Lost City found

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Chemical and heat exchange at vents on deep ocean floors has a large influence on marine chemistry. The discovery of a spectacular new type of venting system has given the story another twist.

One of the revelations of twentieth-century science was that the deep oceans contain vast mountain chains, rising from the sea floor. Here, as a consequence of plate tectonics, hot material rises from within the Earth's mantle, generating new ocean crust and forming mid-ocean ridges. Over the past 25 years, it has emerged that because of hydrothermal activity there are places on these ridges where large-scale chemical and fluid exchange occurs between the solid Earth and the ocean, and unusual animal communities thrive. The amazing undersea images of these hydrothermal fields, especially of sulphide-rich 'black smoker chimneys' and lush chemosynthetic animal communities, came as a complete surprise.

Now we have another reminder of how little we know about the part of our planet's surface — over 60% of it — that is occupied by sea floor. As Kelley *et al.* describe on page 145 of this issue[1], last December they discovered a new type of seafloor hydrothermal field, using the research vessel *Atlantis* and the submersible *Alvin*. The field, called Lost City, is in the North Atlantic, off the Mid-Atlantic Ridge (see map on page 146). It is visually spectacular, and has a style of venting and a geographical setting that distinguish it from any previously discovered system of hydrothermal vents.

Lost City is characterized by massive white structures, up to 60 m high, rather than black smokers (Fig. 1). It is situated near a 'slow-spreading' mid-ocean ridge (the significance of which is discussed below), but not on the ridge itself. Instead, it is 'off-axis', nearly 15 km away from the ridge axis. The distinction between off- and on-axis is drawn at a crustal age of about one million years; because mid-ocean ridges are spreading, the further the crust from the axis, the older it is. In the case of Lost City, 15 km corresponds to 1.5 million years.

Since the discovery of undersea hydrothermal sites, the overriding goal has been to understand the influence of hydrothermal activity on ocean chemistry. This matters because ocean chemistry largely determines how well the oceans can buffer changes in the climate system, and also what kind of life can thrive in it — as has been the case throughout Earth's history. The oceans may well have been the place where life on Earth originated.

Lost City is a different type of vent system to those previously known. Further research will be aimed at tackling three questions in particular. First, what is the relative importance of off-axis, compared with on-axis, activity in terms of overall hydrothermal activity on the sea floor? Second, what are the differences between fluids generated by reaction with rocks that are typically found much deeper in the oceanic crust (peridotites or

