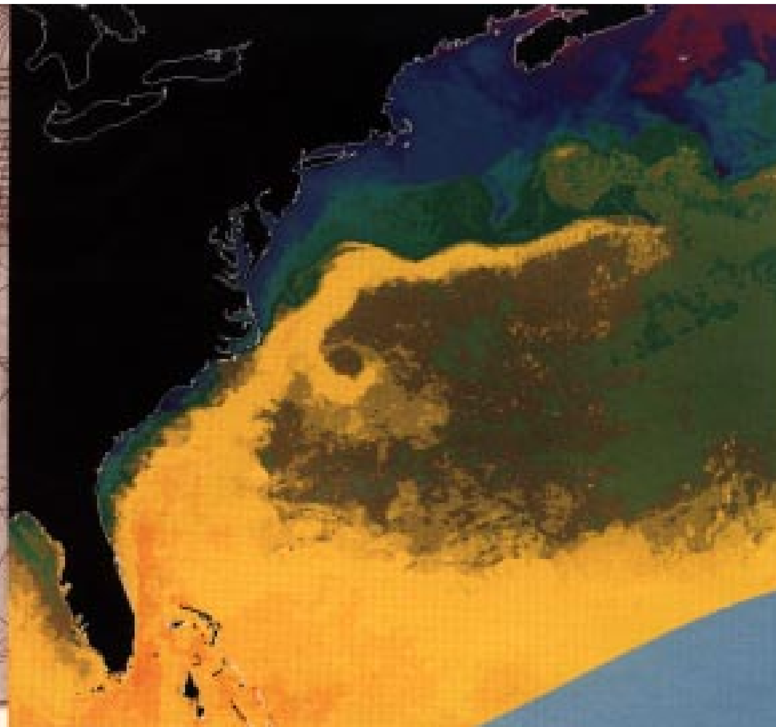
WATCHING THE RINGS GO ROUND AND ROUND

Phil still has many questions about the Stream. He wonders: "Where is the water going? Where did it come from? How much is it flowing?" But the question that has occupied him most over the years is: "How much does it change?"

As the Stream travels, it meanders back and forth, like a river. It changes. When its sides come together, they pinch off into eddies, or rings. If the Stream loops to the south, carrying cold inshore water, it forms a cold core ring. If the

TO FIND OUT MORE ABOUT THE CORIOLIS EFFECT...send a self-addressed, stamped envelope to: Editor, *Ocean Explorer*, Fenno House, Woods Hole Oceanographic Institution, Woods Hole, MA 02543. We'll send you a simple experiment that will allow you to create the Coriolis effect in your own home.

The Gulf Stream is part of a much larger system called the North Atlantic Subtropical Gyre, shown here in a very simplified diagram. The gyre moves in a clockwise curved path. This is partly due to the Coriolis Effect, a law of physics which says that the earth's rotation affects the movement of objects on its surface. At the Equator, the earth rotates at a speed of 1664 kph. At the poles, the earth rotates at 0 kph. Water moving between the Equator and the North Pole seems to move in a clockwise curved path, to compensate for these differing speeds.



PETER CORNILLON/UNIVERSITY OF RHODE ISLAND

THE GULF STREAM:
THEN...This is the first version of several of the "Franklin-Folger" charts made between 1770 and 1786. It was thought to be lost until 1978, when Phil Richardson found it at the Bibliothèque Nationale in Paris. Of it, Phil has written: "[It] remains today a good summary of the mean path and width of the Gulf Stream and the speeds in its high-velocity core."

...AND NOW This recent satellite image of the Gulf Stream uses color to describe the different water tempeartures. Warmer water is yellow, and colder water is green, blue and purple. It is surprising to see how closely this up-to-date image resembles the one drawn more than two hundred years ago, based only on the knowledge of Gulf Stream mariners.

Stream loops to the north, it carries warm water from the Sargasso Sea, and forms a warm core ring.

THE GULF STREAM AND CLIMATE

Larry Pratt wonders about the effects of the ocean on climate. "The water in the ocean is heated up in the tropics by the sun. It gets transported north, and keeps some of the northern regions warmer than they would be if there were no oceans. The Gulf Stream helps this happen, in ways that we are trying to understand better."

As the Stream meanders, eddies of warm Sargasso Sea water spin across the Stream's axis and mix with cool inshore water. Inshore water also spins in eddies across the axis to the Sargasso Sea. Larry wonders how eddies form and detach from the Gulf Stream.

