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MONITORING THE GROWTH OF MINERAL DEPOSITS ABOVE ARTIFICIAL HYDROTHERMAL VENTS ON THE SEAFLOOR

Chimney-like structures that vigorously discharge hot fluid at 300–350 °C with billowing "smoke" from their tops are found in active seafloor hydrothermal fields. Although chimneys themselves are not economically important mineral deposits in terms of size and ore grade, mineralogical studies enable us to construct genetic models to explain how submarine mineral deposits are initiated and how they grow (e.g. Hannington et al. 1995). The earliest stage in the formation of a chimney wall involves the rapid precipitation of Ca-sulfate around a jet of hot fluid above the vent orifice by turbulent mixing with ambient cold seawater. During the mixing process, metal sulfides (e.g. zinc, iron, and copper–iron sulfides) also precipitate because the solubility of metal elements drastically drops as the fluid temperature decreases. Whereas most of the fine-grained sulfide particles are dispersed as "smoke," some particles are trapped within and between grains of anhydrite in the nascent chimney wall. Over time, the accumulation of metal-sulfide minerals alters the original white anhydrite chimney and turns it a gray to black color. In the process, the porous and fragile chimney wall starts to solidify.

We had an opportunity to study chimney growth above the scientific boreholes that vented hot fluids in the Iheya-North field, middle Okinawa Trough, East China Sea. The scientific drillings were undertaken by the Integrated Ocean Drilling Program (IODP) during Expedition 331 from September to October in 2010. Some drillings successfully reached a hydrothermal reservoir through its cap rock layer. This led to the formation of four artificial hydrothermal vents in the boreholes (Takai et al. 2011). Subsequent visits (several months and about one year after the drilling) used a remotely operated vehicle to document the growth of infant chimneys and collect samples of the mineral deposits (Kawagucci et al. 2013; Nozaki et al. 2016). At the borehole that had been drilled on top of the 30 m high hydrothermal mound known as North Big Chimney (NBC), the fluid was as hot as 310 °C and chimney growth was rapid. This chimney grew continuously to a height of 15 m within 25 months, even though the upper part was broken twice during the ROV visits (Fig. 1).

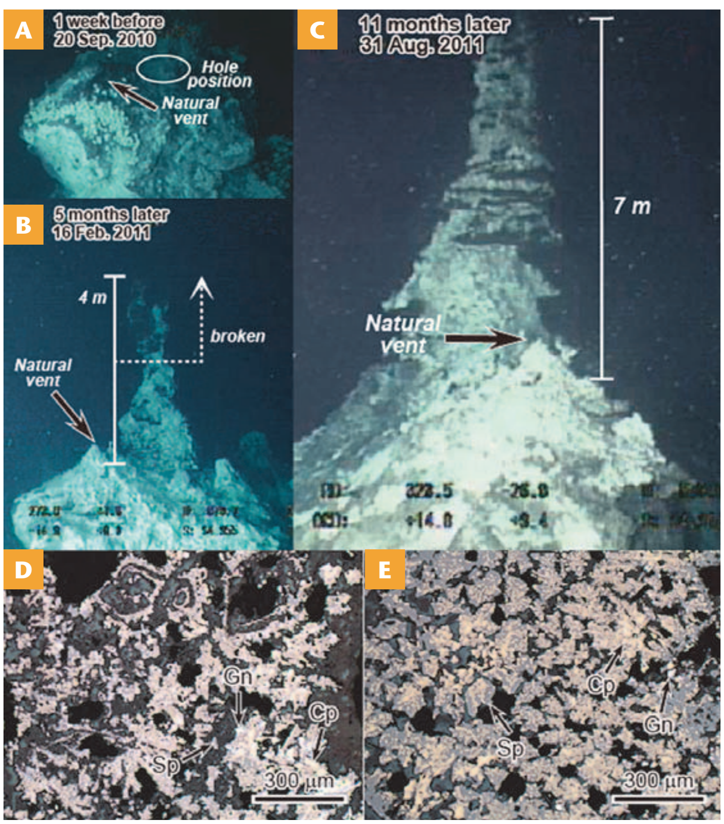

Figure 1 Artificially created hydrothermal vent in the Okinawa Trough, western Pacific. (**A, B and C**) Rapid vent growth, indicated by dates on photos A–C, of the chimney on the artificial hydrothermal vent above the North Big Chimney mound. (**D and E**) Representative photomicrographs of the chimney's mineralogy and textures, taken under reflected light. Cp (chalcopyrite), Gn (galena), Sp (sphalerite) (Nozaki et al. 2016).

Two of the infant chimneys were dominated by Ca-sulfate minerals, but five other infant chimneys consisted mainly of sulfide minerals. Among the former samples, the sulfate minerals were commonly replaced, or overgrown, by sulfide minerals (Fig. 2). This supports the traditional concept of how chimneys grow. The latter samples exhibited mineralogical zoning: sulfide-rich inner layers and sulfate-rich outer layers, suggesting an ongoing metal accumulation process. Relatively rare mineral occurrences and textures of terrestrial Kuroko-type ore were commonly observed (Fig. 2). Elemental abundance of the major metals (Zn, Cu, Pb, Fe) in some sulfide-rich chimneys is comparable to that of the high-grade Cu–Pb–Zn bodies on land, albeit the As and Sb concentrations are relatively low.

