volume of bromine are required to explain the quantities of OClO measured⁶ at McMurdo. Bromine in this quantity could account, through channel (1), for a substantial fraction of the ozone depletion. These inferences are intriguing, but should be viewed with caution.

Preliminary studies¹⁸ of the dimerization of ClO show that this, too, could be a significant feature of low-temperature chlorine chemistry. Photolysis of the dimer¹⁹ leads to a cycle for ozone destruction, and, possibly, to production of

OClO. More data are required before the detailed mechanisms of the ozone changes can be identified unambiguously and discussion of ozone depletion, in Antarctica and globally, still involves much uncertainty. Nevertheless, the recent observations have changed the nature of the discussion irreversibly. □

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Hydrothermal activity

Venting events in hot water

Joe Cann and Ros Strens

IN August 1986, in the course of routine surveys of the crest of the Juan de Fuca Ridge in the north-east Pacific, oceanographers discovered a gigantic thermal anomaly in the deep-ocean water. When they returned two months later it had disappeared. The chemistry of the anomalous water showed clearly that it had formed by mixing of very hot, hydrothermal fluid with normal cold ocean water. The observation, reported by E.T. Baker, G.J. Massoth and R.A. Feely on page 149 of this issue, clearly indicates a new kind of hydrothermal activity, very different from the steady venting of black-smoker fluids into the oceans to which we have become accustomed over the past ten years, although that in itself is a remarkable enough phenomenon.

In the normal black-smoker systems, very hot (350 °C) water emerges from the sea floor along the axes of mid-ocean ridges in discrete vent fields. The water carries dissolved iron, copper and zinc sulphides that are precipitated, when the acidic hot-vent water mixes with neutral cold sea water, to make chimneys and mounds of sulphides. Fossil analogues of such deposits are well known, and study of the active systems has been fruitful in advancing understanding of ore-deposit genesis.

The hydrothermal fluids involved originate as normal sea water that descends in the cold limb of hydrothermal convection cells and penetrates into reaction zones 1–3 km below the sea floor, where it is heated by hot rock or molten magma and reacts chemically with its surroundings, before being discharged as hot black-smoker fluid through rather narrow upflow zones. Discharge rates are probably in the range 1–100 kg s⁻¹ with corresponding heat flux (above ambient sea water) of 1.5–150 MW. The discharge forms a turbulent plume into which cold sea water is rapidly entrained and which rises to about 100–300 m above the vent field before spreading sideways as a layer about 100 m thick, marked by a temperature anomaly,

by particles of oxidized sulphide, by high levels of dissolved manganese and by other features characteristic of the black-smoker fluids, such as an anomalously high ³He/⁴He ratio.

Just such a normal steady-state plume can be seen on Baker, Massoth and Feely's Fig. 1 on page 149, which shows a north-south cross-section through the ocean above the crest of the Juan de Fuca Ridge near its southern end. The plume rises to about 200 m above the bottom, showing

A black smoker vent along the mid-ocean ridge.

that normal hydrothermal activity is taking place there. However, above the normal plume is a very different feature, a body of water, centred 800 m above the bottom, 600–700 m thick and 16 km across, with an astonishing temperature anomaly of more than 0.2 °C over a large part of its volume.

This body, the megaplume, contains a heat excess of about 7×10^{16} J above ambient sea water, equivalent to about 0.07 km³ of black-smoker fluid. Water samples from within the megaplume contained large grains of anhydrite (CaSO₄, precipitated from cold sea water when heated by vent fluids), chalcopyrite (CuFeS₂) and amorphous SiO₂, which would have settled out of the megaplume

within a few days. Baker, Massoth and Feely thus argue that the megaplume must have been no more than a few days old when they sampled it, and must have been created over a few days at most. To deliver so much heat so quickly, the mass flux of hot water must have been hundreds to thousands times that of normal black smokers (if it was at the same temperature), and the heat flux at least tens of thousands of megawatts. The fact that the top of the megaplume rose a kilometre above the ocean floor supports the high heat flux proposed.

What causes such a catastrophic emission of hot water? Baker, Massoth and Feely relate it to an episodic spreading event simultaneously injecting magma into a hydrothermal system and fissuring the system to allow hydrothermal fluid to escape suddenly. Certainly the amount of heat involved is about right, but there are potential problems, both with generating chemically more or less mature hydrothermal fluids and with transporting heat into the fluid fast enough. Heat transfer would be most effective in the type of violent submarine eruption that produces thermal granulation of magma into a glassy sand (hyaloclastites), and such eruptions are known from the geological record. It is very unlikely, however, that chemical changes would happen fast enough during such an eruption, as young hyaloclastites show little sign of water-rock reaction.

It is interesting that the volume of black-smoker fluid calculated as contributing to the megaplume (0.07 km³) is approximately the volume of hot water contained in a single hydrothermal system (as estimated from the volume of the high-temperature reaction zones in Cyprus; see Richardson, C.J., Cann, J.R., Richards, H.G. & Cowan, J.G. *Earth planet. Sci. Lett.* **84**, 243–253; 1987). Could the megaplume be the result of a catastrophic surge in the flow of a normal system that led to its emptying itself of hot water? We have predicted that such an instability could result from the rapid non-linear changes in the physical properties of sea water that occur at about 400 °C at sub-seafloor pressures (Cann, J.R., Strens, M.R. & Rice, A. *Earth planet. Sci. Lett.* **76**, 123–134; 1985). Systems might surge as part of a cyclic pattern rather than in response to tectonic events.

Whatever the answer, the fact that such a short-lived event as the megaplume has been discovered at this early stage of research into hydrothermal plumes suggests that megaplume activity could be a common, intermittent feature of hydrothermal systems. This would have major implications for biological activity, chemical flux into the oceans and sulphide precipitation on the ocean floor. □

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