IFM-GEOMAR

Leibniz-Institut für Meereswissenschaften
an der Universität Kiel

IFM-GEOMAR Report 2002-2004

From the Seafloor to the Atmosphere

- Marine Sciences at IFM-GEOMAR Kiel -

INSTITUT FÜR MEERESKUNDE KIEL

GEOMAR

PAX OPTIMA RERUM ACADEMIA HOLSATORUM CHILONIENSIS

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Preface

For the first time, the Leibniz Institute of Marine Sciences (IFM-GEOMAR) presents a joint report of its research activities and developments in the years 2002-2004. In January 2004 the institute was founded through a merger of the former Institute for Marine Research (IfM) and the GEOMAR Research Center for Marine Geosciences. This report addresses friends and partners in science, politics and private enterprises. It gives an insight into the scientific achievements of IFM-GEOMAR and its predecessor institutes during the last three years.

3.14 Seafloor Hydrothermal Systems

Circulation of seawater through the oceanic crust is the principal process responsible for the formation of submarine hydrothermal systems. Seawater, which deeply penetrates into the oceanic crust at seafloor spreading centers, is modified to a hydrothermal fluid with low pH, low Eh, and high temperatures during water-rock interaction above a magmatic heat source. This hydrothermal fluid is then capable of leaching and transporting metals and other elements, which eventually precipitate as massive sulfides at and below the seafloor.

Today, more than 200 sites of hydrothermal activity and seafloor mineralization are known on the ocean floor (Fig. 1). About 100 of these are sites of high-temperature venting and related mineral deposits. They occur on fast-, intermediate-, and slow-spreading mid-ocean ridges, on axial volcanoes and off-axis seamounts, on sediment-covered ridges, in subduction-related island arc and back-arc environments, and along rifted continental margins, at water depths ranging from >4,000 m to <100 m. Different types of hydrothermal systems are hosted by different rocks including mafic to ultramafic as well as felsic volcanic rocks and sediments.

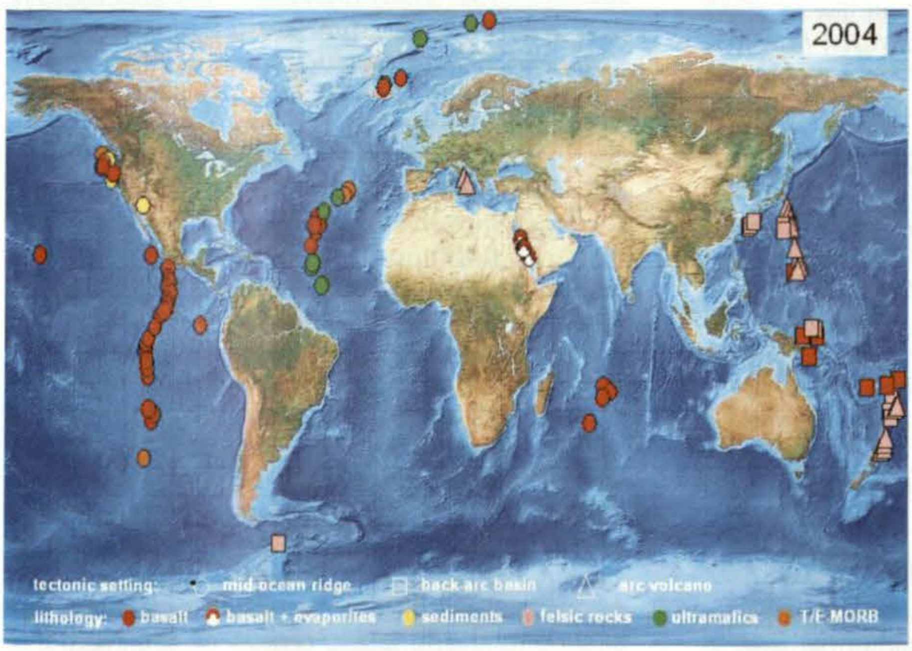

Figure 1: Map of worldwide distribution of seafloor hydrothermal systems.

