Interactions between fluids, minerals, and organisms in sulfur-dominated hydrothermal vents in the eastern Manus Basin, Papua New Guinea – A report from RV *Sonne* Cruise 216

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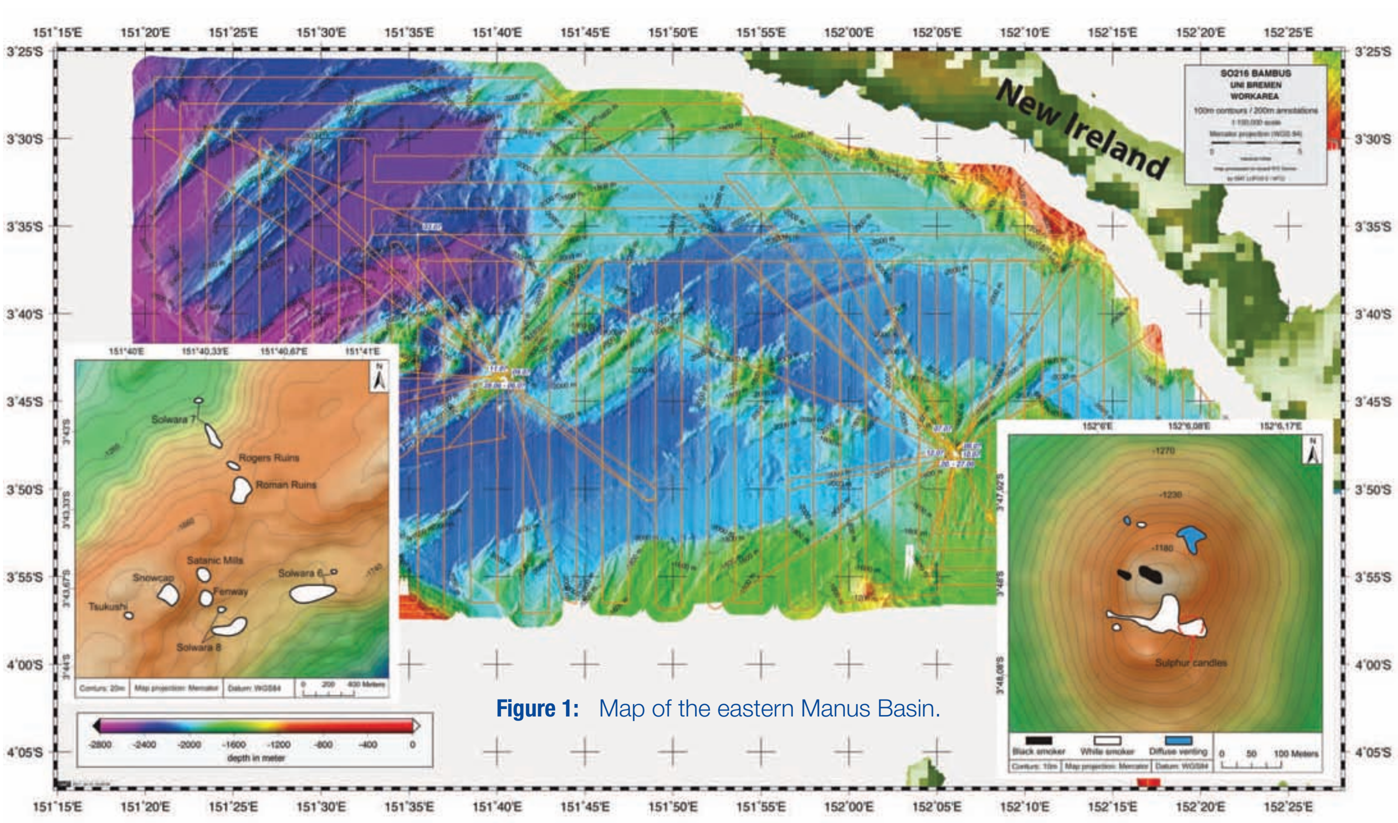

Figure 1: Map of the eastern Manus Basin.

Background

Magma-hydrothermal systems in backarc basins are variably affected by slab-derived flux. The Manus Basin is located in a tectonically particularly active area and exhibits frequent neovolcanic centers of extreme geochemical variability (Sinton et al., 2003). Intense hydrothermal activity in water depth of 1200-1700 m has been observed at many of these volcanic structures, in particular in the Eastern Manus Basin.

