PNAS COMMENTARY

Surprising discovery of off-axis hydrothermal venting on the East Pacific Rise

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Since the discovery of hydrothermal activity on the seafloor at mid-ocean ridges (MORs) more than 40 years ago, questions about the relative role of magmatic and tectonic processes on the chemical and physical evolution of vent fluids have been expressed with increasing frequency. These questions have largely been motivated by geological and geophysical observations at MORs characterized by slow and intermediate spreading rates. In PNAS, McDermott et al. (1) use a highly integrated approach taking full advantage of deep submersible assets, geophysical data, and hydrothermal vent fluid temperature and chemical data, to document the existence of a large, tectonically controlled vent field on the fast-spreading East Pacific Rise (EPR). In contrast to previous observations of vents on the EPR at 9°N to 10°N (2, 3), which are largely, if not entirely, associated with the magmatically active axial summit trough (AST) (4), the newly discovered YBW-Sentry vent field is located ∼750 m east of the EPR axis, and about 7 km north of the previously studied on-axis vents. Finding more sparsely distributed vents in an area that has traditionally been ignored in favor of axial sites requires high-resolution bathymetry possible only with the autonomous vehicle technology developed by the namesakes of the YBW-Sentry site (Yoerger, Bradley, and WaldenYBW-Sentry (Yoerger, Bradley and Walden, engineers at Woods Hole Oceanographic Institution). Moreover, the proximity of the vents to a normal fault links hydrothermal and tectonic activity in a compelling way, underscoring the importance of the discovery, while broadening implications. Thus, McDermott et al. propose very different heat sources and fluid pathways for the off-axis YBW-Sentry vent fluids and on-axis vents located farther south on the EPR. In effect, the on-axis vents are thought to derive heat from localized diking (magmatic) events that enhance vertical fluid flow within zones of high permeability that are largely restricted to the ridge axis, while the YBW-Sentry vent fluids tap heat sources more closely related to the underlying axial magma lens (AML) and provide fluid flow paths that diverge from the ridge axis. The authors are correct in recognizing the discovery of the off-axis YBW-Sentry vent field as an alternative explanation for vent systems elsewhere where considerations of spreading rate alone might dispel the role of tectonics in the source of fluids and fluid pathways. Off-axis hydrothermal vents associated with fast-spreading MORs could serve as a presently underappreciated source of heat and chemicals that might be significant on a global scale.

The interpretations of divergent chemical and physical processes described by the authors (1) for the off-axis YBW-Sentry vents and on-axis vents, south of the EPR study area, are supported by extensive analysis of vent fluid chemistry obtained at each of the hydrothermal vent sites. For example, recent chemical data reported by McDermott et al. (1) for hydrothermal fluid issuing from YBW-Sentry vent structures indicate a temperature of ∼368 °C. Importantly, the dissolved chloride composition of the vent fluid is 518 mm/kg, which is about 4% below that of seawater, indicating phase separation in the NaCl–H_2O system at conditions just slightly offset from the seawater two-phase boundary. The authors use this information, with constraints imposed by chemical geothermometers and geobarometers, to estimate the temperature–pressure conditions in the subseafloor from which the vapor-dominated fluids issuing from YBW-Sentry vent structures are derived. In contrast to the observed seafloor vent fluid temperature of 368 °C, model data indicate subseafloor temperature and pressure for the YBW-Sentry vent fluid of 437 °C and ∼380 bar, respectively. The calculated pressure is equivalent to a depth of ∼1.3 km beneath the seafloor, within ∼160 m of the seismically imaged AML. Broadly similar approaches applied to on-axis vents reveal a very different picture. In this case, data indicate origin temperatures and pressures significantly lower than for the off-axis YBW-Sentry vent fluids, with evidence of relatively near-seafloor phase separation, especially in the aftermath of eruptive events, well illustrated and carefully documented by the authors of the present study. Thus, inherent differences in location and relative stability of the heat sources fueling on- and off-axis vents at EPR 9°N to 10°N can be expected to result in corresponding differences in chemical and physical (temperature, pressure) stability of respective vent fluid systems, as observed.

The YBW-Sentry vents and their geological context contribute to the understanding of the construction and evolution of oceanic crust. Although 750 m may not seem like a great distance from the axis, known vents are so tightly localized in the AST that this discovery stands out as something very different. Although high-temperature vents in other spreading systems occur in diverse settings (5), in some cases, in association with AMLs, and on fault scarps, the connection between these elements has not been made previously. Axial vents have a high probability of being modified by dike intrusion, clogging with mineral precipitates, and burial by lava flows near the AST. The

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Author contributions: W.E.S. and J.A.K. wrote the paper.

The authors declare no competing interest.

See companion article, "Discovery of active off-axis hydrothermal vents at 9°54′N East Pacific Rise," 10.1073/pnas.2205602119.

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Published July 21, 2022.

off-axis vents are less vulnerable to magmatic events but can benefit from having their permeability structures reset by fault reactivation from nearby axial dike intrusion (6). Thus, the off-axis vents may have greater longevity and preservation potential. The relatively large size of the YBW-Sentry vent field suggests it has outlasted its nearest axial neighbors. As recognized by McDermott et al. (1), the geological and hydrothermal stability of the off-axis vents may also have important implications for the preservation and dissemination of vent-related biological communities, and could provide larva to repopulate on-axis vents in the aftermath of seafloor eruptions that would disproportionately impact these sites.

