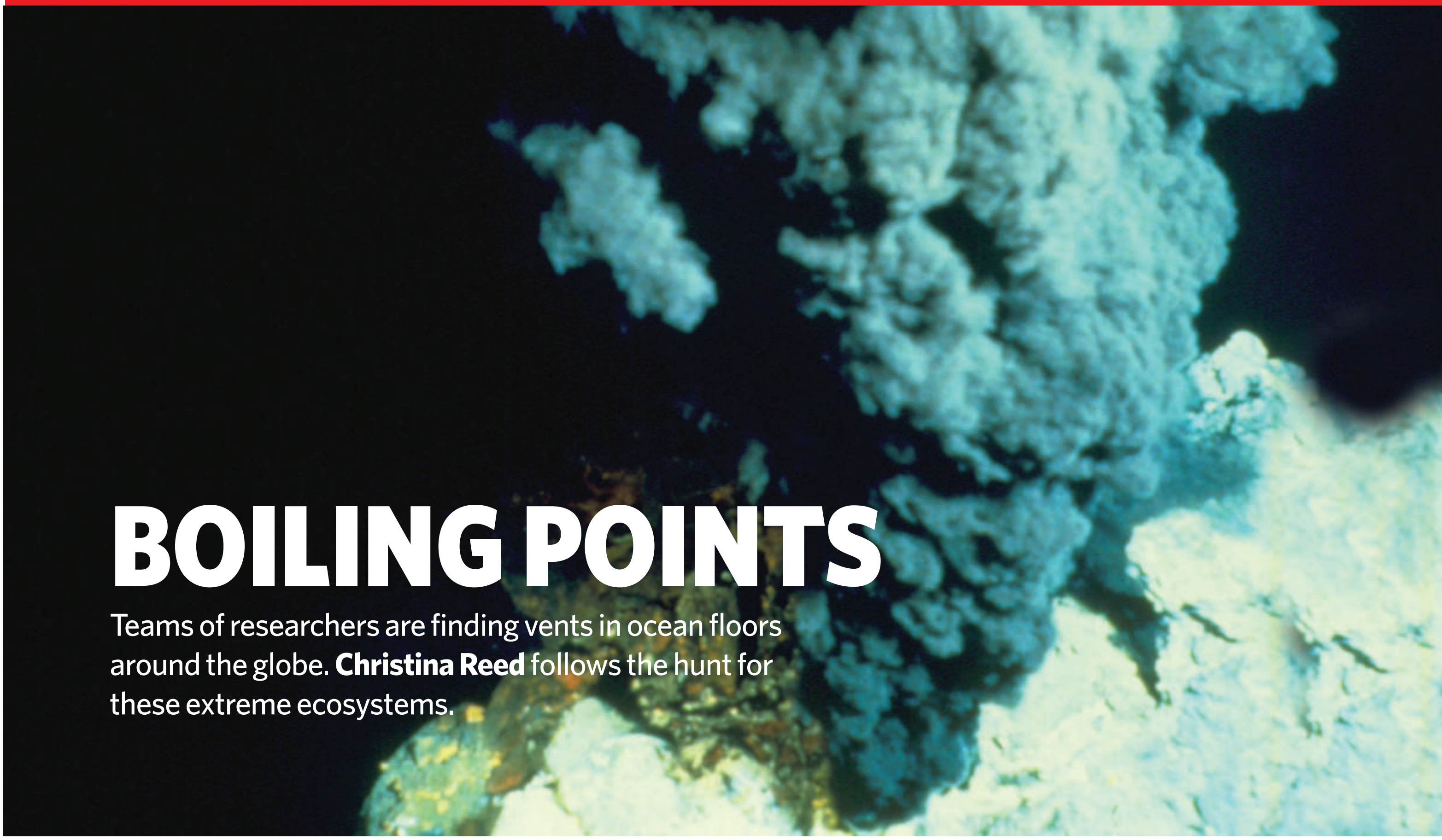

BOILING POINTS

Teams of researchers are finding vents in ocean floors around the globe. **Christina Reed** follows the hunt for these extreme ecosystems.

B. MURTON/SOUTHAMPTON OCEANOGRAPHY CENTRE/SPL

Before Rachel Haymon sailed to the Galapagos Islands last December, a fellow oceanographer made her a bet on whether she would find a particular kind of hydrothermal vent. The Galapagos region is where scientists discovered these vents, underwater fissures where superheated water bubbles out of the sea floor. But one of the most dramatic vent phenomena — black smokers, chimneys that spew a flood of dark mineral particles — had never been seen in the area.

According to some, this was because the geological setting of the Galapagos should not permit the formation of black smokers. But in retrospect, Haymon says, she should have upped the ante on her bet. On 14 December her team discovered the first Galapagos black smoker.

