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Variability of physico-chemical conditions in 9°50′N EPR diffuse flow vent habitats

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Abstract

The physico-chemical characteristics of habitats have been considered to be one of the prime determinants of animal distribution within hydrothermal vent sites. However, the relative importance of abiotic to biotic influences is still debated. The primary aim of this study is twofold. The first is to determine and compare the ranges of physico-chemical conditions that characterize mussel-dominated and tubeworm-dominated communities at different sites within the vent field of the 9°50′N segment on the East Pacific Rise. The second is to better understand the processes that determine the variability of physico-chemical conditions in these habitats. In situ chemical and temperature measurements confirmed the high variability on small spatial and temporal scales within single aggregations of animals. The correlation of temperature and sulfide or pH revealed substantial differences between similar habitat-types at different sites, which cannot be attributed to changes in the extent of fluid dilution in the subseafloor. Further investigation of habitat variability within individual sites highlighted specific chemical features for the four sites studied, emphasizing the importance of an extensive in situ chemical analyses survey before using temperature as a proxy for chemical conditions. At Tica and Biovent, the fluid source characteristics were shown to vary only slightly within the sites, among aggregations discretely distributed over several meters distance. The variability of the total sulfide concentration and chemical speciation with temperature in the various habitats at each of these sites, can be reasonably simulated from the conservative mixing model of a single source fluid with seawater. The small variation of the empirical trends between different types of faunal assemblages at Tica suggests that changes in the fluid chemistry are not a prime determinant of the temporal succession of mussels and tubeworms. The findings of very similar sulfide–temperature relationships in two sites of different age and faunal compositions, Biovent and Tica, further support this idea. The two other sites, Mussel Bed and Riftia Field, differ both in the animal communities present and their chemistries show significant discrepancies from the predictions of the conservative mixing model. At Riftia Field, elevated iron concentrations and relatively low sulfide levels were correlated to unusually low pH, which could not be fully explained by conservative mixing of a typical diffuse vent fluid with seawater. The increased acidity results in a dramatic reduction in the anionic form, HS^-. This is the form preferentially assimilated by the tubeworms and could explain the decline of the tubeworms at this site. At Mussel Bed the relationship between the sulfide concentration and temperature varied substantially among the aggregations surveyed and may reflect the influence of associated free-living microbial communities on the chemistry of mussel habitats. This study emphasizes the complex interplay of diffuse fluid formation in subsurface, chemical reactivity in the mixing zone, and biological activity in controlling of characteristics of vent habitats.

Keywords: Hydrothermal fluid; pH; Sulfide; In situ chemical measurement; Subsurface biosphere; Microhabitat

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1. Introduction

Mid-ocean ridges harbor highly productive biological communities, discretely distributed around hydrothermal vents. These communities rely on chemosynthetic primary production fueled by reduced and oxidized chemical species at the mixing interface between the hydrothermal vent fluids and seawater (Hessler and Kaharl, 1995; Jannasch, 1995). At many vent fields, the biomass is dominated by animals that host chemosynthetic bacterial symbionts. These animals take up essential metabolites (e.g. carbon dioxide, sulfide, oxygen, and nitrate) from the surrounding medium and transfer them to their symbionts (Childress and Fisher, 1992). Associated with the aggregations of these symbiont-containing animals are abundant communities of other metazoans and microbes (Hessler and Kaharl, 1995).

On the East Pacific Rise (EPR) and Galapagos Spreading Center (GSC), these communities are often dominated by tubeworms and bivalves with sulfide-oxidizing symbionts that form dense aggregations around cracks in the basaltic seafloor where there is a diffuse emission of vent fluids (Hessler and Kaharl, 1995). These diffuse vent fluids are generally enriched in sulfide, methane, hydrogen, carbon dioxide, silicate and, in some cases, ferrous iron, but their chemical composition and temperature are highly variable in space and time (Edmond et al., 1979; Johnson et al., 1988a; Johnson et al., 1988b; Shank et al., 1998; Von Damm and Lilley, 2004). This variability has been explained primarily by spatial and temporal changes in the end-member fluids (Edmond et al., 1979; Johnson et al., 1988a; Johnson et al., 1988b; Von Damm, 1995; Von Damm et al., 1995), as well as the variability in the extent of subsurface dilution. A recent study of diffuse and adjacent focused hydrothermal vent flow sources at various sites around 9°50′N on the EPR also suggested that the diffuse fluids are affected by conductive heat exchange, precipitation processes and microbial activities in the subsurface (Von Damm and Lilley, 2004).

Turbulent conditions characterize the mixing interface where the organisms occur. Large temporal fluctuations of temperature at one point, at a scale of seconds to hours (Johnson et al., 1988a, b; Sarradin et al., 1998), and sharp changes in chemical conditions that correlate with temperature variations, are the result of mixing reduced vent fluids with seawater and subsequent abiotic and biological processes (Johnson et al., 1988a, b; Le Bris et al., 2000; Luther et al., 2001; Le Bris et al., 2003).

The nutritional dependence of vent animals on chemoautotrophic microbes constrains the biological community to these interfaces (Childress and Fisher, 1992). However, a gradient in the vent fluid contribution to the mixed fluid bathing the animals, not only corresponds to a gradient in biologically available chemical energy but also to a gradient in potential environmental stress to the organisms (Mullineaux et al., 2000), as for example, exposure to sulfide which is toxic to most animals (Powell et al., 1987; Visman, 1991). From the observation of the spatial distribution of communities along a gradient of hydrothermal influence, it has been proposed that physico-chemical conditions play a significant role in the distribution, succession, composition, and biomass of these communities (Johnson et al., 1988b; Fisher et al., 1988; Sarrazin et al., 1999; Shank et al., 1998; Desbruyères et al., 2001; Luther et al., 2001). However, numerous studies also stressed the importance of biological interactions in structuring vent communities and suggested that physico-chemical conditions are not the sole determinant of community structure (Hessler and Kaharl, 1995; Shank et al., 1998; Mullineaux et al., 2000; Micheli et al., 2002; Mullineaux et al., 2003).

Addressing these questions requires quantitative methods in order to better assess the physico-chemical conditions and to compare the constraints experienced by the organisms in the various vent habitats. Because the temperature changes can be readily recorded from a submersible or with autonomous probes, temperature is often used as proxy of the hydrothermal fluid contribution and related chemical parameters in diffuse flow habitats (Johnson et al., 1988a; Childress and Fisher, 1992; Sarradin et al., 1998; Mullineaux et al., 2000, 2003; Urcuyo et al., 2003). Focusing on mussel and tubeworm habitats at one site (Rose Garden, GSC), Johnson et al. (1988b) demonstrated that temperature could be used as a conservative tracer of the vent fluid dilution from diffuse flow sources. However, these authors also highlighted several cases of non-conservative behavior for sulfide and oxygen within the faunal assemblages, that was attributed to biological consumption (Johnson et al., 1988b; Johnson et al., 1994). Much remains to be learned from investigations of the physico-chemical conditions in diffuse flow habitats, both with respect to the cause of the variability within a site and among different sites, as well as their biological implications.

In this study, the physico-chemical conditions around tubeworm and mussel aggregations were analyzed at four distinct sites on the well-studied 9°50′N segment of the EPR. Multiple animal aggregations were