Working with scientist Peter Cornillon and others at the University of Rhode Island, Larry created some theories on the formation of eddies. Peter had been studying satellite data (similar to the map shown above) when he noticed a "warm outbreak" — an eruption of warm Gulf Stream water into the Sargasso Sea.

Usually cold, not warm rings are observed there. Peter asked Larry if he could come up with a theory about how such a warm outbreak forms.

Many complex equations later, Larry thought he had a possible explanation. "I came up with a theory which describes how an eddy, or a blob of fluid, can detach from the Gulf Stream without trapping any of the cold fluid in the north," Larry says. "This can occur when a sudden widening of the Gulf Stream forms, which we call an aneurism. The bulging edge of the Stream breaks away to form a ring-shape eddy."

A HEAD FULL OF IDEAS

Nelson Hogg wonders about the Gulf Stream's recirculations. "Why does the Stream move?" he says. "Why does it meander? Are those meanders important in making the Stream recirculate?"

The complicated answers to these simple-sounding questions lie in what Nelson calls the "essentially unstable" warmer water that lies to the south of the Gulf Stream. "It's that instability that causes the movement." Nelson believes that the Stream works hard to get rid of the differences between the warm and the cold water. "It's part of the ocean's system for equalizing itself," he says.

To try to answer his questions, he's set up an array of about 40 current meters, which measure the velocity of water. "The current meters send back a set of wiggly lines," says Nelson. The lines show changes in the Stream's current at those fixed locations.

When he gets the data, Nelson's toughest job begins. That's when he says to himself: "What does all this mean?"

To interpret the data, Nelson moves between observations and theories. He thinks hard. He tries to form conclusions. In this, he says, he's like many physical oceanographers. "We all walk around with these pictures in our minds. Our intuition grows from the data. In the end, you're carrying around your vision of how the ocean works."

From these visions, oceanographers form questions. They test their ideas, to see if the ocean agrees with their visions.

TRACERS TELL THE TALE:

Or, How Do You Know Where Sea Water Goes?

By Tom Gidwitz

To discover how some oceanographers study the ocean, stir a glass of water, then tap a few drops of food coloring into it. The swirling dye will show you eddies and currents that were invisible before. The food coloring is acting as a tracer, revealing the path of the currents in which it travels.

Similarly, chemical oceanographers use tracers to study the slow up-and-down mixing of ocean water. Some of the tracers they use occur naturally in the ocean. Others are placed in the ocean in minute amounts. By keeping track of the tracers' levels, the oceanographers can learn how quickly heat, nutrients, and dissolved materials move from one ocean layer to another. Knowing the rates of these movements helps the scientists study marine life and make predictions about the earth's climate. Read on to find out how two scientists and their colleagues use tracers to learn more about the ocean's endless movement.

BOMB-TEST TRACERS

Thirty-five years ago, high above the surface of the earth, a blazing fireball exploded across the sky. It boiled up through the clouds, rising eight miles to the base of the stratosphere, spewing radioactive material into the air.

This fireball was from a hydrogen bomb test. Earlier in the century, dozens of these blasts were staged in the Northern Hemisphere.

One by-product of these tests has been a great source of information to oceanographers. That is tritium, a radioactive form of hydrogen. Tritium atoms, like ordinary hydrogen atoms, bond with oxygen to form water. Over the years, tritium-laden water vapor created by the bomb tests has condensed and fallen to earth as rain.

An international treaty banned atmospheric tests in the 1960s. But small amounts of tritum still flow into the ocean from the Arctic. Though radioactive materials can be harmful, there's not enough tritium in the air and water to hurt us. In fact, Bill Jenkins, a WHOI geochemist, finds that the tritium helps him do his work. He is using the tritium in ocean water as a tracer to better understand ocean water's up-and-down movement — called vertical mixing — and also sub-surface currents.

TRACKING TRITIUM

"If you look at the surface waters, prior to 1960 there was very little tritium in the oceans," says Bill. "In 1965, it reached a maxium, and then it started dropping off."

Bill says this man-made tritium acts as a tell-tale dye. He and his team have taken thousands of water samples in the Atlantic, analyzed them for tritium, and then plotted their findings on maps. The tracer's movements show how long it takes for a substance in the atmosphere to be mixed into the deep ocean. This information will help scientists better understand the interaction between the ocean and the air.

TRITIUM'S TICK-TOCK

All radioactive elements, including tritium, disintegrate into other substances at steady, predictable rates. For example, tritium degrades (changes) over time into a gas called helium-3. For this reason, tritium can be used as a kind of clock, recording how much time has passed since the water in the samples was last exposed to the ocean's surface.

