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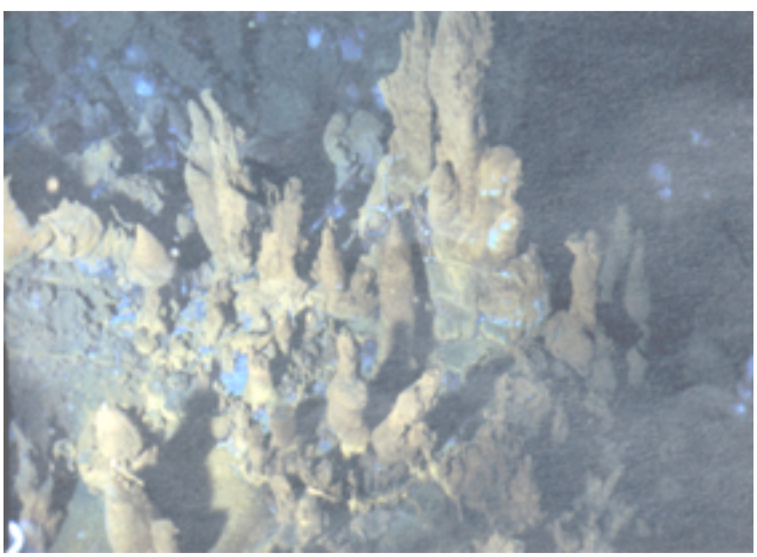
Vents and the Salty Sea

Two thousand miles east of Miami, two and a half miles below the surface in the abyssal darkness of the Mid-Atlantic Ridge, is a hellish mound the size of the Astrodome that is spewing hot, sulfurous, metal-laden plumes. The mound is topped with hydrothermal vents, volcanic-related, submarine fountains formed when seawater, heated by molten rock deep within the crust, shoots up out of the seafloor. It stands in the midst of a sprawling hydrothermal zone that includes a field of manganese slabs and small iron chimneys that weep clouds of shimmering water; sediment glittering with fool's gold; swarms of eyeless shrimp, and vast tracts of ghostly, towering vent chimneys that have been dead for centuries. Hydrothermal vents are some of the ocean's most important and least understood features, and this is the oldest, largest, and deepest known hydrothermal vent site of all. Many WHOI scientists have made discoveries here, but three geochemists—Geoff Thompson and his former students Susan Humphris and Meg Tivey—have devoted years to the site. They've worked together for the better part of a decade and form a spirited team. This special issue of Currents will explore how their partnership is shedding light on a process that cools the planet's core and mantle, balances its chemistry, and perhaps gave birth to life.


Geoff Thompson


Chimneys at TAG's "Kremlin" area

In 1972, the National Oceanic and Atmospheric Administration research ship Discoverer was over the Mid-Atlantic Ridge, when its clawed dredge hoisted a hundred-pound slab of black, crumbly, astoundingly pure manganese oxide to the surface. NOAA scientist Peter Rona guessed immediately that it had precipitated from mineral-rich fluid venting from the Ridge below. To help explain the finding, he turned to WHOI's Geoff Thompson.

"We looked around for the best people in each discipline to help us," says Rona, now a professor of marine geology and geophysics with Rutgers University. "Geoff is a remarkable scientist, and we knew his capabilities as a geochemist and petrologist. He's certainly the best in his field."

Rona and Thompson made repeated voyages and submersible dives at the site, which was soon known as TAG, after the Trans-Atlantic Geotraverse project, the seafloor survey of the Atlantic in which the Discoverer was taking part. Their findings not only confounded theorists who had predicted that the slow-spreading Mid-Atlantic Ridge could not generate enough heat to create hydrothermal vents, but they gradually unveiled a twenty-five square kilometer zone that proved to be the largest, most varied vent site in the world.

HYDROTHERMAL VENTS PROVOKE EXCITEMENT because of their bizarre wildlife, complex mineralogy, and strange shapes. Thompson studies TAG, however, to understand how vents might answer one of the most basic questions about the ocean—why seawater remains salty.

"If you think about it, the sea shouldn't be salty," says Thompson, a vigorous, white-haired Englishman with a crooked grin and a broad Yorkshire brogue. "All the world's rivers flow into the sea, so the sea should either get diluted, or the minerals from the rivers should build up. In fact, the sea should be an alkaline lake, not a sodium-chloride-rich brine. But the remarkable thing about the sea is that it retains its composition and has retained it for over 200 million years. So something has to be going on."

This question first intrigued Thompson when he was a graduate student more than thirty years ago, when he became dissatisfied with the accepted theory that explained the salty sea. The theory added up the chemical reactions between rivers, the sediments they carried, and seawater itself.

