Eos, Vol. 90, No. 13, 31 March 2009

Shallow Submarine Hydrothermal Systems in the Aeolian Volcanic Arc, Italy

PAGES 110–111

The majority of known high-temperature hydrothermal vents occur at mid-ocean ridges and back-arc spreading centers, typically at water depths from 2000 to 4000 meters. Compared with 30 years of hydrothermal research along spreading centers in the deep parts of the ocean, exploration of the approximately 700 submarine arc volcanoes is relatively recent [*de Ronde et al.*, 2003]. At these submarine arc volcanoes, active hydrothermal vents are located at unexpectedly shallow water depth (95% at <1600-meter depth), which has important consequences for the style of venting, the nature of associated mineral deposits, and the local biological communities.

As part of an ongoing multinational research effort to study shallow submarine volcanic arcs, two hydrothermal systems in the submerged part of the Aeolian arc have been investigated in detail during research cruises by R/V *Poseidon* (July 2006) and R/V *Meteor* (August 2007). Comprehensive seafloor video surveys were conducted using a remotely operated vehicle, and drilling to a depth of 5 meters was carried out using a lander-type submersible drill. This research has resulted in the first detailed, three-dimensional documentation of shallow submarine hydrothermal systems on arc volcanoes.

Palinuro Volcanic Complex

The Palinuro volcanic complex is one of the largest volcanoes in the Aeolian arc. It is an entirely submerged volcano that consists of several coalesced eruptive centers located along an east-west trending fault system off the coast of northern Calabria, Italy (see Figure S1 in the electronic supplement to this *Eos* issue (http://www.agu.org/eos_elec/)). The volcanic complex is bounded to the north by the continental slope of the southern Apennine Mountains and faces the Marsili back-arc basin to the south. Overall, the Palinuro volcano is 50 kilometers long and up to 22 kilometers wide at its base. The shallowest portion of the volcano rises to a water depth of less than 100 meters, forming a distinct plateau 3 kilometers in diameter.

Research at Palinuro has focused on a hydrothermal system located in a small topographic depression (~630- to 650-meter water depth) on top of one of the main volcanic edifices in the western part of the volcanic complex. The seafloor in the study area is covered by fine-grained hemipelagic or pelagic sediment with widespread patchy discolorations. Low-temperature hydrothermal activity in the area is indicated by the presence of delicate chimney-like structures composed of iron oxides and festooned with bacterial mats.

The most significant discovery during the seafloor surveys conducted in July 2006 was the occurrence of several colonies of living tube worms (Siboglinidae) in areas of warm-water venting (see Figure S2a). The existence of tube worms related to active hydrothermal venting had not previously been documented in the Mediterranean. Television-guided grab sampling at the site yielded unconsolidated but still warm sediments (up to 60°C measured on deck in recovered sediments) that emanated a strong smell of hydrogen sulfide. The microbial community hosted by the sediments was analyzed using the 16S ribosomal RNA (rRNA) gene as a phylogenetic marker. Phylogenetic analysis of the obtained sequences reveals the presence of a complex microbial community, which is typified by lineages commonly found at black smoker vents and previously undescribed lineages of bacterial 16S rRNA. The discovery of a hydrothermal vent community at Palinuro implies that life normally associated with deep-sea hydrothermal vents may be equally widespread at relatively shallow water vents on arc volcanoes.

To sample the subseafloor portion of the hydrothermal system, shallow drilling (see Figure S2b) was conducted at a closely spaced grid in the area of active fluid venting. Massive sulfides were encountered at depths from a few centimeters up to several meters below a thick cover of unconsolidated sediments. Eleven holes were drilled in an area covering 70 × 50 meters. In one hole, 4.85 meters of continuous core of massive sulfides and sulfates was recovered (see Figure S2c).

Optical microscopy and electron microprobe analysis shows that the recovered massive sulfides are composed mainly of pyrite and barite, with abundant tetrahedrite and minor sphalerite, galena, chalcopyrite, famatinite, covellite, enargite, and rare lead-antimony-sulfosalts. The mineralization is crosscut by a network of veins containing rhombohedral crystals of native sulfur. The mineralogy is distinctly different from seafloor sulfides forming at mid-ocean ridges, but it resembles that of deposits associated with hydrothermal systems in which magmatic volatiles such as carbon dioxide (CO_2) and sulfur dioxide (SO_2) are dominant [*Hannington et al.*, 2005]. Geochemical analysis of the drill core indicates that the massive sulfides at Palinuro are rich in base and precious metals, with one 4.74-meter intersection containing 1.44% copper, 0.39% lead, 0.72% zinc, 50 parts per million silver, and 0.2 parts per million gold. The sulfides are also notably enriched in highly toxic metals such as arsenic, bismuth, mercury, and antimony (T. Monecke et al., Shallow marine sulfide mineralization in the southeastern Tyrrhenian Sea, Italy, paper presented at the joint GAC-MAC-SEG-SGA Annual Meeting, Québec, Ont., Canada, 26–28 May 2008).