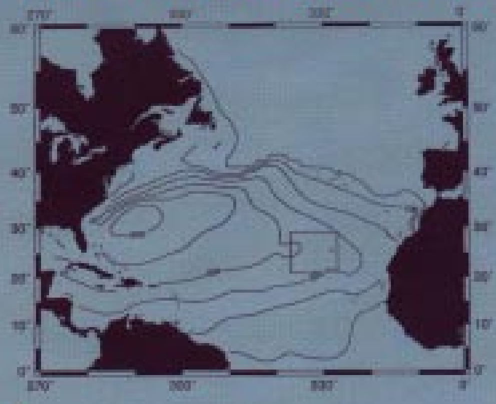
On the surface, the helium-3 formed by tritium escapes into the atmosphere. As the surface water cools and sinks, the degrading tritum's helium-3 becomes trapped and begins to collect. When Bill analyzes a sample of deep ocean water, he measures helium-3. The

amount reveals how long the water has been sinking.

Bill can pinpoint the time of the water's descent to within two months. Once he knows the speed of the water's downward circulation, he can use it to estimate the rates of important biological and chemical processes.

Below is shown a computer image of the movement of the tritium tracer studied by Bill Jenkins. The graphic shows the North Atlantic (without any water). The color in the middle of the image is a "section" of the ocean, cutting north-south through the basin. On the section is painted the distribution of tritium, which can be seen spreading downward and southward in the deep and intermediate depths. The color of the section moves from a low concentration of tritium (blue) to a higher concentration (red).

THREE WAYS TO STUDY A TRACER'S TRAVELS



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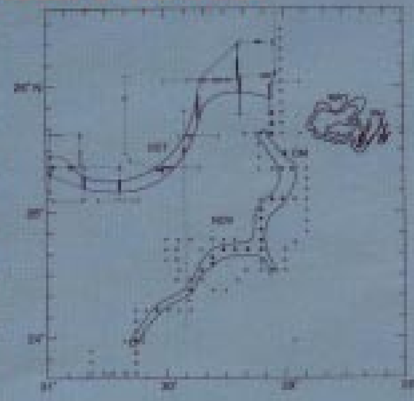
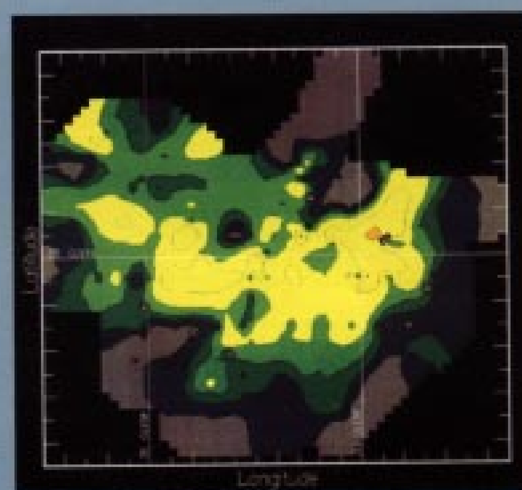


2.

1. Jim injected his tracer at the "+" in the eastern Atlantic. (See box.) One year later, it had spread to an area the size of the box.

2. The squiggly shape at the right shows the tracer's injection point. Within six months, the ocean stretched the tracer into long streaks, two of which are shown here. The dotted lines are the path taken by the research ship that returned to look for the tracer.

3. This is a computerized map of the tracer's distribution one year after injection. The area of greatest concentration of the tracer is shown in orange. Lighter areas are yellow, green and blue.



3.

ADD-A-TRACER

Taking part in another tracer study, the research ship *Oceanus* slowly pushed its way through the waves of the North Atlantic. It was May, 1992, and WHOI scientist Jim Ledwell and other oceanographers were engaged in a pioneering experiment. They were injecting several hundred kilograms of tracer into the water from a device towed a few hundred meters below the surface.

The tracer, sulfur hexafluoride, is a harmless material. The team deposited the tracer in four streaks over an area of about 17 square kilometers.

A few months later, Jim and his colleagues returned to the site. As their ship steamed northward, they took water samples, looking for the tracer. At first, they couldn't find it.

"We [searched] for about two days, says Jim. "And then we found this skinny streak."

SUPER-THIN STREAKS

The ocean's currents had teased the tracer into wavy streaks more than 1500 km long and 10 km wide. Though the streaks were very long, they were very skinny — only 180 meters from top to bottom. These thin streaks helped Jim and the others show that the ocean carries materials sideways much faster than it moves them up and down.