The PACMANUS (PacificAustraliaCanadaManus) hydrothermal area – situated on the dacitic to rhyodacitic Pual Ridge and comprising numerous hydrothermal fields – was discovered roughly 20 years ago (Binns and Scott, 1993). Additional French, German and Australian expeditions sampled sulfides and drill cores from the PACMANUS area. The sulfide accumulations were found to be rich in copper and gold (Moss and Scott, 2001) and it was argued that PACMANUS might be a modern analogue of volcanogenic massive sulfide deposits. To test this hypothesis, the PACMANUS field was drilled during Leg 193 of the Ocean Drilling Program, with boreholes reaching as deep as 387 m below the seafloor (Binns et al., 2002). In the mid-1990s, occurrences of sulfide, sulfur, and bleached felsic rock had been observed in the SuSu Knolls area by dredge and TV-sled surveys. Suzette, the northernmost edifice of SuSu Knolls,

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corresponds to the Solwara1 mining target of Nautilus Minerals. The cone-shaped North Su volcano south of Suzette features large accumulations of sulfur and abundant rock bleaching resulting from acid-sulfate fluid venting. In close proximity to these sulfuric acid vents, black smoker type systems were observed (Tivey et al., 2006). The reasons behind the large range in style and composition of hydrothermal venting and the consequences of this variability for life at these vents remain poorly identified.

Cruise report

We report on the most recent expedition to the Manus Basin, the primary goal of which was ROV-based sampling of hydrothermal systems in the eastern Manus Basin. Cruise SO216 of the German RV *Sonne* took place between June 14th and July 23rd, 2011. The cruise was a follow-up on an RV *Melville* cruise with ROV *Jason2* in 2006, when geophysical mapping, rock sampling and reconnaissance fluid sampling were the primary goals (Tivey et al., 2006; Craddock et al., 2010; Reeves et al., 2011). The specific focus of the SO216 cruise was on vent fluid and biota sampling. The two working areas comprised North Su at 3°48.0'S, 152°06.05'E in about 1200 m water depth and PACMANUS at 3°43.5'S, 151°40.4'E in ~1700 m water depth. During nightly echosounding surveys with the ship-based EM-120 system, a comprehensive and detailed map of the eastern Manus Basin could be completed (Fig. 1). Twenty-two dives with the ROV *MARUM Quest 4000m* were conducted, ten in the PACMANUS and twelve in the North Su area. Samples collected include hydrothermal fluids (using isobaric gas-tight 'Seewald' samplers and teflon KIPS bottles), biological specimen of vent macrofauna, microbial filaments and biofilms, as well as volcanic rocks and hydrothermal precipitates. A range of vent systems was sampled in both working areas (Fig. 1). Geological mapping was carried out throughout the dives, and sections of some dives were specifically committed to mapping certain structures.

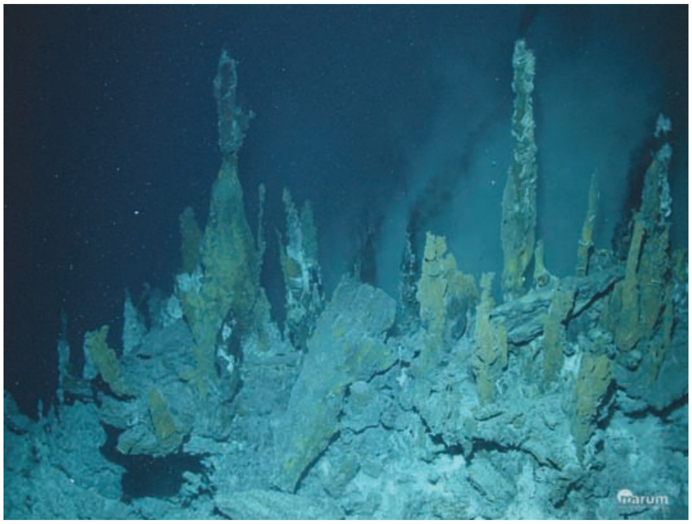

Figure 2: Black smokers at North Su.