Panarea Hydrothermal Field

Panarea is the smallest island of the Aeolian volcanic arc (see Figure S1). Together with several islets to the east of the main island, Panarea forms a small archipelago that emerges from a nearly circular submarine platform with a shelf break at a water depth of 130 meters. This surface represents the flat summit of a submarine stratovolcano that rises more than 1200 meters above the surrounding seafloor and has a basal diameter of 20 kilometers.

The investigations at Panarea focused on the deeper portion of the platform, where water depth varies from 50 to 85 meters. A high-resolution bathymetric survey of the study area [*Esposito et al.*, 2006] previously revealed numerous circular depressions ranging from 20 meters to more than 100 meters in diameter and several meters deep. The floors of the depressions are flat and covered by unconsolidated sand and gravel. The circular depressions are typically surrounded by low-relief walls consisting of locally derived material (see Figure S2d). Because juvenile volcanic ejecta were not observed, the circular seafloor depressions are interpreted to represent craters that formed by submarine gas explosions or by collapse following intense gas venting. The abundance of these craters suggests that submarine gas explosions are a characteristic of the periodic behavior of the Panarea hydrothermal system and may therefore represent a potential volcanic hazard for the area.

Emission of gas and thermal waters is common in most of the craters (see Figure S2d), although venting also occurs outside these seafloor depressions. Eight holes drilled within these depressions encountered massive anhydrite and gypsum below the seafloor. These are interpreted to represent a cap forming at the interface between the rising geothermal waters and seawater-saturated sediments. The presence of sulfides (pyrite and marcasite with minor sphalerite and galena) infilling vugs and fractures within the massive anhydrite and gypsum indicates that the rising fluids are enriched in metals.

Implications of Hydrothermal Venting in Shallow Water

Shallow submarine volcanic arcs account for an estimated 10–15% of the global magmatic budget [*Hannington et al.*, 2005]. While the volume of submarine volcanism is small in comparison with the mid-ocean ridges, the direct input of magmatic volatiles into associated hydrothermal systems is considerably larger than at mid-ocean ridges. Evidence of widespread CO_2 and SO_2 degassing associated with shallow-water hydrothermal vents at Palinuro and Panarea suggests that direct magmatic contributions are important to both subseafloor mineralization and biological communities.

At both locations, metal accumulation occurred entirely by subseafloor replacement, with few readily identifiable surface expressions of an underlying hydrothermal system. The observed metal enrichment underscores the importance of shallow submarine geothermal activity as a potential source of toxic metals in areas extensively exploited by fishing. However, it is noteworthy that the degassing and shallow submarine hydrothermal venting in the Aeolian arc also appear to have provided a stepping-stone for colonization of the Mediterranean by vent organisms normally found on deep mid-ocean ridges.

Acknowledgments

We thank the captains, officers, and crews of R/V *Poseidon* cruise P340 and R/V *Meteor* cruise M73/2. We are also indebted to the shipboard scientific and technical parties. The research was supported by the German Research Foundation, the Leibniz Institute of Marine Sciences, and Neptune Minerals.

References

de Ronde, C. E. J., G. J. Massoth, E. T. Baker, and J. E. Lupton (2003), Submarine hydrothermal venting related to volcanic arcs, *Spec. Publ. Soc. Econ. Geol., 10*, 91–110.

Esposito, A., G. Giordano, and M. Anzidei (2006), The 2002–2003 submarine gas eruption at Panarea volcano (Aeolian Islands, Italy): Volcanology of the seafloor and implications for the hazard scenario, *Mar. Geol., 227*(1-2), 119–134.

Hannington, M. D., C. E. J. de Ronde, and S. Petersen (2005), Sea-floor tectonics and submarine hydrothermal systems, in *Economic Geology 100th Anniversary Volume*, edited by J. W. Hedenquist et al., pp. 111–141, Soc. of Econ. Geol., Littleton, Colo.