And that isn't the only new find. In the past couple of years, marine scientists have discovered numerous vents. What was once a handful of isolated vents has expanded into a dizzying diversity of oceanic wonders. Researchers don't yet know what to make of all the finds, but for now they are sitting back and enjoying the feast.

The recent finds include the most northerly active high-temperature chimneys in cold Arctic waters; chimneys in the South Atlantic; and the biggest plume ever recorded of hydrothermal chemicals released from an underwater eruption. With each new discovery, marine scientists are realizing that the unusual is to be expected. Variations in geology, chemistry, physics and biology make every vent field unique.

Take, for instance, the warm water flowing from hydrothermal vents in the chilly waters of the Arctic Ocean. Here, 500 metres below the surface, iron-oxidizing bacteria, including the species *Gallionella ferruginea*, cover the sea floor for kilometres. Within this region, known as Gallionella Garden, short mineralized chimneys sprout up, each around 15 centimetres high and often topped with delicate sea lilies (*Heliometra glacialis*) that make them look like one of Dr Seuss's cartoons.

In July 2005, a team led by Rolf Pedersen of the University of Bergen, Norway, visited this site. It lies along the Mohns Ridge, where tectonic plates are pulling apart, or 'spreading' at a rate of about 16 millimetres per year; speedier ridges can spread by up to 200 millimetres per year. The researchers sent down a remotely operated vehicle called *Bathysaurus* to look at the region. Using temperature sensors, the group discovered that the chimneys bathed the sea lilies with a flow of fluid typically at 0.5 °C. That's warm for the Arctic Ocean; the background temperature at this site measured −0.3 °C.

> **"When you consider the size of the ocean and how hidden everything is, we've only begun to really know what's there."** — Rachel Haymon

The team then sent *Bathysaurus* to the base of an escarpment, formed when an earthquake pushed up the sea floor 100 metres. Following the base of the cliff wall, the submersible found a series of hydrothermal mounds, each topped with several smoker vents. The fluid pouring out of the smoker chimneys here was far hotter. Because it was bubbling, the team estimated it must be at least 263 °C. And sure enough, when *Bathysaurus* extended its 260 °C-maximum sensor into the flow, the probe was knocked out of commission.

Smoking chimneys

While hovering over the site, the research team noticed something unusual just below their ship. "The echo sounder recorded something coming up," says Pedersen. He wondered whether the echo sounder had detected fish that had followed a drift of nutrients wafting up from vents on the sea floor. Using a similar signal farther down the ridge, the team discovered another vent field within hours, just 5 kilometres away from Gallionella Garden.

After years of laboriously tracing chemical plumes to locate vent sites, the scientists were thrilled with the ease of their discovery. The echo sounder not only helped them locate the vents, but also imaged the plumes and what appeared to be an associated school of fish. "This had never been done before," says Pedersen. Next summer, the team will return to the vents to sample fish and other animals, microbes and fluids, and then use the new technique to search for vent sites in deeper waters farther north.

As some researchers push north, others are going south — finding hydrothermal vents on the southern part of the Mid-Atlantic Ridge.

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Hot spots: minerals and heated water spewed out of hydrothermal vents may support marine life that wouldn't otherwise survive.

E. BOGASON

This is the underwater mountain range that runs like a backbone down the middle of the Atlantic Ocean. As many as two dozen hydrothermal-vent fields have been found in the northern part of this mountain chain. But few expeditions had searched for vents in the south. So it was with an eager crew that the RSS *Charles Darwin* embarked on a month-long expedition in February 2005, to map the sea floor along a 250-kilometre stretch of the ridge.

Near 5° S, the team found two potential vent sites a kilometre apart, and mapped each with high-resolution sonar using an underwater robot named ABE (for autonomous benthic explorer vehicle)[1]. On one of ABE's trips, its mission was to photograph the field of potential black smokers with a digital camera. "When we brought ABE back on deck, it was burnt through," says the expedition's leader, Chris German of the National Oceanography Centre in Southampton, UK. ABE's images showed that "the cooking place", as German calls it, contained fresh basaltic lava flows and what looked like shrimps, mussels and crabs.

In April, the German research vessel *Meteor* visited three sites in the area. At one site, called Turtle Pits, a team led by Karsten Haase of the University of Kiel, Germany, sampled boiling fluids at temperatures close to 400° C.

"This temperature is the highest measured so far along the entire Mid-Atlantic Ridge," says team member Andrea Koschinsky, a geochemist at the International University Bremen in Germany. The high temperature indicates that fluids are being heated close to a magma source, most likely from a recent upwelling or volcanic eruption. "The effect of recent volcanic activity on submarine hydrothermal systems has so far been documented only along fast- and intermediate-spreading centres, such as the East Pacific Rise, but not from slow-spreading ridges where volcanic eruptions are rare," she says.