Studying these modern seafloor hydrothermal systems provides important insights into the formation and development of seafloor vent sites, which in turn have a global impact on the chemical composition of seawater and the alteration of the oceanic crust. The physicochemical properties of the hydrothermal fluids, the alteration, the sulfide textures as well as the structure and the geological setting of the deposits can be studied in these natural laboratories.

Our understanding of the hydrothermal systems forming at the seafloor, however, has been limited over the past 20 years by the fact that, until recently, only two dimensions of the hydrothermal sites have generally been accessible. Neither the subseafloor extent nor the temporal evolution of the deposits have been explored in detail. The recently set-up hydrothermal research working group at IFM-GEOMAR is aiming at documenting the variability of seafloor hydrothermal systems as well as at determining their extent, character of the subsurface, evolution through time, and evaluating the impact of the released metals on the marine environment.

Exploring the third dimension of active seafloor hydrothermal systems is necessary to fully understand these hydrothermal systems. The Ocean Drilling Program (ODP) and its successor the Integrated Ocean Drilling Program (IODP) provide one possible framework to perform these investigations. A recent ODP drilling leg was conducted at the felsic-hosted PACMANUS hydrothermal site near the crest of Pual Ridge in the eastern Manus back-arc basin (Papua New Guinea). It provided samples, which allowed us to determine the complex and multi-stage alteration history of the rocks beneath this hydrothermal site. Our data show how the physical and chemical variables in the hydrothermal fluids controlled the alteration mineral paragenesis, and how water-rock reactions affected the chemical and isotopic exchange between felsic rocks and hydrothermal fluids. A surprising picture emerged. Using the mineralogy and composition of the alteration minerals it was possible to reconstruct both the composition of the fluids, which altered the rock (especially the relative proportions of hot hydrothermal fluid and seawater) and also the temperature of alteration. Instead of the expected steady decrease in fluid temperature and increase in seawater proportion in the fluid as the seabed is approached, we found the situation shown in Figure 2. There is a clear temperature maximum just below the seafloor, probably reflecting the importance of a capping seal of either fresh lavas or alteration products in containing the hottest, most buoyant fluids.

Drilling at hydrothermal sites is technologically challenging because of the friable nature of the host rocks, their altered derivatives and the massive sulfides. Drilling from a surface ship during, for instance, ODP drilling does often not allow the controlled drilling and good core recovery necessary in these environments. A far better alternative is to place the drill rig on the seafloor using a portable drilling device such as the British Geological Survey "Rockdrill", a system capable of drilling up to 5 m holes into the seafloor (Fig. 3). This system was successfully deployed in 2002 from the German Research Vessel SONNE to conduct shallow drilling operations at the PACMANUS site. Drilling with the "Rockdrill" recovered the massive sulfide-rich sections just below the seafloor, which were not accessible by ODP drilling technology, and revealed high base- and precious metal contents at depth, similar to those in massive sulfide chimneys previously collected from the surface (Fig. 4). The shallow drilling revealed a wealth of mineralogical features which imply that seawater penetration, reworking of primary sulfide material and possibly multi-staged hydrothermal activity are important processes during the evolution of the deposit, allowing us to greatly refine our models of ore-deposit formation in the deep sea.

A completely different hydrothermal system occurs in the fore-arc region of the New Ireland arc (Papua New Guinea). Here, magmatic