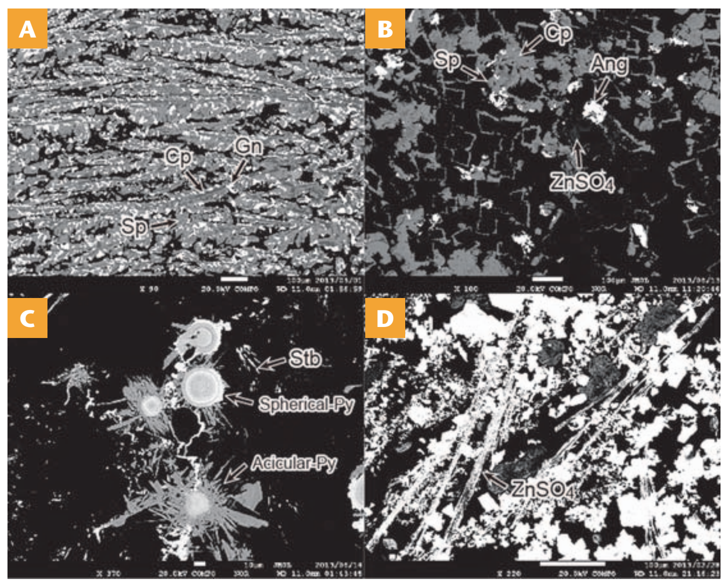

Figure 2 Representative back scatter electron images of sections from the infant artificial hydrothermal vent chimneys. (**A**) Dendritic chalcopyrite (Cp), sphalerite (Sp), and galena (Gn). (**B**) Encrustation and pseudomorph textures of the sulfide minerals after sulfate minerals. Ang (anglesite). (**C**) Spherical pyrite (Py) crystals showing chemical zoning; these are restricted to the outermost parts of the sulfide-rich chimney. Also present is stilbite (Stb). (**D**) Acicular unidentified Zn-sulfate minerals in the outer part of the infant chimney (Nozaki et al. 2016).

These observations suggest the possibility of exploiting the seafloor sulfide deposits (Fig. 3). The sulfide-rich part of the artificial NBC chimney grew to a total mass of 82.3 tons at a rate of ~40 tons per year (Nozaki et al. 2016). This rapid accumulation rate is due to the extremely large hydrothermal vent (more than 50 cm in diameter) that had been created artificially by the borehole, with a consequence that there was slow mixing with the ambient cold seawater so enhancing the efficiency of sulfide deposition. If this is the case, controlling a vent's

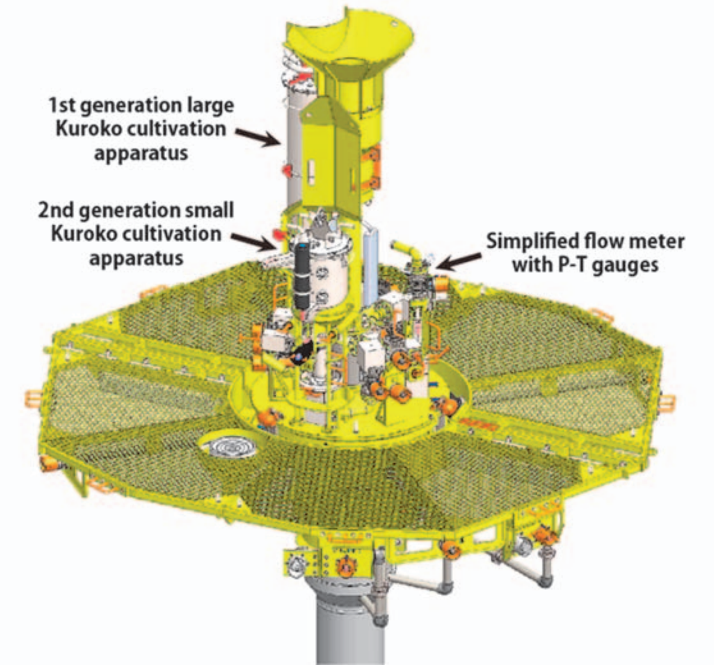

FIGURE 3 Diagram of the Kuroko cultivation apparatus due to be installed in the artificial vents at the North Big Chimney mound in February 2016.

growth, and its ore grades, by mixing and quenching the hydrothermal fluids with ambient seawater would contribute to the effective recovery of mineral resources from hydrothermal fluids. In order to test this idea, we are going to install an apparatus in the artificial hydrothermal vents (FIG. 3). It consists of a system that regulates the hot fluid flow rate, secures the path and space for mineral deposition, and carries sensor loggers for observing the secular changes in the pressure, temperature, and flow rate of the hydrothermal fluid, and it can weigh the minerals precipitated within the hollow space in the cell. This apparatus is due to be deployed during the *D/V CHIKYU* cruise, which is scheduled for February 2016, and that will be recovered after one year. We very much look forward to seeing the results of this experiment.

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JOURNAL OF MINERALOGICAL AND PETROLOGICAL SCIENCES

Vol. 111, No. 1, February 2016

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FIVE YEARS AFTER THE NUCLEAR DISASTER IN FUKUSHIMA

Five years ago (March 2011), the Great East Japan earthquake struck the Tohoku district causing 19,335 deaths; 2,600 people are still missing. The resulting Fukushima Daiichi nuclear disaster released ~520 PBq of radionuclides, forcing residents to evacuate miles away from the contaminated area. Surface environment contamination by radioactive ^{137}Cs has been a serious issue and will continue to be an issue for decades due to the long half-life (30.07 years) of ^{137}Cs. To date, decontamination has generated tons of bags of Cs-contaminated wastes, which need to be stored safely until the dose decreases to background levels. Various long-term issues still remain in Fukushima including the tritium-contaminated water in storage tanks. Currently, decommissioning of units 1–4 is the most challenging issue due to the high-radiation levels in the reactors. Decommissioning is projected to take ~40 years or longer. Many of us will not be alive when all the issues are finally resolved. However, we can make scientific contributions to partially solve these issues now and, more importantly, we can share our scientific knowledge with younger scientists who will be responsible for mediating these difficult issues in the future.