In May, 1993, Jim and his team returned to measure the tracer. Over the winter, the current had spread it into a patch that measured more than 150,000 square kilometers. The patch still held remnants of the streaks, but they were less defined. And the patch was still very thin. It was only a few hundred meters thick.

This summer, the oceanographers will go back to the site once more. Jim expects the patch to have moved west, and to have doubled in area, while keeping its pancake shape.

Jim will stage future tracer experiments in deeper water and near layer boundaries. These experiments will help clarify where mixing is occuring and also its strength. By using an injected tracer, Jim can precisely control the experiment and obtain highly detailed results. "We can put it right at one layer and know exactly where it started," Jim says. "This is about as direct a measurement of mixing as you can get."

HITCHHIKERS *on the* L

How do you get from one place to another if you can't travel on your own? You catch a ride on a plume! By Nathalie Ward

This is a light micrograph image of the larva of a vent gastropod. It has been enlarged hundreds of times.

Miles beneath the surface of the ocean lies the Mid-Ocean Ridge, the 40,000 km-long underwater mountain chain that circles the globe like stitches on a baseball. Scattered widely along the Ridge, and elsewhere in the deep sea are chimney-like formations called "black smokers." These formations are found at hydrothermal vents, cracks in the seafloor through which hot, chemically-altered sea water gushes upward like water in a geyser that's called a hydrothermal plume.

Tucked in amongst the black basaltic rocks surrounding the vents are a strange menagerie of living things that call the vents home. Here are such creatures as giant tube worms that look like cut-off rubber hoses; gardens of sea anemones looking more like chrysanthemums than like animals; beds of clams as big as dinner plates; furry mats of bacteria; and sightless white crabs. While creatures that live on land or nearer the sea's surface depend on the sun's energy to create their food, these deep-sea creatures are nourished by chemicals that percolate up from within the earth's crust.

Researchers have found that most adult vent creatures are unable to travel on their own. Moreover, they can survive only near vents. Studies have shown that these vent communities are short-lived, some lasting for just ten years. How do new communities of creatures pop up? How are they formed? How do the larvae (offspring) of these creatures travel from one vent field to populate a new field?

This hydrothermal vent site is home to brachyurian crabs, vent clams, tube worms, anemones, and even a curious fish.

Illustrations by Patricia Wynne

ARVAL HIGHWAY

THE DRIFTERS

Lauren Mullineaux, a biologist at WHOI who has studied larval transport (the movement of larvae from one place to the next) for more than ten years, is working on the answer. She believes that the larvae of vent creatures travel to their new homes like microscopic hitchhikers, rising in the warm, chemically-charged plumes that shoot up from the hydrothermal vents.

Like passengers on a highway travelling to a new destination, vent larvae disperse and colonize new communities. Lauren's research suggests that some of the larvae colonize new vent habitats by drifting along with bottom currents until they reach the next vent site.

Some of these migrants stick pretty close to home. They may locate and settle at another vent site, perhaps only thirty meters away.

But some vents lie tens or hundreds of kilometers away from any others. How do the larvae travel there? Lauren believes that some of the larvae of vent animals are swept into the plume's warm fluids and carried away, like passengers on a hydrothermal hot-air balloon.

The buoyant plume rises about 200 meters above the sea floor. At this level, the plume spreads out, moving with the horizontal water currents it meets there. Scientific studies show that the larvae rise from the seafloor to the level of the spreading plume within a few hours.

DROP-OUTS

How much time do the larvae spend travelling along the spreading plume "highway"? The answer depends in part on how long they live. Lauren and other researchers work to discover how far the larvae can travel and still survive. They wonder what clues alert these deep-sea travelers that a favorable vent site lies below them. What prompts them to drop out of the plume to settle on the seafloor?

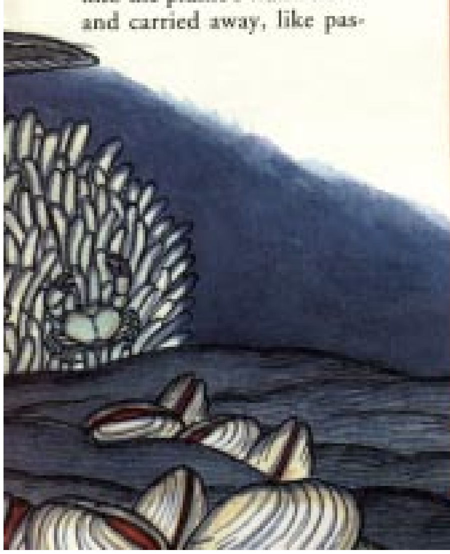
WHO'S WHO?