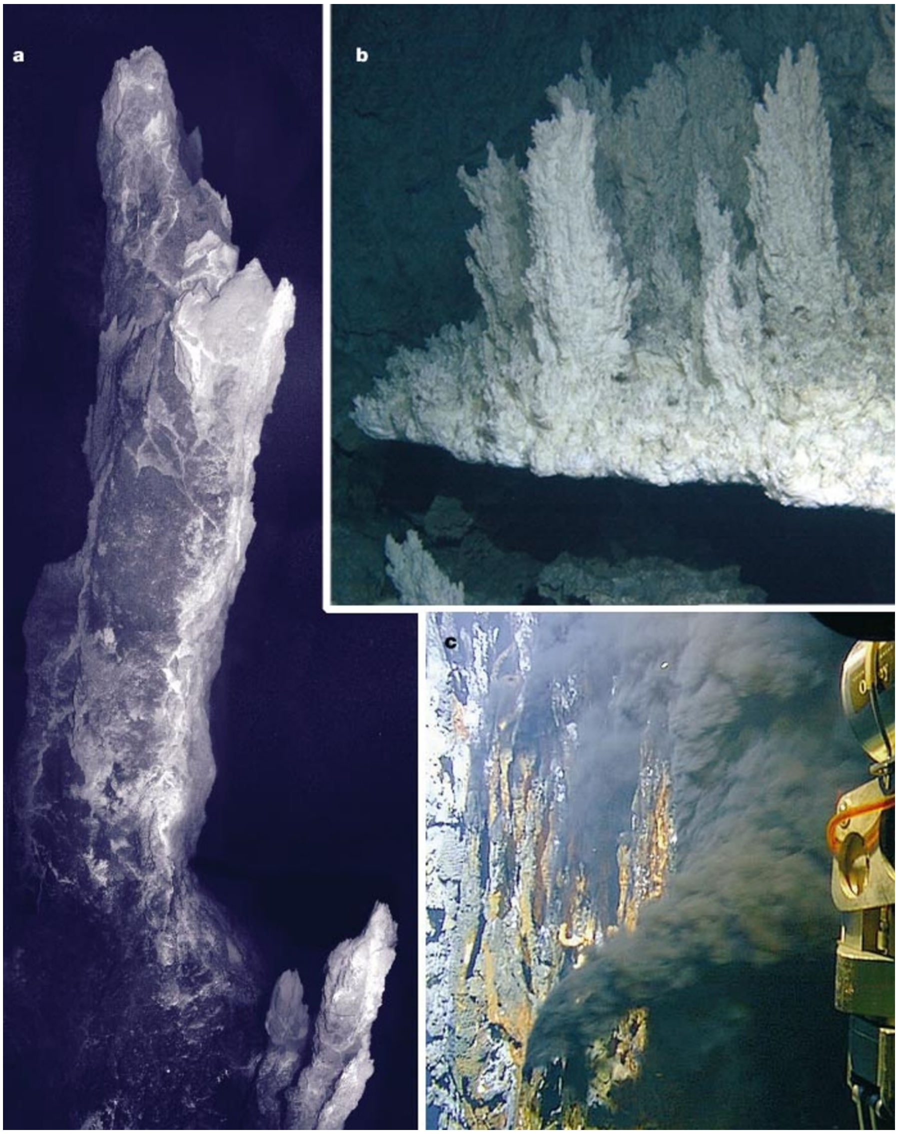

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Figure 1 **Hydrothermal vents in white and black.** a, **Mosaic of a structure, composed of carbonate and over 10 m in height, typical of those at Lost City identified by Kelley *et al.*[1]. Water depth here is 700–800 m.** b, **A carbonate flange (ledge) at the same location. Some of these flanges are host to microbial communities that thrive in the warm (40–75 °C) vent waters. Lost City lies 15 km off the axis of the slow-spreading Mid-Atlantic Ridge. Because of the high pH and low temperature of the hydrothermal fluids, their iron concentrations should be low. So mineral structures develop from carbonates and hydroxides, which tend to be light coloured.** c, **Brandon Vent, a black smoker on the southern East Pacific Rise at a depth of 2,834 m. Apart from being especially hot (405 °C), Brandon is typical of fast-spreading mid-ocean ridges. The acid and iron- and sulphide-rich hydrothermal fluids turn black as they mix with the cool (2–5 °C) alkaline sea water surrounding the vent. All images were taken from the submersible *Alvin*.**

ultramafics), as seems to be the case at Lost City, and those that result from reaction with the basalts that are present closer to the surface? Third, what is the nature of the microbial communities that might exist at Lost City?

It has long been known that the amount of heat lost by convection on the flanks of mid-ocean ridges is much larger than that lost from the axis itself[2]. The ratio is roughly 70:30, and the reason is that, although the axis is hotter, the flanks have a much larger area. But chemical concentrations (for instance, of iron) tend to be much higher on the axis than away from it. So debate over the relative contributions of off-axis and on-axis fluxes has centred on whether the chemical anomalies found on the axis are great enough to outweigh the greater heat (and probably water) flux on the flanks. The trouble is that off-axis venting is difficult to locate because the lower temperature of the fluids means that certain indicators in the water column (temperature, particles or salinity) or on the sea floor (large constructional features, or animal communities) are absent. Lack of knowledge of off-axis vents has also hampered attempts to estimate the overall chemical flux to the ocean through hydrothermal activity and its importance, relative to the contribution of rivers, to ocean chemistry[3].

The mid-ocean ridge system is huge, around 60,000 km in total length, and different ridges in the system spread at different rates. The Mid-Atlantic Ridge, with which the Lost City is associated, is slow-spreading (at a full opening rate of only 2.5 $\mathrm{cm\ yr^{-1}}$). This compares with up to 15 $\mathrm{cm\ yr^{-1}}$ on fast-spreading ridges such as the East Pacific Rise. The previously identified sites[4,5] of off-axis hydrothermal activity are all close to ridges spreading at intermediate rates, as opposed to the slow-spreading location of the Lost City. The topography of slow-spreading ridges is especially rugged, which further hampers the search for hydrothermal sites.

The spreading rate of a mid-ocean ridge is relevant to hydrothermal fluids because a determinant of the fluids' nature is the rock with which they react in passing through the ocean crust. Faster-spreading ridges are dominated by basaltic (mafic) rock types; on slower-spreading ridges, however, fluids may also react with deeper-lying peridotites (ultramafics), leading to the formation of serpentinites and thereby to different fluid compositions. Most of the known seafloor hydrothermal sites are found on basalt. But on slower-spreading ridges, the ultramafic parts of the oceanic crust are often exposed or closer to the sea floor, and venting fluids may be derived by reaction with this rock type.

