Deep-sea ecosystems at oceanic ridges and volcanic arcs

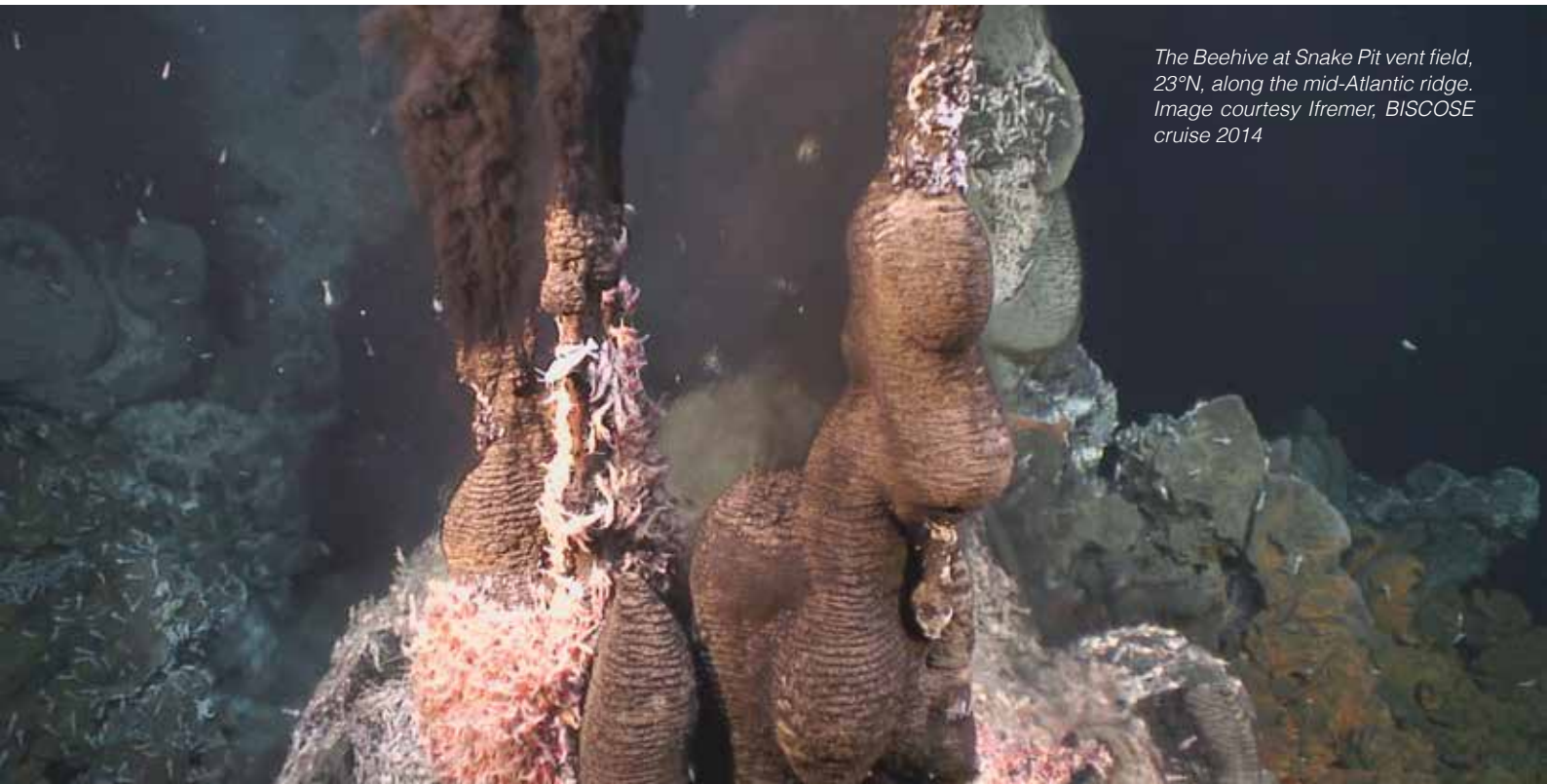
Seafloor massive sulphide deposits are encountered along the 60,000km of oceanic ridges and at submarine volcanic sites, which together represent over 20% of the world's seafloor. These geological features are found in all oceans, encompass a depth range of over 3000 metres and form highly heterogeneous environments that are home to a wide range of deep-sea ecosystems. Habitats in these regions include both active and inactive hydrothermal vents, ridge flanks composed of hard volcanic rock, and surrounding areas of soft sediment. The environmental impacts of exploiting SMS deposits are therefore complex, and can affect a range of ecosystems in different ways.