The ratio and spatial distribution of convective and conductive heat loss from the seafloor has implications for the accretion of oceanic crust. Focused venting on-axis suggests magma delivery to the shallow crust beneath the axis, whereas venting and heat loss over a wider area extending beyond the axis implies deeper crustal intrusions (7). Off-axis vents and documented off-axis melt lenses support the latter view.

In studies of older oceanic crust in tectonic windows, deep drill holes, or ophiolite complexes, the relative age of various igneous and deformation structures is commonly interpreted with respect to the timing of hydrothermal mineralization. Based on current views, that are heavily influenced by the historical axial-biased investigations, it would be logical to interpret magmatic, deformational, and hydrothermal structures as features that developed beneath the AST. These include the nearly pervasive hydrothermal metamorphism of the upper kilometer or so of the crust, including the lower part of the lavas and the sheeted dike sections, but also more focused, high-temperature alteration along discrete fault zones (Fig. 1) that, in some cases, penetrate deeply into the crustal section (8, 9). There are no independent constraints on the timing of these processes on older crustal sections, but the subsurface fracture zone of the YBW-Sentry vent field suggests that late faults with high-temperature mineralization can form well off-axis. This is useful in establishing the relative timing of igneous and metamorphic processes, while also broadening considerably the volume of the subsurface where initial crustal construction and metamorphism occur.

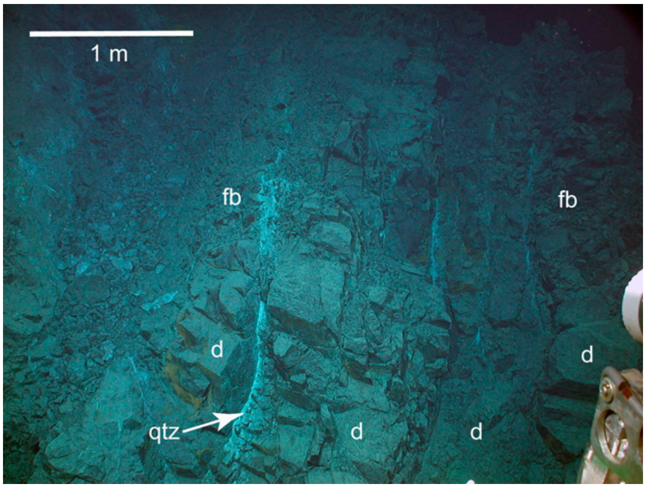

Fig. 1. High-temperature hydrothermal conduit in sheeted dikes (crustal depth ∼1,000 m): quartz veins (qtz) in high-permeability fault breccia (fb) parallel to sheeted dikes (d) at the Pito Deep Rift, Alvin Dive 4077. Faulting associated with the off-axis YBW-Sentry vent field (EPR) similarly serves as a means of enhancing hydrothermal fluid transport in the ocean crust, with implications for the development of vent structures on the seafloor.

The investigative approach that led to the discovery of the YBW-Sentry vent field points the way to future investigations. The YBW-Sentry vents were discovered in the context of one of the NSF RIDGE 2k (R2k) focused study sites. Intensive geological and geophysical mapping of the area (10), further stimulated by a recent eruption in 2005–2006 (11), resulted in a comprehensive characterization of this spreading system that allows McDermott et al. (1) to link the vents to a fault zone penetrating through the upper oceanic crust to near the edge of a seismically imaged melt lens (12). Without this holistic approach, these connections would not be possible. The combination of geochemical constraints on depths of fluid reactions, multichannel seismic images of a melt lens, and a surface fault scarp make it possible to form the logical interpretation of a high-permeability fault conduit connecting the hydrothermal reaction zone near the lens through the sheeted dikes and into overlying lavas.

The search for high-temperature vents on the seafloor has led to a nested-scale approach using ever-higher-resolution tools to progressively focus on vent sites. This approach, largely pioneered in the R2k program, is now widely used, and has been very successful in locating vents and helping make efficient use of deep submergence assets for sampling and detailed imaging. The initial focus has been the very narrowly defined AST of the EPR where the density of vents is relatively high. For the spatial resolution (one to two pixels) needed to image even large vent sites like YBW-Sentry, dense, near-bottom surveys that can only cover limited areas are required, so the survey area must be limited by other studies.

Evidence is growing that the crustal accretion processes at the EPR extend beyond the narrowly defined surface expression of the axis. Multichannel seismic surveys have documented off-axis magma lenses at various crustal depths. Mapping of magnetic reversals into gabbroic rocks of tectonic windows has suggested slow cooling of the middle crust (13). Active faulting is detected in crust out to a few million years old (14). Low-temperature deposits have been found along abyssal hills several kilometers off the EPR axis (15). These observations and the YBW-Sentry vent field hint that there is much more to learn about MORs in off-axis regions. The low-hanging fruit from investigations of on-axis vents has been bountiful, but the next steps in investigating the distribution and diversity of high-temperature vents and their geological, thermal, chemical, and biological significance to the global MOR system will require new approaches and new survey strategies, applied over much greater areas. Whether or not the discovery of the off-axis YBW-Sentry vent field will result in a fundamental shift in thinking about MOR hydrothermal systems remains to be seen, but it clearly points the way to future investigations beyond the axis.

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