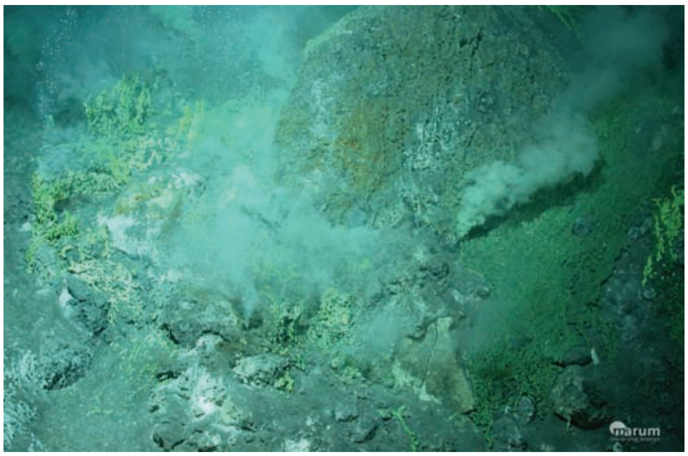

Figure 3: White smokers in the Sulfur Candles area.

A summary of the preliminary observations is provided here. This report supersedes a communication in the previous issue of InterRidge News by Adam Schaen, whose account of participation in SO216 with an InterRidge travel bursary was inadvertently published as the cruise report. A detailed cruise report can be downloaded from:
http://elib.suub.uni-bremen.de/edocs/00102250-1.pdf.

North Su

The North Su volcano host countless hydrothermal vent sites, which fall into three categories: (i) black smoker vents, (ii) white smoker vents, and (iii) diffuse vents. While the black smokers cluster in the summit area, white smoker vents are common in a 120 m long and 50 m wide, east-west-trending area south of the main summit. The dense coverage with thick white smoke (most likely made up of sulfur particles) renders mapping and sampling in this area particularly challenging.

The black smokers are up to 9 m high spires and occur in water depths ranging from 1150 to 1200 m (Fig. 2). They show an inner lining of dense chalcopyrite, surrounded by a pyrite-sphalerite-rich outer layer and a Fe-Mn-oxide coating. In the westernmost extension of the black smoker clusters, a vent at 1190 m water depth was found, which shows flashing typical of fluid boiling. The temperatures measured (332°C max.) correspond to the boiling temperature of seawater at 124 bar. The chimneys at the summit are hosted mainly in volcanic ash, which is often cemented by barite to form hard slabs. Where these slabs are broken up, clear fluids vent at the seafloor. More fluid seepage has been observed in numerous locations downslope, in particular in large patches of diffuse venting 90 m northeast of the summit in 1200 m water depth. This site features a diverse fauna (snails, mussels, tubeworms, fish, barnacles), which is associated with the venting of 14-30°C warm fluids through fans of poorly sorted talus.

A prominent ash cone is located 100 m south of the summit and features numerous small craters on the top and smooth flanks with more blocky pyroclastic deposits. The cratered summit features extensive white staining and currents have created ripples in the fine ash. This cone was not observed when North Su was mapped during the Magellan cruise in 2006. The new ash cone buried steep walls and talus slopes with countless white smoker vents, some of which were sampled in 2006.

The newly discovered Sulfur Candles area is the easternmost and most spectacular of the white smoker clusters. It features hundreds of white smoker vents, many of which also emanate what appears to be gas bubbles, but is likely liquid CO_2 (Fig. 3). We hypothesize that the slowly rising bubbles contain liquid CO_2, forming when the temperature drops below 31°C. At 3°C (ambient temperature at 1200 m depth), liquid CO_2 converts to CO_2-clathrate at the interface with seawater. This behavior was documented by collection of liquid CO_2 bubbles at Sulfur Candles. Prominent bubble flares were also visualized using the ship-based Parasound system. The Sulfur Candles site is situated in volcaniclastic sediments, which are impregnated with liquid sulfur around the vents. The sulfur is exuded when water and bubbles vent at the seafloor where it forms sub-meter-high, chimney-like structures (Fig. 3). The sulfur chimneys grow fast (in minutes), but do not grow tall. Most of the sulfur is hence not located in chimneys. Additional sulfur trickles downslope and pools in certain areas, where it forms dense aggregates composed of thousands of anastomosing sulfur fingers that coalesced to meter-thick irregular pods and flows.

