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Stone Soup

Geochemist Meg Tivey is deciphering the recipe that turns the scalding fluid from hydrothermal vents into mineral chimneys and mounds.

Meg Tivey

Meg Tivey peered out of Alvin's viewport, straining to see beyond the sub's headlights into the darkness at the bottom of the sea. Rock music was playing over the sub's sound system, but the atmosphere in the cramped cabin was tense—for almost an hour, ever since they had arrived at the bottom, Tivey, colleague Susan Humphris, and pilot J. Patrick Hickey had been flying over nothing but acres of white sediment. They could not find TAG's active mound.

If TAG were on land they could have followed its hydrogen sulfide stench. Instead, they had to fly up above the seafloor and use the image on Alvin's sonar screen to detect the ninety-story black plume rising from the mound.

Within minutes of driving toward the image shown on the screen, an immense cloud of black smoke boiled up and engulfed the sub, shrouding its windows and startling its occupants. Alvin was directly atop the chimney mound.

"Smoke! We're in smoke!" someone called.

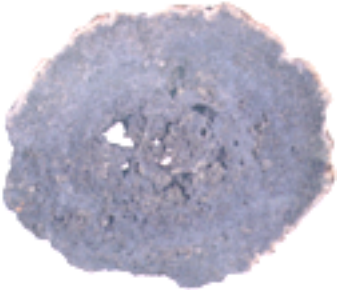
"I can't see anything!"

"A huge cloud is in front of us!"

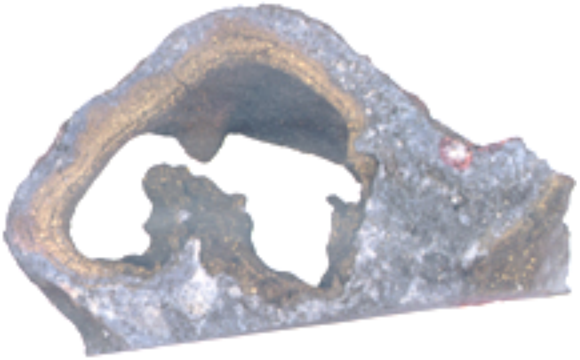
"Oh my god, look at this!"

As Hickey quickly backed the sub away, Tivey experienced the mix of emotions she often feels in Alvin's six-foot diameter cabin at the bottom of the sea. "Its exciting whenever you dive on a new site," she confides, "but I do get a little nervous."

Nervous or not, Tivey has made fifteen dives to hydrothermal vents. A geochemist in the Department of Marine Chemistry and Geochemistry, she is one of the world's leading experts in the processes that turn scalding mineral-laden hydrothermal vent fluid into sulfide chimneys and metal-rich mounds. For Tivey, a vent chimney is an ever-evolving object, a stony palimpsest on which crustal minerals and cold bottom water write an engrossing history that she's eager to decode. Her goal is to create a model that can describe a vent chimney's future and past.



Left: A white moker chimney cross-section, lined predominantly with zinc sulphides.



Right: A black smoker cross-section. The inner layer which was adjacent to 360°C fluid, is copper-iron sulphide. The outer layer is mostly calcium sulphate.

"The sulfides from the vents have very complex minerals and textures, and those textures record the history of how the mixing occurred," Tivey says. "I've been trying to see if I can actually pick up a sample, look at the texture, and say, 'Based on this, I know what the fluid composition was that formed it, I know how fast the fluid was moving, I know how much seawater was mixing in.'"

Her hydrothermal studies begin with a descent to the seafloor to collect samples and make observations. They continue at Woods Hole where such tools as X-ray diffraction, electron microprobes, and computer models help her figure out how vent chimneys grow.

In a way, Tivey's fascination with vent morphology is similar to the pleasure most of us find in counting the rings in a tree stump or admiring how falling snow collects on a winter's day. But where our imaginations are satisfied with the simple events of the everyday, Tivey likes to contemplate phenomena at the furthest reaches of physics, where the temperature climbs into triple digits and high pressures can squish theories flat: At TAG, the water pressure exceeds 6,000 pounds per square inch, and the vent fluid is hot enough to melt lead.