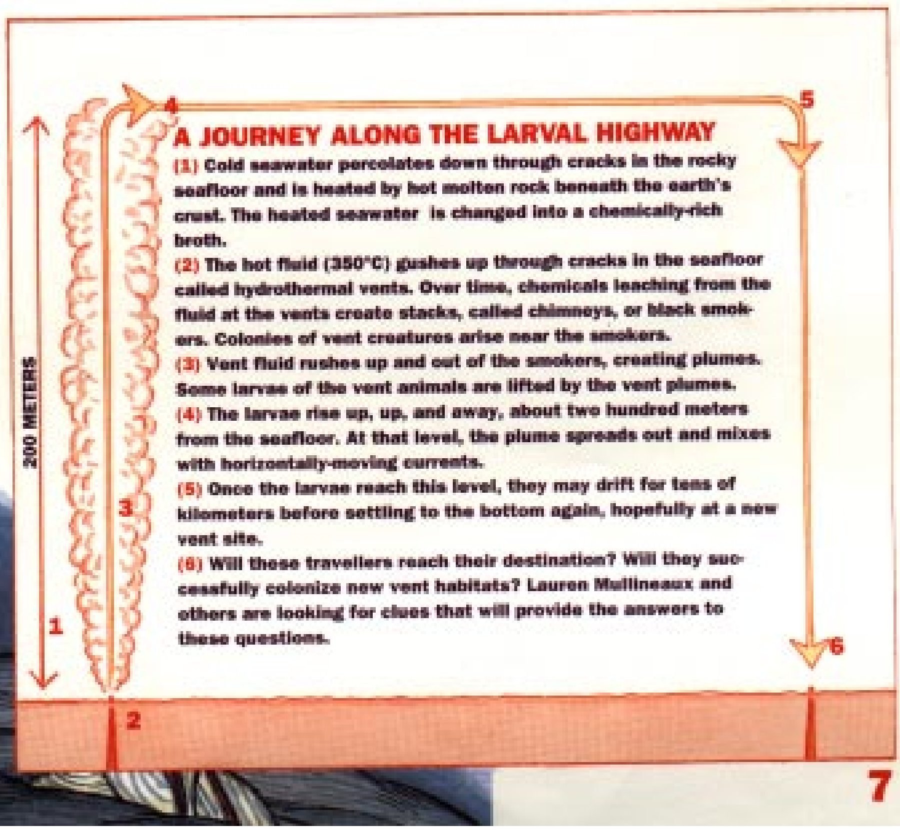
Many questions about hydrothermal larval transport remain unanswered. Even figuring out who's who in the larval porridge is difficult. "Identifying vent larvae is like a game of mix and match," says Stacy Kim, WHOI graduate student. "We know what the adult animals look like, but the larvae are often unrecognizable variations of the adult." To look closely at these minute creatures, researchers use a very powerful technique called scanning electron microscopy, which they call SEM.

TAG, YOU'RE IT!

Lauren and her colleagues want to know how the larvae of vent animals colonize new habitats, and how often, and when, and where they do so. How will they get this proof? "We'll use genetic tags," says Lauren. "They may be useful for telling where larvae came from." She believes that some vent animals may have a genetic code (the specific way in which the DNA in their cells is organized) that is as distinctive as a fingerprint.

Lauren says that using techniques that distinguish the larvaes' genetic codes may provide answers to which vent sites the animals originate from, and where they travel to — a series of different addresses along the deep-sea larval highway.





A JOURNEY ALONG THE LARVAL HIGHWAY

(1) Cold seawater percolates down through cracks in the rocky seafloor and is heated by hot molten rock beneath the earth's crust. The heated seawater is changed into a chemically-rich broth.

(2) The hot fluid (350°C) gushes up through cracks in the seafloor called hydrothermal vents. Over time, chemicals leaching from the fluid at the vents create stacks, called chimneys, or black smokers. Colonies of vent creatures arise near the smokers.

(3) Vent fluid rushes up and out of the smokers, creating plumes. Some larvae of the vent animals are lifted by the vent plumes.

(4) The larvae rise up, up, and away, about two hundred meters from the seafloor. At that level, the plume spreads out and mixes with horizontally-moving currents.

(5) Once the larvae reach this level, they may drift for tens of kilometers before settling to the bottom again, hopefully at a new vent site.

(6) Will these travellers reach their destination? Will they successfully colonize new vent habitats? Lauren Mullineaux and others are looking for clues that will provide the answers to these questions.