COMMENTARY

More to hydrothermal iron input than meets the eye

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Because of its role in regulating primary production over large parts of the ocean, recent decades have seen growing interest in the distributions and cycling of iron (Fe) in the ocean. Until relatively recently, however, the role of Fe input from hydrothermal vents was neglected, in part because of poor sampling of the abyssal ocean. Although new observational constraints have now led to the recognition of hydrothermal vents as an important route for Fe supply, a major outstanding question has been to assess the far field influence of hydrothermal Fe. In PNAS, Fitzsimmons et al. (1) highlight hydrothermal signals in the three profiles of dissolved Fe from the South Pacific Ocean, which imply long-range transport of hydrothermal Fe for hundreds to thousands of kilometers from source. As such, these results raise important questions of how to represent these processes in the global models that are required to assess the impact of different Fe sources on the ocean carbon cycle, including biological productivity and air–sea CO_2 exchange (2).

Until less than 10 y ago, hydrothermal vents were disregarded as important sources of Fe to the wider ocean as the Fe supplied was assumed to fall out in particulate forms close to the vent site (3). However, three main lines of evidence have led to a reversal of this paradigm in the last few years. First, correlations between apparent anomalies in the vertical profile of Fe and the acknowledged hydrothermal tracer ^3He were documented in the Pacific Ocean (4). Second, dedicated hydrothermal sampling expeditions found sharp increases in dissolved Fe levels close to vent sites (5). Finally, the comprehensive ocean sections conducted as part of the ongoing GEOTRACES program (www.geotraces.org) observed striking "hotspots" of Fe associated with ocean ridges in the Arctic (6), Atlantic (7), and Southern Oceans (8, 9) (Fig. 1). These new insights required the inclusion of hydrothermal Fe in ocean models and led to the implication that hydrothermal Fe may be important in buffering the oceanic Fe inventory against short-term fluctuations in other inputs, such as dust (10).

It is in this context that the new study by Fitzsimmons et al. (1) is placed. In line with previous work, the authors also find a characteristic "bump" in the dissolved Fe profile at around 2,000-m water depth that is not connected to the remineralization of organic matter. Instead, this Fe anomaly is coincident with a maximum in ^3He, which points to a hydrothermal signal. What is novel about the Fitzsimmons et al. (1) study is that they find this anomaly at three sites in the southern Pacific Ocean that are between 800 and 6,000 km from the closest vent sites. Their calculations imply transit times of ∼10 to ∼100 y to their sampling sites closest to and farthest from the East Pacific Rise (EPR) vent system. Thus, Fitzsimmons et al. (1) highlight the potential for long-range transport of hydrothermal Fe. Such a feature is not readily apparent in the only global model to consider hydrothermal Fe input (10), suggesting a need to refine the treatment of the longevity of hydrothermal Fe plumes.

Two main hypotheses exist to explain the longevity of hydrothermal Fe plumes and both are based around increasing the stability of the hydrothermally derived Fe. The first hypothesis focuses on the stabilization of Fe by organic compounds, called ligands, that appear to increase in hydrothermal plumes (5, 11). The second hypothesis highlights the role of colloidal nanoparticles that form in the vent plume (12). Because these nanoparticles do not sink rapidly and are only slowly oxidized (13), they can act as an Fe "carrier phase,"

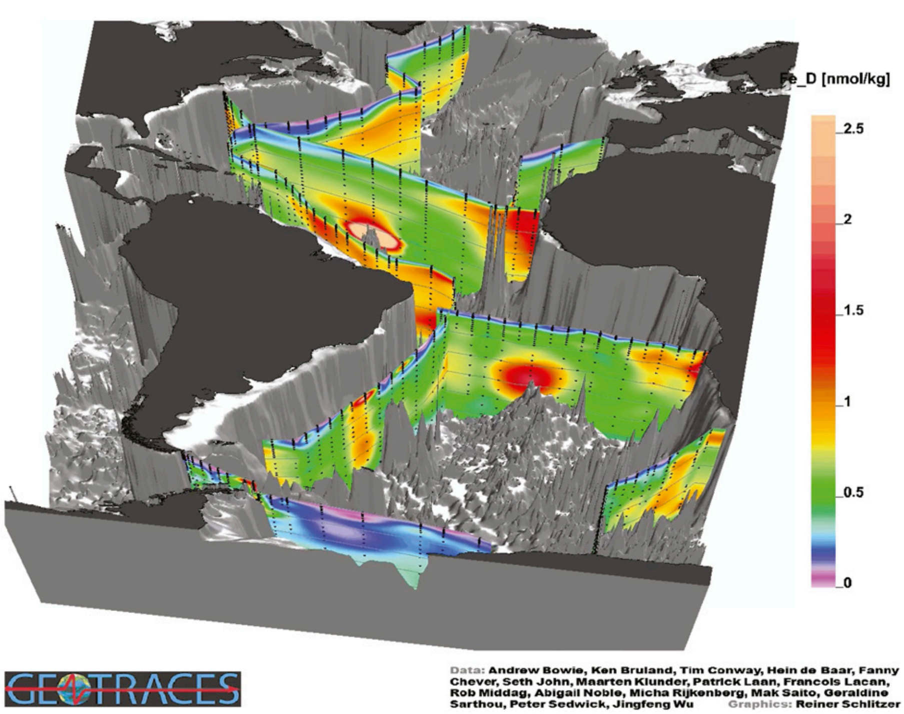

Fig. 1. The distribution of dissolved iron (nmol/kg^{-1}) in the Atlantic Ocean from the GEOTRACES intermediate data product 2014 (20). The plumes of elevated iron associated with the mid-ocean ridge are striking.

