International Research:

MEDITERRANEAN SEA

Drilling submarine hydrothermal systems in the Tyrrhenian Sea, Italy

S. Petersen[1], T. Monecke[2], N. Augustin[1], A.A. De Benedetti[3], A. Esposito[4], A. Gärtner[1], A. Gardeler[1], J.B. Gemmell[5], H. Gibson[6], G. He[7], M. Hügler[1], A. Kayser[1], R. Kleeberg[8], J. Küver[9], N. Kummer[8], K. Lackschewitz[1], F. Lappe[1], K.M. Perrin[10], M. Peters[11], R. Sharpe[5], K. Simpson[12], D. Smith[13], and B. Wan[7]

Over the past decade, modern seafloor research has greatly intensified in volcanic arc environments, especially those of the western Pacific. The discoveries of native sulfur lakes, venting of highly acidic fluids, and sites discharging liquid CO_2 showed that arc hydrothermal systems are distinct from those at mid-ocean ridges (de Ronde et al., 2001; Stoffers et al., 2006; Embley et al., 2007). However, relatively few studies have focused on the mineral endowment and the characterization of the size and anatomy of seafloor sulfide and sulfate deposits of volcanic arcs.

During R/V *Meteor* cruise M73/2 (14-30 August 2007), three hydrothermal vent sites in the southeastern Tyrrhenian Sea were studied that are known to be associated with sulfide and sulfate deposits (Minitti and Bonavia, 1984; Tufar, 1991; Marani et al., 1997; Dekov and Savelli, 2004). Drilling at the Palinuro and Marsili volcanic complexes and offshore Panarea Island (Fig. 1) was conducted by an international team of scientists from Australia, Canada, China, Germany, Italy, and the UK employing the British Geological Survey (BGS) Rockdrill 1, a lander-type seafloor drilling device (Petersen et al., 2005). Key questions to be addressed during this project included the role of boiling and/or magmatic degassing on mineral precipitation and its effect on associated microbial communities as well as the role of the various sources of sulfur within the hydrothermal system. Recovery of up to 5-m long drill cores revealed, for the first time, the subseafloor nature of hydrothermal sulfide and sulfate deposits forming in an arc environment.

The Palinuro volcanic complex (Fig. 2) represents a complex submerged arc volcano that consists of several coalesced eruption centers located along an E-W trending fault system extending seaward off the northern limit of Calabria, Italy. It is bounded to the north by the continental slope of the Southern Apennines and faces the Marsili back-arc basin to the south. Palinuro has an overall extent of 50 km with a maximum width of 22 km at its base and rises to a water depth of ~70 m. Research at Palinuro focused on a sulfide occurrence located in a small topographic depression (ca. 630 to 650-m water depth) at the summit of a volcanic edifice in the western part of the volcanic complex. Low-temperature hydrothermal activity is widespread as evidenced by staining of the fine-grained sediments covering the seafloor and local protrusions of iron oxide crusts and chimneys. The discovery of living tube worm colonies (Fig. 3a) and shimmering water during a previous research cruise in 2006 indicates that active venting is still taking place,

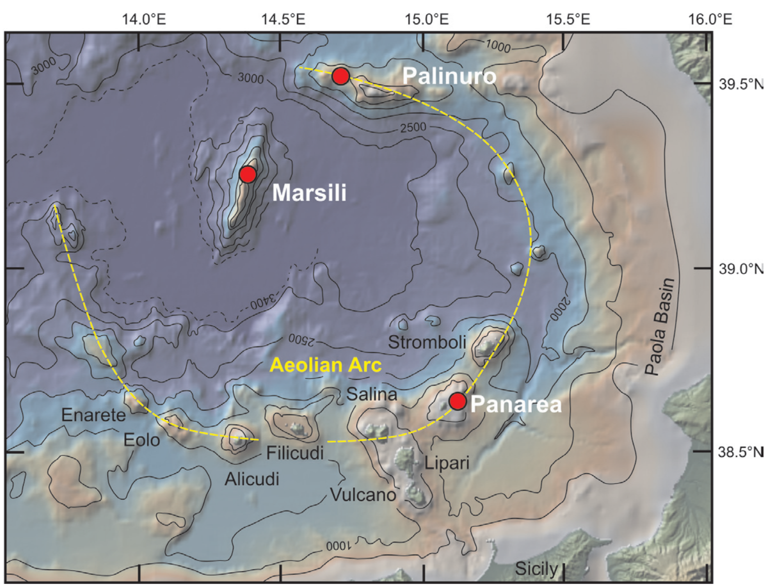


Figure 1: Regional map of the Aeolian arc with the locations of the study sites. Source: GeoMapApp.