The German team discovered another vent field at 9° 33′ S, the most southerly vent field known so far on the ridge. Because very young and small mussels dominate the ecosystem, the group dubbed the field 'Liliput'. In April, Koschinsky will lead the next *Meteor* cruise to the region, with a freshly mended ABE ready to track down any more hot vents.

Oceanographers increasingly realize that when it comes to vents, they don't know what is out there. So they have taken to using plume sensors whenever possible — even when mapping a suspected plate boundary. Such was the approach of marine geologist Bramley Murton, when on board the *Charles Darwin* in the Indian Ocean in 2003.

Plume clues

Somewhat optimistically, Murton attached a series of sensors called miniature autonomous plume recorders (MAPRs) to the towline of a dredge he was using to conduct a geochemical survey of the slow-spreading Carlsberg Ridge. Geologists only thought the ridge existed because Russian magnetic mapping of the sea floor in 1970 had predicted it should be there — not because anyone had actually seen it. Murton's expedition was the first to map the ridge with multibeam swath bathymetry, a kind of sonar that produces beautiful high-resolution images of the seafloor topography. The MAPRs were attached to the dredge, just in case, to pick up any hints of a plume from a submarine eruption.

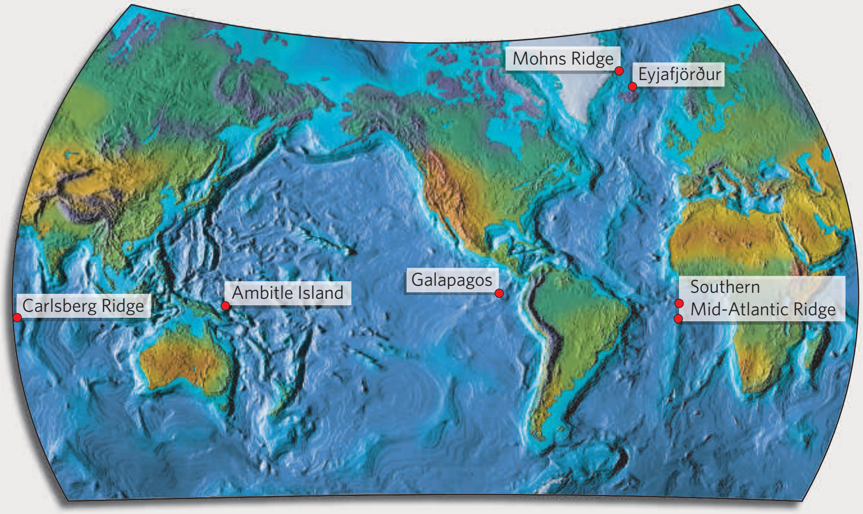
Murton's team managed to map the ridge, and excitedly pulled up glassy basalt rocks from it, but the biggest surprise was the MAPR results. The sensors had detected, in the chemistry of the water, evidence for a recent underwater explosion. Further lab tests, the results of which were announced at the American Geophysical Union meeting in San Francisco last December, showed that they hadn't come across just any hydrothermal plume. It was an 'event plume', meaning it came from a single underwater eruption.

Most plumes that oceanographers use to track down vents come from a single chimney or vent field. If the chemical signal from a vent field is like the smoke from a candle, that from an event plume is like the smoke from a wildfire. Even more surprising, this one turned out to be the most energetic and biggest event plume ever seen — 7 to 20 times larger than those previously recorded. It had risen 1,400 metres above the sea floor, measured one kilometre wide, and was drifting for 70 kilometres along the ridge. Twenty million cubic metres of lava would be needed to create the heat to drive such a plume, says Murton. Clearly it came from a major volcanic eruption.

Because the Carlsberg Ridge is one of the slowest-spreading, and so supposedly less active oceanic ridges, many had thought it unlikely to be the location of a major volcanic eruption. At ridges such as this, heat is thought to be released more slowly from the underlying magma.

Such oceanographic revelations show the

RECENT HYDROTHERMAL VENT EXPEDITIONS



importance of exploring new areas. But the search doesn't always have to involve month-long, deep-sea expeditions that typically cost millions of dollars. Scientists are increasingly seeing hydrothermal vents through a dive mask rather than through a submersible's viewport.

Because the sea floor is on average about 4 kilometres from the surface, hydrothermal vents are frequently referred to as 'shallow' if they are anything less than 1 kilometre below the surface. But truly shallow hydrothermal vents, the kind a researcher can scuba dive to, are very different from their deep-water counterparts, as recent studies have shown.