Geoff Thompson and Mark Hannington of the Geological Survey of Canada inspect TAG sulfide samples recovered by Alvin, 1990, Credit: Peter A. Rona

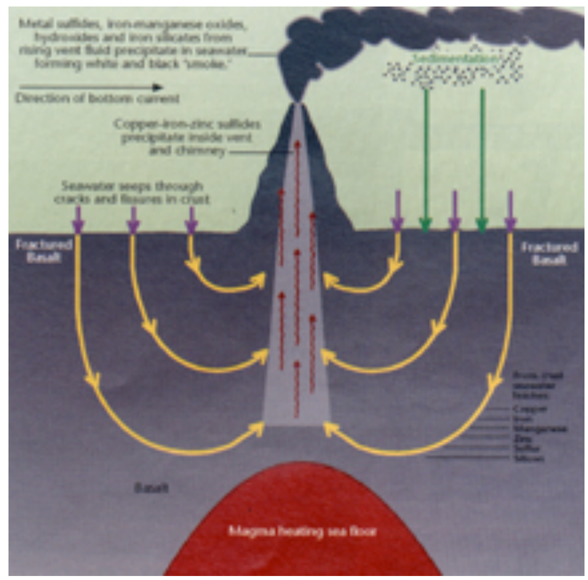
Thompson thought this theory was like an out-of-whack account book. "When you tried to balance what's coming into the sea with what's going out, it didn't balance. The budget was off by large amounts."

For example, millions of tons of magnesium flow into the sea every year, but magnesium's concentration in seawater and sediment remains constant. According to the theory, this influx somehow vanished.

Thompson set to work on his own theory, an enormously complex set of equations and analyses that has grown to follow the trail of more than thirty of seawater's ninety dissolved elements.

"Some people just play with one element, but that only defines parts of the process. You've got to do a lot of elements. Each one tells you a little bit more of what goes on."

THE SEAFLOOR FOUNTAINS



Hydrothermal vents after the chemical composition of circulating seawater and the earth's crust.

Discovered less than twenty years ago, hydrothermal vents have a global impact: They dissipate heat from the earth's hot mantle, influence the chemistry of the air and oceans, and provide a home for sulfur-eating bacteria that some researchers say were the first forms of life. Vents form where magma rising from the earth's hot mantle nears the seafloor—at volcanic centers, island arcs, deep trenches, and at spreading ridges between tectonic plates.

At spreading ridges such as the Mid-Atlantic Ridge, bodies of 1,100°C (2,000°F) magma rise from the mantle to form new crust. These hot, molten rock chambers slowly rise as the plates move apart. As the new crust cools, it contracts and cracks. The seawater above the ridge presses down on this new crust, percolating into the cracks and fissures as far as three miles deep, until it meets the hot rock adjacent to the rising magma.

The water quickly warms to over 360°C (680°F). Although the pressure of the overlying sea prevents it from boiling, it expands with the heat and, now extremely buoyant, shoots back towards the seafloor. On the way, it deposits magnesium and sulfate in the crust, and in return takes up copper, iron, manganese, zinc, and sulfide.

This scalding brew jets from the crust into the near-freezing seafloor water. The dissolved minerals from the hottest vents precipitate into dark plumes of copper, zinc, and iron sulfides. These plumes of black 'smoke' can rise up to a thousand feet above the seafloor, and chimneys of calcium sulfate form around these 'black smoker' vents. Cooler vent water forms lighter plumes and chimneys called 'white smokers.' More water enters the seafloor to fill the void left by the rising vent fluid, and a convection cell forms. The cycle continues until the smokers seal up, the underlying magma cools, or the vent field migrates off the hot spreading ridge.

Oceanographers have found dozens of vent fields in the world's oceans, and some predict hundreds more will be found, strung intermittently like beads along the ridges. Some scientists estimate that each year a volume of water equal to the annual flow of the Amazon River passes through the ocean's hydrothermal vents, a rate fast enough to filter the entire ocean every ten million years.

For years the seafloor was dismissed as a static, chemically inert, abyss. But in the 1960s, Thompson discovered that the ocean reacted chemically with the volcanic rocks that form the basement of the seafloor. The interchange is slow at low temperatures, but it has been going on for aeons and accounted for a measurable part of the budget.

Thompson also discovered in the 1960s that high temperature reactions occur in the crust near the ridge axes. In the 1970s Susan Humphris, under Thompson's direction, studied rocks altered by high temperature for her graduate thesis. They predicted that a hot, acid, metal-laden solution would return to the ocean from the basement rocks. But they did not know the form it would take—they envisioned a cooler solution, mixing with cold seawater in the crust and seeping out in a diffuse fashion.

The sources of these high temperature reactions remained unknown until the discovery of hydrothermal vents in 1977 at the Galapagos Rift in the Pacific Ocean. Minerals from this new chemical source and analyses of the venting solutions provided Thompson with new clues on the exchange of elements. In essence, vents are submarine refineries that cycle some minerals from seawater to rock, and dissolve others back into seawater (See below). The fluid exiting the hydrothermal vent systems is from one-third to twice as salty as the seawater that enters.