Active hydrothermal vents

Hydrothermal vents are found in areas of intense volcanic and tectonic activity, such as mid-oceanic ridges and back-arc basins. Cold seawater (<4°C) enters fractured oceanic crust, heats up and circulates through the subsurface rocks, becoming enriched in various elements. This hot (up to 400°C) and acidic hydrothermal fluid rises and is expelled at the seafloor to form a hydrothermal vent or chimney structure. Hydrothermal fluids are generally acidic, anoxic and enriched in sulphur and metals such as iron, manganese, zinc and copper. Extensive particle plumes are dispersed from vents, travelling several kilometers and significantly contributing chemical input to the deep ocean.

The discovery of hydrothermal vents in 1977 came with a biological surprise: luxuriant faunal communities thriving in the darkness of the deep ocean. Microorganisms are the main actors, sustaining dense animal populations in an otherwise food-deprived environment. At vents, bacteria and archaea use chemicals (mainly hydrogen sulphide but also methane, iron and hydrogen) from the hydrothermal fluids and oxygen from seawater to grow and produce organic matter. This process, called chemosynthesis, is extremely productive and the biomass attained by some vent communities can sometimes rival that of a rain forest. Microorganisms constitute the base of the food chain, either by living in close association with invertebrates (through symbiosis) or by being directly consumed by a variety of organisms. The fauna living at vents have developed several adaptations to cope with their paradoxical habitat and many species are endemic (unique) to hydrothermal ecosystems. While the densities of animals are very high, their diversity is quite low, reflecting the specialisation of vent fauna.

Hydrothermal fauna form dense communities that are often dominated by a large "engineer" species. These provide a three-dimensional habitat and shelter to a variety of smaller organisms. Different assemblages are patchily distributed on sulphide edifices or on surrounding basalts in areas of relatively low-temperature fluids (<30°C).



The Beehive at Snake Pit vent field, 23°N, along the mid-Atlantic ridge. Image courtesy Ifremer, BISCOSE cruise 2014

Different hydrothermal sites around the globe have distinctive taxa: tube worms and alvinellid polychaetes are characteristic of the Pacific Ocean; large symbiotic gastropods are typical of the western Pacific back-arc basins, and shrimp swarms are strongly associated with Atlantic vent sites. The less-known Indian Ocean vents are colonised by a mixture of Atlantic-like and Pacific-like fauna. To date, over 632 active vent fields have been reported in the world's oceans and new vents are constantly being discovered, bringing their share of new species to science. However, many aspects of hydrothermal vent ecology remain poorly known.

The siboglinid tube worms Riftia pachyptila are amongst the most emblematic engineer species of hydrothermal vents from the Eastern Pacific. Copyright Ifremer, PHARE cruise 2002

Sulphide deposits at inactive hydrothermal vents

Very little is known about the fauna of sulphide deposits at inactive hydrothermal vent sites. Microbial communities are specific and different from both active vents and the surrounding basalts. The larger fauna shows affinities with that living on other non-mineralised substrates, but there is no known evidence of fauna that are endemic to sulphide deposits at inactive hydrothermal vents.

Non-mineralised hard substrates

New seafloor is generated at mid-ocean ridges, so hard substrate of basalt (cooled lava) is more common in these environments than anywhere else in the deep sea, though with time they become progressively covered with fine sediments. Limited studies of the fauna that live on the non-mineralised hard substrates near vent sites suggest strong affinities with the better-known hard rock fauna of continental margins and seamounts. This bathyal fauna can be observed on the flanks of the ridge near vent sites, with some species making incursions into the vent fields. These fauna live on the flanks of the mid-ocean ridge, and are dominated by corals, gorgonians, sponges and fishes. Most of the species feed on particles suspended in the water. The diversity is higher here than in the chemosynthetic ecosystems, but densities are very low. Diversity and species richness is dependent on water depth and on the amount of organic matter supplied by surface productivity. Species may be shared with continental margins and seamounts, but ecological and biological connectivity is still unknown.

Soft sediments

A dark rocky seascape punctuated by hydrothermal vents is the most conspicuous scenery when exploring in a hydrothermal field. Away from these volcanically active and geologically young areas, basalt and mineral deposits are progressively draped by fine sediments at a rate of 10 to 30 mm per thousand years. In the North Atlantic, 95% of the oceanic ridge is covered with sediment. Sediment particles are mostly raining down from the ocean surface, but can also settle out from hydrothermal plumes or submarine volcanic eruptions. The sediment fauna on mid oceanic ridges and back-arc basins has received little attention until now. As is the case for hard substrates, the fauna of hydrothermal sediments is characterised by high densities and low diversity, while away from hydrothermal vents the fauna is more diverse but less dense. Increased interest in these environments is resulting in the constant discovery of new species, though many other species are also found on the better-known continental margin environments. The biological connectivity between rocky fauna living on continental margins and ocean ridges has not yet been demonstrated.

Tube worms and scale worms are abundant in hydrothermal sediments of a Mid-Atlantic Ridge vent field (Snake Pit, 3500 m depth). Image courtesy Ifremer, BICOSE cruise 2014.

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