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See companion article on page 16654.

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transporting Fe away from the vent in the dissolved pool. Using laborious size-fractionated filtrations, Fitzsimmons et al. (1) highlight a greater contribution of colloidal Fe at the station closest to the EPR vent system. In addition, the authors suggest that increases in both the proportion and absolute concentration of noncolloidal (so-called soluble) dissolved Fe at the two farthest sites imply active exchange between these Fe pools during transport.

When their Fe and ^{3}He datasets are combined, Fitzsimmons et al. (1) find the Fe/^{3}He ratio declines sharply from their station closest to the EPR vent system compared with the two farthest stations (in both the southeast and southwest Pacific). This feature is indicative of the scavenging loss of Fe but not ^{3}He. Taking their minimum Fe/^{3}He ratios as representative of the net imprint of hydrothermalism and estimates of the global ^{3}He flux, Fitzsimmons et al. (1) suggest an overall Fe flux from hydrothermal systems of 7×10^8 mol Fe/yr^{-1} that is not dissimilar to prior estimates (5, 10). An intriguing aspect of the Fitzsimmons et al. (1) study is that the reduction in the Fe/^{3}He ratios as a function of transit time from source implies that if larger datasets of Fe/^{3}He could be combined with water transit times from ^{3}He sources, it may be possible to estimate the deep ocean scavenging rate of Fe. However, although colocated maxima in Fe and ^{3}He are indicative of a common source, disentangling the influence of subducted surface waters and other aspects of mixing from hydrothermal activity is not likely to be straightforward (14) [see also figure 4 of Fitzsimmons et al. (1)].

A number of contemporary studies have also highlighted other aspects of hydrothermal input important for trace metal cycling. For example, notable hydrothermal anomalies have also been noted for manganese (Mn) (1, 15) and even zinc (16) (see, for example, www.egeotraces.org). Field studies have also shown significant Fe input from shallow hydrothermal island arc systems, especially in colloidal nanoparticle forms (17). These systems may be especially important for the Fe cycle because they will inject Fe at far shallow depths than the mid-ocean ridges previously considered and might be mixed to surface waters in a different manner. Another potentially useful tool is the emerging field of Fe isotopes, which appear to "fingerprint" distinct Fe sources and have independently suggested long-range transport of hydrothermal Fe in the Atlantic (18). One thing that has clearly emerged in the last few years is that hydrothermal activity impacts ocean Fe cycling in a more complex manner than first thought (10).

Placing these results in a wider context requires taking a more global view of the ocean Fe cycle, and in particular the processes that control the residence time of Fe in the ocean interior. As an illustration, modeling suggests changes to the residence time of Fe within observed uncertainties may have a larger impact on the global carbon cycle than perturbations to dust supply (2). In addition, new basin scale datasets from the GEOTRACES program highlight widespread variability in the Fe distributions in the ocean interior (Fig. 1). In addition to distinct Fe sources, microbial activity, particle scavenging of Fe, complexation of Fe by organic ligands, and the transformation of Fe between different chemical species will also contribute to such patterns, but their relative rates and variability are poorly known. In part this is because of their interleaving influences on the dissolved Fe pool commonly measured at sea and the complexity of obtaining rate measurements. An opportunity for progress may lie in examining the parallel evolution of Fe and other trace metals that are cycled in slightly different manners (19). For example, I found it noteworthy that Fitzsimmons et al. (1) found parallel Fe–Mn anomalies at the two stations closest and farthest from the EPR, but this was less apparent at their intermediate site (figure 2 in ref. 1). A more holistic examination of Fe and other trace metals alongside other biogeochemical variables, such as oxygen, and particle concentrations in the context of ocean circulation pathways may help provide a fuller understanding of oceanic Fe cycling.

Fitzsimmons et al. (1) report that their estimate of hydrothermal Fe input is only a few percent of total atmospheric dust supply of Fe but rightly highlight that the fate of hydrothermal Fe is to be upwelled in the Southern Ocean (10). Because this is the largest Fe-limited region in the world Ocean, it illustrates the potential role played by hydrothermal Fe in supporting Southern Ocean primary productivity and the associated food webs. The results of this study equally imply that recent modeling results, suggesting hydrothermal sources contribute around one-third to the global Fe inventory (2), are likely underestimates. Better understanding the processes that regulate the long-range transport of hydrothermal Fe will enable global biogeochemical models to more accurately represent this Fe source and reduce uncertainty in how hydrothermalism impacts the cycling of both Fe and carbon in the ocean (2).

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