"A striking feature of black smoker chimneys is how thin their walls are," Tivey says. "They vary in thickness from about five inches to as little as a quarter of an inch." The porosity of the chimney walls changes throughout their lives—the pressurized, frigid seawater passes through these thin walls to mix with the hot vent water in constantly altering ratios. As a result, a chimney cross-section can reveal well-ordered sequential layers or a hodgepodge of metal sulfides.

But chimney structures are simple compared to the evolution of TAG's active mound. The mound first came to life as a stream of hot fluid seeping through seafloor faults. The fluid's minerals precipitated, formed chimneys that grew and collapsed to form a base for more chimneys. The cycle has been repeating off and on for 20,000 years—to date the mound has accumulated over five million tons of sulfides.

Tivey likens the mound to a leaky oven baking up a stew of intense chemical activity. Hot vent water escapes through the mound's chimneys, drawing in cold seawater through cracks in its sides and the surrounding seafloor. These continuous infusions of hot vent water and cold seawater cause the minerals within the mound to combine, precipitate, dissolve, and reprecipitate. The metal ores cycle into ever-purer deposits of ore—in fact, small nuggets of pure gold have been found in TAG chimneys.

This process, called zonation, leads to complicated plumbing. "One of the fascinating things at TAG is that there are black smokers and white smokers seventy meters apart," Tivey says. The white smokers on one side of the mound vent ten times as much zinc but have less copper and a lower temperature than the black smokers on the mound's other side. "The simplest explanation is that inside the mound the zinc sulfide is dissolving and concentrating at the white smoker chimneys." Zonation was initially described based on observations of ancient mineral deposits on land. "At TAG, we're seeing it go on right now. We can go down, study and measure the metals in the fluid."

And these studies are more than academic: Hydrothermal vent research has already helped land-bound geologists in their search for precious metal ores. (See sidebar, below.)

ANCIENT TREASURE FROM THE DEEP

Artisans throughout the ancient Mediterranean made tools, weaponry, and household implements from Cypriot copper. This suit of armor is from Mycenae, the ancient Greek kingdom where Agamemnon is said to have ruled in the 13th Century B.C. It is made of bronze, an alloy of copper and tin.

In Homer's lliad, Agamemnon, military chief of the Greeks at the siege of Troy, dons an ornate metal breastplate, a gift from the King of Cyprus. What Agamemnon does not know as he marches into battle is that he is protecting himself with a chunk of hydrothermal vent.

The Troodos Mountain chain that makes up Cyprus's rocky spine is an ophiolite—a section of oceanic crust and upper mantle that plate tectonics has lifted high on land. Millions of years ago those mountains lay at a spreading center at the bottom of the sea. At that ancient spreading center, just as at TAG today, hydrothermal vents were precipitating metal ores in concentrated deposits. As a result, scattered through the Troodos Mountains are copper-iron-zinc sulfide deposits, rich ore bodies that have been mined for thousands of years. So central did these ore bodies eventually prove to the economies of the ancient Mediterranean that the island, then known as Kypros, lent its name to copper.

The Troodos ophiolite with its hydrothermal ores is only one of many similar ophiolites that have been mined in the Middle East, the Americas, Europe, the Himalayas, and the islands of the western Pacific. Geologists have found vent fragments embedded in many of these ophiolites.

The deposits at contemporary vent systems on spreading ridges, however, are much smaller, because the precipitating metal sulfides drift away in the rising plumes. But in steep, narrow rift valleys, which are typically found in young ocean basins, falling sediment can bury the vents and trap the metals. In the Red Sea, a buried vent system is building up a huge ore body that contains at least thirty million tons of iron, zinc, and copper; six thousand tons of silver; and fifty tons of gold.

Deep-sea vent deposits are uneconomical to mine at current mineral prices, although a pilot mining project in the Red Sea has begun.