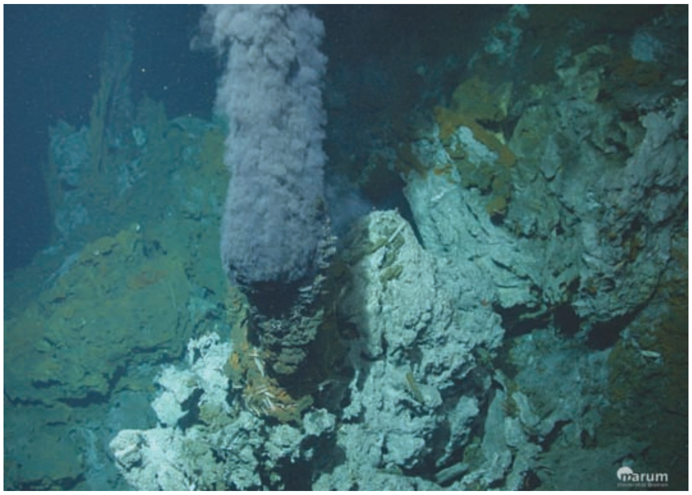

Figure 4: Venting at Big Papi, in the Fenway hydrothermal field.

PACMANUS

The PACMANUS hydrothermal area comprises several hydrothermal vent sites on the Pual Ridge in a 2.5 km^2 area in 1640 to 1780 m water depth (Fig. 1). The Fenway, Snowcap, Tsukushi, Satanic Mills, Roman Ruins, and Roger's Ruins hydrothermal vent sites were visited. Nautilus Minerals discovered additional hydrothermal vent sites in the area (Solwara 6, 7, and 8), from which we collected first high-temperature fluid samples.

The Fenway hydrothermal field comprises an anhydrite-hosted black smoker complex (Big Papi), two small chimney clusters 50 m northeast and northwest of Big Papi, and a large patch of diffuse venting in the northern part. Big Papi vents 304°C black smoker fluids through sparse chimneys around the base of the anhydrite mound (Fig. 4). The activity of venting is much weaker than in 2006, when boiling (358°C) black smoker fluids emanated from countless orifices at the mound's summit. The Fenway hydrothermal mound is partly collapsed and covered with anhydrite blocks and sand. Through these deposits, venting of 70-110°C hot, clear fluids occurs and several fluid samples were collected. The sulfide chimney at Fenway exhibits a thick chalcopyrite lining and outer parts that are rich in sphalerite and marcasite with a Mn/Fe-oxide coating. Fenway is hosted predominantly in fine pyroclastic sediment, in particular the diffuse patch north of Big Papi. That area was a focus point of biological sampling and Symcatcher incubation experiments. It features snails (mainly *Ifremeria nautilei*), mussels (*Bathymodiolus manusensi*) and several species of tubeworms, commonly in a patchy style of distribution.

Solwara 8 is located 300 m southeast of Big Papi and features clusters of up to 12 m high and Cu-rich chimneys and porous, more bulbous Zn-rich ones. We recorded a temperature of 304°C when sampling fluid venting from a chalcopyrite-lined orifice sticking out of a beehive structure.

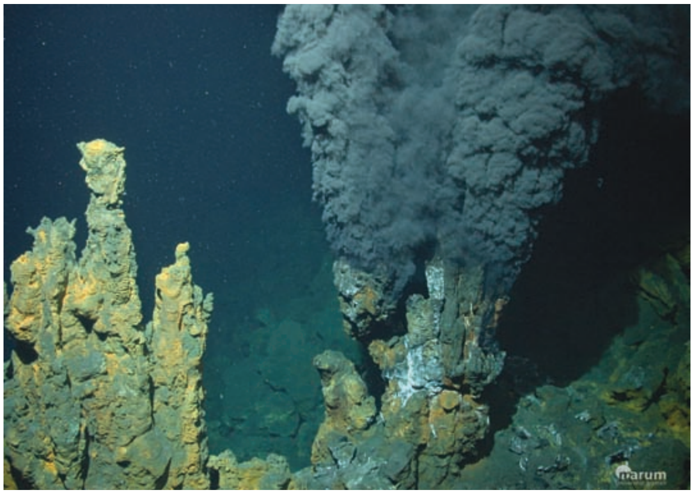

Figure 5: Vigorous venting of black smoker fluids at Solwara 7.