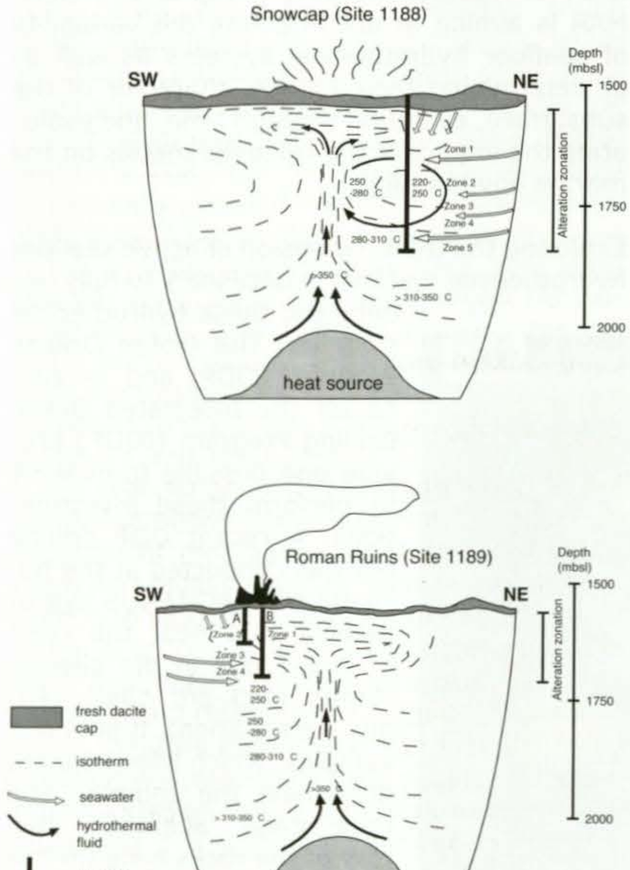

Figure 2: Schematic diagram showing the alteration zones underneath two active hydrothermal sites in the Eastern Manus Basin (Papua New Guinea).

Figure 3: The British Geological Survey Rockdrill onboard RV SONNE.

Figure 4: Massive sulfide cores drilled at the PACMANUS Hydrothermal field (Papua New Guinea).

rather than hydrothermal fluids are responsible for the development of a vein-style, gold-rich mineralization at the summit of a 600 m high submarine volcano (Conical Seamount). Drilling the upper 5 meters of this unusual system, albeit recovering only a limited amount of mineralized samples, provided evidence for a more widespread occurrence of altered and mineralized material in the subsurface. The extension of the mineralized area and the recovery of altered material below a carapace of less-altered volcanic rocks indicate the possibility of a larger gold-mineralized hydrothermal system at depth. Based on these results an application for deep drilling with the Integrated Ocean Drilling Program (IODP) has been put forward.

Plate growth at slow- and ultra-slow spreading centers, which account for 20 - 40% of the total length of the global mid-ocean ridges, appears to involve the exposure of significant amounts of mantle (ultramafic) rocks on the seafloor. So far, only four out of more than 200 known submarine hydrothermal sites are hosted by ultramafic rocks, and our understanding of these sites is limited. During the recent *R/V METEOR* cruise M60/3 the ultramafic-hosted Logatchev site on the Mid-Atlantic Ridge was investigated in detail using the remotely operated vehicle QUEST. Geological mapping and sampling of this field revealed that about 25% mafic rocks and 75% ultramafic rocks are present at the seafloor in this region. Visual observation and structural interpretation imply that the area surrounding the hydrothermal field is covered by ultramafic debris flows originating higher up on the rift valley walls. The geochemistry of the hydrothermal fluids and the massive sulfides suggest reactions between ultramafic and mafic rocks underneath the Logatchev hydrothermal field.

Outlook

The temporal evolution of seafloor hydrothermal systems and its effects on the hydrosphere can only be studied through long-term monitoring. For this purpose IFM-GEOMAR is planning to actively participate in the NEPTUNE program, a multi-year, multi-million dollar effort to study plate-scale hydrothermal processes along the Juan de Fuca Ridge using instrumentation linked to a fiber-optic cable network. Future studies in the framework of SPP1144 will include drilling of the Logatchev hydrothermal field using the lander-type Rockdrill II of the British Geological Survey and exploring and investigating new hydrothermal sites in the southern Atlantic, south of the Romanche Fracture Zone (see chapter SPP1144). Access to new underwater technology such as remotely operated vehicles (ROV's) and autonomous underwater vehicles (AUV's) will be necessary to conduct our future work on hydrothermal systems.

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Thomas Kuhn, Klas Lackschewitz, and Sven Petersen