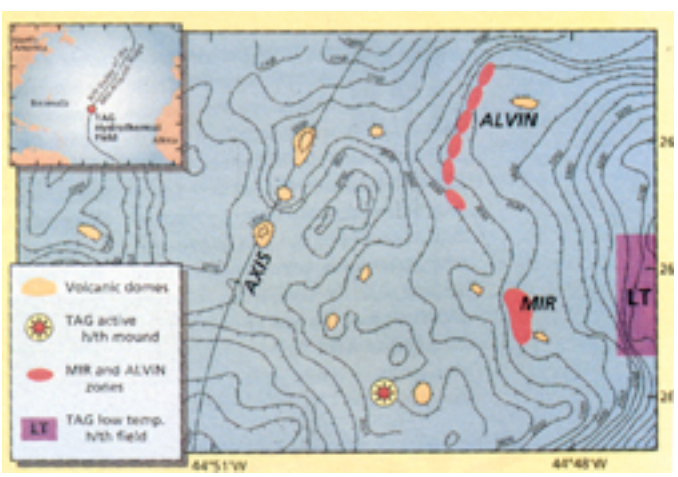
TAG presented Thompson with a spectrum of hydrothermal fluids and structures, from copper-sulfide-belching black smokers to fossil stacks long dead to tiny cracks venting water scarcely hot enough to warm a pot of tea. In the 1980s, Thompson brought his former student Susan Humphris and then post-doctoral fellow Meg Tivey onto his team. Since then, they've been dissecting the vent structures, the chemical reactions inside, and the rock beneath the mound.

But Thompson could not put their findings into his theory without knowing the pace at which TAG developed. To do that, he and French colleague Claude Lalou dated TAG chimney samples collected during Alvin dives. Just as archaeologists use radioactive carbon 14 to date Egyptian mummies, they measured how much radioactive lead, uranium, thorium, and carbon remained from when the chimneys formed. It is a long, exhausting processs that can take a year to yield a single date. But the technique is precise enough to date deposits to within decades, and it provided Thompson with the timetable he needed to refine his theory.

TAG is like a Giant Metals factory that runs in fits and starts. It started up about 125,000 years ago, when 200°C (390°F) manganese-rich fluid began to rise from seafloor cracks. Twenty-five thousand years later, 360°C (680°F) vents appeared. These vents smoked on and off for 100,000 years; the last inexplicably fell dormant about 200 years ago. TAG's active mound, the site of today's black smokers, came to life at least 20,000 years ago. It vents in 50 to 200-year spurts, then shuts down for 4,000 to 6,000 years. Its present cycle, one of five or six such cycles, has been underway for about fifty years.

This geochronology allows Thompson to estimate the rate at which vent systems add or remove chemicals from the ocean, and he factors this into his oceanwide accounting. In its broadest outlines, his theory attributes half of some of the sea's chemicals, such as magnesium, to river input, and half to a mix of reactions from seafloor volcanic rock and hydrothermal activity.

Yet, the more Thompson studies hydrothermal vent systems, the more variables he has to define. And though he recently retired from the WHOI staff, he's eagerly seeking new answers. "Within the TAG mound itself there's a whole fascinating subset of science," Thompson says. "People like Meg and Susan are looking at the subtleties. There's still a whole mess of stuff to be done, a whole fascinating area of research."



A bathymetric map of the TAG site. Depth contours are in meters.

THE MOTHER OF ALL VENT FIELDS

TAG is located on the Mid-Atlantic Ridge where a lifted, tilted block of basement rock pinches the Ridge's nine-kilometer-wide rift valley to two-thirds its normal size.

Since 1972, towed cameras, sonar imagers, and dozens of dives at TAG by WHOl's Alvin, the Russian Mir submersibles, and the Japanese Shinkai 6SOO have revealed a large number of earthquake faults, two extensive inactive vent zones, a low temperature hydrothermal field, and the enormous active chimney mound. Ten gently sloping volcanic domes scattered across the site may mark the magma chambers that have supplied TAG's heat.

Scientists attribute TAG's wealth of features to the Ridge's slow spreading rate—since new crust spreads out from the axial valley at only about two centimeters per year (the speed that fingernails grow), the vent features have not spread far apart since hydrothermal activity began 100,000 years ago.

The eighteen-story active mound covers an area the size of two football fields. Formed of minerals and metal ores, calcium sulfate slabs, and the rubble of collapsed chimneys, it is riddled with cracks and orifices venting diffuse black and white smoke. At its apex is a spectacular cluster of black smokers that are home to millions of blind shrimp, and white anemones dot its cooler portions. Farther down the sloping mound is an area of strangely shaped chimneys called "the Kremlin," named for their likeness to Moscow's onion-shaped domes. The Kremlin vents white smoke and shimmering water at temperatures from 260~C to 300°C.

The Alvin and Mirzones, named for the submersibles that explored them, are inactive zones that include thousands of relict chimneys, some standing twenty-five meters tall.

TAG's energy output is immense: It annually releases enough heat to electrify the city of Chicago for a year.