The top of the Snowcap knoll is decorated with countless patches of diffuse fluid seepage. Two reentry funnels mark the ODP Site 1188 drilled to depths up to 387 m in 2000. On the northwestern side of Snowcap lies a small field of sulfide chimneys (variably Cu- and Zn-rich) populated with snails and Paralvinella. These chimneys vent clear to light gray fluids with temperatures of ≤224°C, but the presence of abundant dense chalcopyrite suggests higher venting temperatures in the past. Immediately southwest of the chimney cluster is a mound of native sulfur, which is densely populated by snails and is surrounded by sediments.

Satanic Mills features numerous clusters of sulfide chimneys; the largest one extends for 60 m from north to south and is about 10 to 15 m wide. The chimneys grow directly on top of fresh block lava, in particular near flow fronts of lava with little chimney debris lying around. Fluid temperatures up to 345°C and local CO_2 bubbling were observed. Tsukushi was relatively inactive, though venting of moderate-temperature clear fluids and oxide mounds were observed, similar to 2006.

Roman Ruins, Roger's Ruins, and Solwara 6 and 7 form a northwest-southeast trending line, roughly perpendicular to the strike of Pual Ridge. Solwara 7 is hosted in a field of block lava and consists of a 50-m diameter main cluster of vents and a smaller accumulation of active chimneys just south of it. The highest temperature of venting (348°C) was measured here in vigorously venting black smoker fluids issuing from a small chimney that grows on top of sulfide rubble (Fig. 5). Roger's Ruins, located 200 m southeast of Solwara 7, comprises a small cluster of mostly inactive vents. Its activity was much greater in 2006, in particular in the area of Marker 8, which was very active in 2006, but appeared inactive in 2011. Extensive areas around Roman Ruins are covered with Fe-oxyhydroxide deposits that occasionally form chimneys. Although there is abundant venting of shimmering water through these mounds, no macrofauna could be observed here. The northeastern part of Roman Ruins is mostly inactive, in contrast to the situation in 2006, when lots of black smoker activity was observed there. The central part of Roman Ruins features copious amounts of sulfide chimney rubble, which is exposed on the southeastern flank of the ridge with the active black smokers. In contrast, the southwestern extension of Roman Ruins has volcanic rock talus exposed on the slopes. This part is also more hydrothermally active than the northeastern end of the field. The area between Roman Ruins and Solwara 6 is covered by variably sedimented block lava. Solwara 6 is also situated in block lava flows. There are a few inactive chimneys in the western part of the system; other areas show diffuse venting. Nautilus Minerals reported more activity in this area during their 2007 survey, including active black smokers.

Summary and outlook

The hydrothermal systems in the eastern Manus Basin reveal an extraordinary variability in fluid chemistry, both on a spatial and on a temporal scale. This variability is obviously tied to the changes in magmatic activity including magma degassing of SO^2 and CO^2. At North Su, we were able to document a volcanic eruption that must have happened between 2006 and 2011 and led to a drastic change in the location and style of acid-sulfate fluid venting. At PACMANUS, activity, temperatures and gas contents of fluids have undergone marked changes since 2006.

With the samples collected, we will address a number of questions: What are the gas-water-rock interactions and fluid mixing processes in the subsurface and how do they mediate mass flux to the seafloor? What energy sources in volcanic magma-hydrothermal systems reach the seafloor and how are they used by microorganisms? And how do they determine the physico-chemical environment of the vent fauna? Moreover, we would like to know how the different chemical compositions of vent fluids influence the composition of biocoenoses. What are the dominant metabolic reactions in the different habitats and how much biomass can potentially be produced? Finally, we will investigate what kinds of symbiotic relationships have evolved within the different hydrothermal systems of the Eastern Manus Basin and how they are influenced by the variable fluid chemistry. Characterization of sulfur species in fluids, with emphasis on sulfur redox intermediates and their roles as electron donors and/or as electron acceptors for microbial growth is another goal of post-cruise studies. We are also interested in learning what sulfur-oxidizing asymbiotic microorganisms dominate the geochemically distinct diffuse vents and how they fix carbon.

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