[1]Leibniz-Institute of Marine Sciences, IFM-GEOMAR, Kiel, Germany; [2]Colorado School of Mines, Golden, CO, USA; [3]Università degli Studi Roma Tre, Rome, Italy; [4]Istituto Nationale di Geofisica e Vulcanologia, INGV, Rome, Italy; [5]CODES, University of Tasmania, Hobart, Australia; [6]Laurentian University, Sudbury, Canada; [7]China Ocean Mineral Resources R&D Association, COMRA, Beijing, China; [8]TU Bergakademie Freiberg, Germany; [9]Department of Microbiology, Institute for Material Testing, Bremen, Germany; [10]Neptune Minerals, Milsons Point, Australia; [11]University of Muenster, Germany; [12]Mineral Deposit Research Unit, University of British Columbia, Vancouver, Canada; [13]British Geological Survey, Loanhead, UK

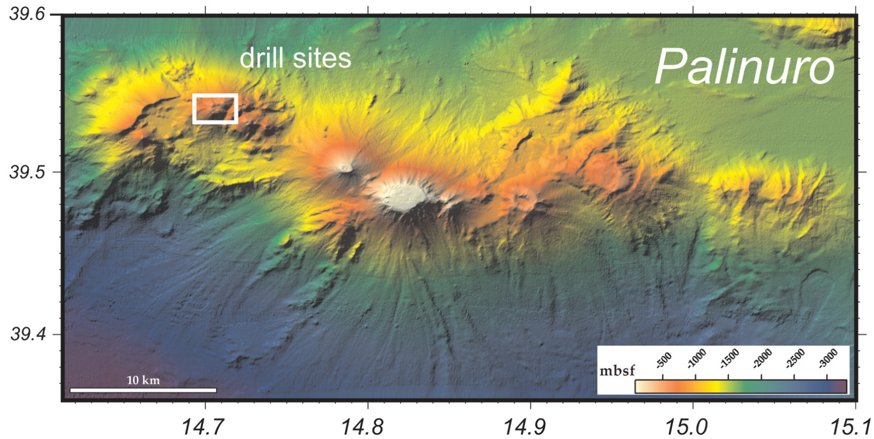
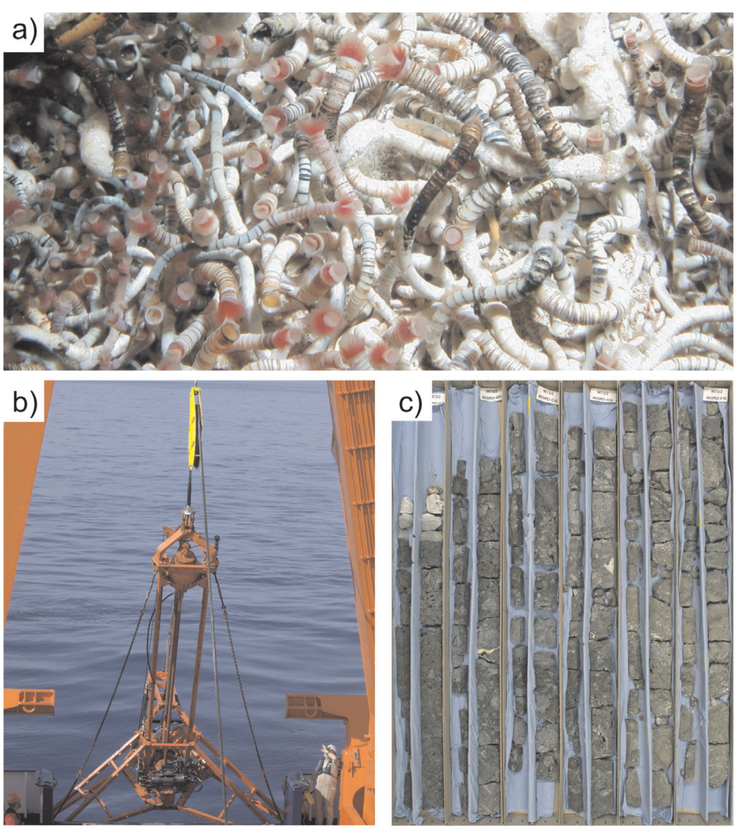