—Thomas Monecke, Colorado School of Mines, Golden; E-mail: tmonecke@mines.edu; Sven Petersen, Klas Lackschewitz, and Michael Hügler, Leibniz Institute of Marine Sciences at the University of Kiel, Kiel, Germany; Mark D. Hannington, University of Ottawa, Ontario, Canada; and J. Bruce Gemmell, University of Tasmania, Hobart, Australia

---

FORUM

Do We Need Better Predictions to Adapt to a Changing Climate?

PAGES 111–112

Many scientists have called for a substantial new investment in climate modeling to increase the accuracy, precision, and reliability of climate predictions. Such investments are often justified by asserting that failure to improve predictions will prevent society from adapting successfully to changing climate. This Forum questions these claims, suggests limits to predictability, and argues that society can (and indeed must) make effective adaptation decisions in the absence of accurate and precise climate predictions.

Climate Prediction for Decision Making

There is no doubt that climate science has proved vital in detecting and attributing past and current changes in the climate system and in projecting potential long-term future changes based on scenarios of greenhouse gas emissions and other forcings. The ability of climate models to reproduce the time evolution of observed global mean temperature has given the models much credibility. Advances in scientific understanding and in computational resources have increased the trustworthiness of model projections of future climates.

Many climate scientists, science funding agencies, and decision makers now argue that further quantification of prediction uncertainties and more accuracy and precision in assessments of future climate change are necessary to develop effective adaptation strategies. For instance, the statement for the May 2008 World Modelling Summit for Climate Prediction (http://wcrp.ipsl.jussieu.fr/Workshops/ModellingSummit/Documents/FinalSummitStat_6_6.pdf) argues that "climate models will, as in the past, play an important, and perhaps central, role in guiding the trillion dollar decisions that the peoples, governments and industries of the world will be making to cope with the consequences of changing climate." The statement calls for a revolution in climate prediction because society needs it and because it is possible. The summit statement argues that such a revolution "is necessary because adaptation strategies require more accurate and reliable predictions of regional weather and climate extreme events than are possible with the current generation of climate models." It states that such a revolution is possible because of advances in scientific understanding and computational power.

If true, such claims place a high premium on accurate and precise climate predictions at a range of geographical and temporal scales as a key element of decision making related to climate adaptation. Under this line of reasoning, such predictions become indispensable to, and indeed are a prerequisite for, effective adaptation decision making. Until such investments come to fruition, according to this line of reasoning, effective adaptation will be hampered by the uncertainties and imprecision that characterize current climate predictions.

Limits of Climate Prediction

Yet the accuracy of climate predictions is limited by fundamental, irreducible uncertainties. For climate prediction, uncertainties can arise from limitations in knowledge (e.g., cloud physics), from randomness (e.g., due to the chaotic nature of the climate system), and from human actions (e.g., future greenhouse gas emissions). Some of these uncertainties can be quantified, but many simply cannot, leaving some level of irreducible ignorance in our understanding of future climate.

An explosion of uncertainty arises when a climate change impact assessment aims to inform national and local adaptation decisions, because uncertainties accumulate from the various levels of the assessment. Climate impact assessments undertaken for the purposes of adaptation decisions (sometimes called end-to-end analyses) propagate these uncertainties and generate large uncertainty ranges in climate impacts. These studies also find that the impacts are highly conditional on assumptions made in the assessment, for example, with respect to weightings of global climate models (GCMs)—according to some criteria, such as performance against past observations—or to the combination of GCMs used.

Future prospects for reducing these large uncertainties remain limited for several reasons. Computational restrictions have thus far restricted the uncertainty space explored in model simulations, so uncertainty in climate predictions may well increase even as computational power increases. The search for objective constraints with which to reduce the uncertainty in regional predictions has proven elusive. The problem of equifinality (sometimes also called the problem of "model identifiability")—that different model structures and different parameter sets of a model can produce similar observed behavior of the system under study—has rarely been addressed. Furthermore, current projections suggest that the Earth's climate may soon enter a regime dissimilar to any seen for millions of years and one for which paleoclimate evidence is sparse. Model projections of future climate therefore represent extrapolations into states of the Earth system that have never before been experienced by humanity, making it impossible to either calibrate the model for the forecast regime of interest or confirm the usefulness of the forecasting process.