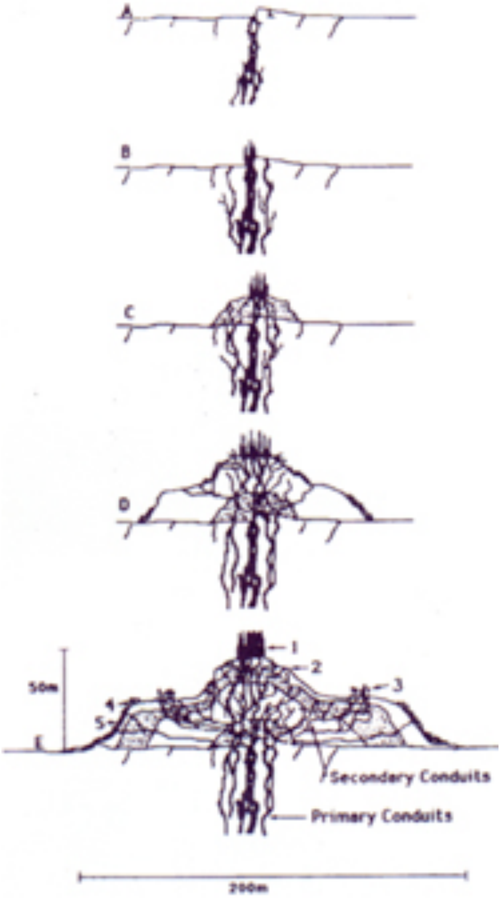
TIVEY BEGAN STUDYING VENTS during her second year in graduate school at the University of Washington while she was on a cruise to the Pacific's Juan de Fuca Ridge off Washington. When the dredge picked up chunks of sulfides, the find resulted in the discovery of the Endeavour vent field, and she was hooked.

On that same cruise she met Maurice Tivey, a Canadian geophysicist. A year later, on another cruise, they became engaged. The next year, a week after their marriage, they were again at sea on their first Alvin cruise. Maurice Tivey, now a WHOI geophysicist, has joined in the TAG studies. Using data collected in 1990, he and his colleagues found a magnetic low beneath the TAG site that may indicate the hot fluids have chemically altered a pipe-like conduit beneath the mound, marking the path the fluids have followed over thousands of years.

The Tiveys now have two young children, and they carefully plan their research cruises so that one of them is always at home. Although the Tiveys send e-mail messages from ship to shore, and the kids beam computer drawings out to sea, the separations can be difficult and lengthy. "For instance, I'm going to be out at sea for almost three weeks this summer, " Tivey says, "and then Maurice walks on the ship right after."

WHEN TIVEY FIRST SET OUT TO predict the chemical reactions that take place inside vent chimneys, some of her colleagues said her goal was impossible. "At first, I thought, 'Wow, we've got the fluid composition, we've got the rocks, we should to be able to link these together.' But I was told 'You're not going to be able to do that. You're too close to the critical point of water.'"

When a substance under pressure is heated to its critical point, its customary properties change markedly: Its liquid and vapor states become virtually identical, and the vibrating molecules lose much of their polarity. At TAG, the seawater presses down with the weight of three tons per square inch, and its boiling point approaches 400˚C (752˚F). To replicate these pressure-temperature conditions on land requires an extremely strong pressure vessel and very small samples that do not precisely replicate a vent's flowing, superheated, ultrapressurized fluids.



A hypothetical diagram of the TAG mound's growth. Numbered features are:

1. Black smoker chimneys at 350-360°C
2. Black and white diffuse smoke at 240-260°C
3. "The Kremlin:" clear solutions and white smokers at 260-300°C
4. Standing and toppled inactive chimneys
5. Sulphide debris

Tivey, however, was undaunted by her colleagues' doubts. She realized that when she descends in Alvin to observe a vent, the conditions are the same as in any conventional laboratory, except they're turned inside out: On the seafloor, the researcher is in the pressure vessel instead of the samples, and the high pressure-high temperature phenomena unfold in the open.

"The seafloor vents are perfect natural laboratories. We have to sit in a submersible, but we don't have to build this huge apparatus in the lab. We can study the fluid transport and metal complexing at high temperature and pressure. We can test the thermodynamic data and the theories."

Tivey points out that although many questions remain, the pace of hydrothermal knowledge is accelerating. In the last two years the number of confirmed vent sites on the Mid-Atlantic Ridge has doubled to four. "The progress we've made in the last fifteen years is pretty substantial," she says. "Not long ago no one had ever seen a black smoker chimney. Now they seem to be found at mid-ocean ridge crests whenever we take a close look."