This is what seems to be happening at Lost City, where the vent fluids are quite cool (40–75 °C) and alkaline (pH 9 and above). Another example of seafloor hydrothermal fluids derived from serpentinites is at the Mariana trench and island arc system in the western Pacific[6]. Here the fluids are cooler than ambient sea water and likewise have higher pH values. A similar situation occurs on land — hot springs issuing from serpentinite substrate have extraordinarily high pH values[7].

Two other places, both on the Mid-Atlantic Ridge, have been discovered where the hydrothermal fluids seem to be derived from ultramafic reactions. They are the Logatchev and Rainbow sites, at 14° 45′ N and 36° 16′ N, respectively[8,9]. The chemistry of the fluids at these sites is fundamentally different from those at basaltic sites (they are high in iron, calcium and transition metals, but low in silica). In contrast to the Lost City, however, Logatchev and Rainbow have high temperatures (350 °C or above) and very acidic pH values.

What about the microbial communities at seafloor hydrothermal sites? Such communities depend on chemical energy, often in the form of reduced gases such as hydrogen and hydrogen sulphide, for their existence. Anomalously high concentrations of methane, another reduced gas, have been found in the water column near the Logatchev site[10], but no discrete methane source has ever been located. Another unusual aspect is the hydrogen content of the fluids issuing from ultramafic source rocks, which is greater than that of most basalt-derived hydrothermal fluids. It is not as high as the hydrogen content in vent fluids immediately after volcanic perturbation, but such perturbations are only transient events. These high levels of gas led to speculation as to the importance of ultramafic sites as microbial incubators and in the evolution of life on Earth. At 40–75 °C, the hydrothermal fluids at Lost City present a much more hospitable temperature range for life than the 350 °C or so of the Rainbow and Logatchev sites. Kelley *et al.*[1] have done some culturing work with microbes from the site. But it will take detailed DNA analyses to see whether they are unique, and if they are more like the microorganisms thought to have existed on the early Earth than are known microbial communities.

Even in the twenty-first century, unexpected discoveries in our oceans are capturing our imagination and forcing us to revise our ideas about processes on Earth. We cannot yet be sure what the chemical controls on the hydrothermal fluids at Lost City may be, or how they might be affected by biological activity. However, as much of the global ridge-crest system can be characterized as slow-spreading, with ultramafic source rocks, we can be sure that Lost City will provide new ways of thinking about seafloor hydrothermal activity in general and its effect on ocean chemistry. ■

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1. Kelley, D. S. *et al. Nature* **412,** 145–149 (2001).
2. Stein, C. A., Stein, S. & Pelayo, A. M. in *Seafloor Hydrothermal Systems: Physical, Chemical, Biological and Geological Interactions* (eds Humphris, S. E. *et al.*) 425–445 (Am. Geophys. Union, Washington DC, 1995).
3. Elderfield, H. & Schultz, A. *Annu. Rev. Earth Planet. Sci* **24,** 191–224 (1996).
4. Maris, C. R. P. & Bender, M. L. *Science* **216,** 623–626 (1982).
5. Mottl, M. J. *et al. Geology* **26,** 51–54 (1998).
6. Fryer, P. *et al. EOS* **68,** 1534 (1987).
7. Barnes, I. *et al. Contrib. Mineral. Petrol.* **35,** 263–276 (1972).
8. Bogdanov, Y. A. *et al. BRIDGE Newsl.* **9,** 9–13 (1995).
9. Donval, J. P. *et al. EOS* **78,** F832 (1997).
10. Charlou, J. L. *et al. EOS* **78,** F831 (1997).

Cognitive neuroscience

Bold insights

Marcus E. Raichle

Functional magnetic resonance imaging tracks changes in oxygen levels in the brain in response to different stimuli. The neural basis of these changes has, at last, been pinned down.

Over the past decade, research in the field of cognitive neuroscience has grown exponentially. To probe the mysteries of the human brain, scientists combine the experimental strategies of psychology with techniques that enable them to examine how brain activity supports mental processes. Leading the way are two techniques for imaging brain function: positron-emission tomography (PET), and magnetic resonance imaging, or functional magnetic resonance imaging (fMRI) as it is now called. fMRI is the main tool for imaging normal brain activity.

fMRI effectively measures the level of oxygen in the blood in the brain, which varies because changes in brain activity are invariably accompanied by changes in blood flow, causing the oxygen level in the blood to rise in the brain region concerned. The robust empirical relationship between changes in brain activity and blood flow has fascinated scientists for well over a century[1], but its neural basis has, until now, remained largely unknown. Despite this, researchers have assumed that the signals they obtain from fMRI are related to actual changes in neuronal activity. On page 150 of this issue,