Figure 2: Bathymetric map of the Palinuro volcanic complex showing the location of the drill sites at this working area during R/V *Meteor* cruise M73/2.

although hot fluid venting and smoker activity have not been observed (Petersen et al., 2008). The occurrence of tube worms related to active hydrothermal venting has, to our knowledge, not previously been documented for the Mediterranean Sea or the Atlantic Ocean. Drilling in the area revealed that a zone of massive sulfide mineralization is buried beneath a layer of unconsolidated sediments. A total of eleven successful holes were drilled recovering 12.7 m of massive to semi-massive sulfides. One deployment yielded 4.9 m of continuous core consisting of massive sulfides and sulfates (Figs. 3b, c). All drill holes ended in mineralization and, therefore, the mineralized zone remains open in all directions.

Additional coring was performed in areas of increased sediment thickness using the vibrocorer function of BGS Rockdrill 1 and a conventional gravity corer. Pore water was sampled from the sediment cores to constrain down-hole variations in pore water and sulfur isotope chemistry. TV-guided grab sampling at Palinuro retrieved warm (Tmax = 60°C) native sulphur cemented sediments indicating that hydrothermal activity is ongoing in the study area.



Panarea, the smallest of the Aeolian Islands, forms a small archipelago that emerges from a submarine stratovolcano that rises more than 1200 m above the surrounding seafloor. Submarine gas venting is widespread around Panarea and likely related to a regional seismic and volcanic event that started in 2002 and affected the subaerial volcanoes of the area including Stromboli and Aetna. A high-resolution bathymetric survey of the near-shore (<70 m water depth) study area previously performed by our Italian co-workers (Esposito et al., 2006) revealed the presence of numerous circular depressions ranging from <10 to over 100 m in diameter.

Shallow drilling at Panarea was mainly conducted within the circular depressions and a channel-like trough interpreted to have formed by overlapping of several craters along one NW-SE striking fault. A total of 38 holes were drilled at water depths ranging from 60 to 90 m. A number of drill holes returned massive anhydrite and gypsum with disseminated sulfides locally infilling vugs and fractures. These massive sulfates are interpreted to represent a cap forming at the interface between seawater and ascending hydrothermal fluids. Additional drilling recovered variably altered volcanic rocks allowing correlation between the geology on land and in the near-shore environment.

The Marsili volcanic complex represents a prominent NNE-SSW trending volcanic feature located in the central part of the <2 Ma old ocean crust-floored Marsili back-arc basin (Fig. 1). It is the largest volcanic edifice in the Tyrrhenian Sea and has an overall length of 55 km, a maximum width of 30 km, and a height of 3000 m. Marsili possesses a long and narrow summit region that stretches 20 km along the main axis of the volcano and rises to a water depth of ca. 500 m. The morphol-

Figure 3: **(a)** Living siboglinid tube worms at the western summit of the Palinuro volcanic complex. **(b)** BGS Rockdrill 1 during operation onboard R/V *Meteor* cruise M73/2; **(c)** Drill core totalling 4.9 meters of massive sulfides and sulfates recovered from the Palinuro volcanic complex.

ogy of the volcanic edifice suggests that this complex represents the superinflated spreading ridge of the Marsili back-arc basin (Marani and Trua, 2002). During R/V *Meteor* cruise M73/2, TV-guided grab sampling and drilling were conducted at two peaks of the elongated summit region. Weakly altered basaltic or andesitic lava and iron oxides were recovered, but sulfide mineralization was not encountered.

Detailed bathymetric mapping using a ship-based Kongsberg EM120 multibeam system was conducted around all three sites showing complex volcanic structures with multiple volcanic eruptive centres at Palinuro and Marsili. The bathymetric survey at Panarea complemented previous mapping of the near-shore environment (Esposito et al., 2006). In addition to the geological investigations, extensive sampling of microbiological material was conducted during the cruise for further analyses. Onshore research will focus on the study of the microbial community structure and investigations constraining the presence and diversity of functional genes of the sulfur and carbon cycles. Cultivation of microbial groups adapted to the hydrothermal environment, including sulfur oxidizers, chemolithoautotrophic thermophiles, actinomycetes, and phototrophs, will be conducted.

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