Deadly cocktail

In an Icelandic northern fjord called Eyjafjörður, researchers discovered in 2004 a rich shallow-water vent ecosystem. "The area contains not a single vent, but a series of chimneys and fissures stretching for about 500 metres," says geologist Bjarni Gautason, who works for the company Iceland GeoSurvey. The tops of some of the chimneys are only a 14-metre dive from the surface. All the chimneys spout fresh water, contaminated with less than 1% sea water, and at temperatures reaching 77 °C. The chimneys "form their own landscape providing a unique habitat for the animals and plants in the area", Gautason says.

"We know about some other shallow-water hydrothermal-vent sites in the world, but none that makes chimneys like the ones here," says biologist Hreiðar Valtýsson of the University of Akureyri in Iceland, and a member of Gautason's team. "So we think ours are quite special."

But shallow vents aren't always the kind you would want to visit. Near Ambitle Island, Papua New Guinea, some vents spew out a toxic cocktail of arsenic with a splash of sea water. As much as 1.5 kilograms of arsenic flows daily from these vents into the surrounding coral reefs[2].

For up to 200 metres around the vents, microbes coat the sediment and corals with a red and green biofilm. These organisms seem to be able to survive the contamination, and so may give researchers a chance to study arsenic in a marine environment, and see how microbes cycle it through the ecosystem. In the past few years, studies have suggested that arsenic from silt is getting into the water supply in Bangladesh and is potentially poisoning millions of people. The vents near Ambitle Island could provide clues on how to address such a problem.

In Bangladesh, arsenic is being reduced, by microbial activity, from As(V) in the sediment to the more soluble As(III), which seeps into the groundwater and contaminates the drinking water. Jan Amend, a microbial geochemist at Washington University in St Louis, hopes that his team's work at the Ambitle vents will help researchers better understand how microbes might catalyse the reverse chemical reaction, oxidizing As(III) back into the less soluble As(V). "This part of the arsenic cycle has not received nearly as much attention," he says.

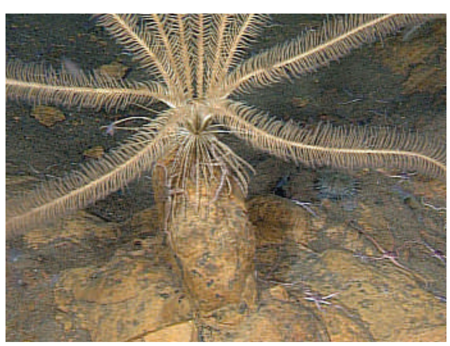
Heat may also play a major role. Geochemists studying hydrothermal systems on volcanic islands off the coast of Italy have found that high water temperature can lead to higher concentrations of arsenic in the groundwater fed by those systems[3].

Highway of the Pacific

Still, much is uncertain as to how the geology of a region influences the temperature and minerals that precipitate at different vent sites. The Galapagos spreading ridge, the site of Haymon's recent explorations, is one such example. A 'hot spot' of magma from deep in the Earth formed, and continues to form, the Galapagos Islands. The amount of magma and heat released from this hot spot has created a thick, possibly pliable crust in the region that could permit only low-temperature hydrothermal vents to emerge. And that's all previous expeditions had found.

But Haymon thought that the spreading ridge north of the islands, where the hot magma lies close to the sea floor, would yield the focused flow of high-temperature fluid needed to form black-smoker chimneys. And nobody had yet explored this area for vents.

UNIV. BERGEN



Iron-oxidizing bacteria living in and around deep-sea vents make conditions perfect for sea lilies.

A few hours after discovering the first Galapagos smoker chimney, named Plumeria after a tropical flower[4], Haymon's team spotted a cluster of as many as six black-smoker chimneys, 12 to 14 metres high. In a nod to the Galapagos' most famous marine reptiles, the team dubbed the chimneys the Iguanas. Two weeks later, the group came upon two other sites featuring more black smokers.

The discovery allows for the possibility that the underwater Galapagos chimneys, like the islands themselves, are home to unique animal species. Or it may be that the chimneys provide a highway for animals exploiting the special conditions the vents create; larvae could drift in the vent plume from chimney to chimney, up and down the mid-ocean ridge. "We saw animals, but I could not say from looking whether they were new species," she says. Only further exploration, collection of the organisms, and genetic testing will tell.

It may be fitting that the Galapagos — the site that fuelled Charles Darwin's ruminations on evolution — are now the focus of the latest underwater mystery. But Haymon isn't surprised. "When you consider the size of the ocean and how hidden everything is, we have only begun to really know what's there," she says. "I'm convinced there are many surprises left for us." ■

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