Chemical Geology 438 (2016) 36–57

Contents lists available at ScienceDirect

Chemical Geology

journal homepage: www.elsevier.com/locate/chemgeo

Enargite-luzonite hydrothermal vents in Manus Back-Arc Basin: submarine analogues of high-sulfidation epithermal mineralization

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A R T I C L E I N F O

Article history:
Received 20 January 2016
Received in revised form 16 May 2016
Accepted 22 May 2016
Available online 24 May 2016

Keywords:
Enargite
Epithermal
Hydrothermal vent
Luzonite
S—Cu isotopes
Seafloor

A B S T R A C T

Active and inactive hydrothermal chimneys composed almost entirely of enargite and luzonite, rare minerals in seafloor hydrothermal deposits, were found at the summits of two submarine volcanoes, North Su and Kaia Natai, in the Manus Back-Arc Basin. Detailed mineralogical and geochemical studies revealed that most probably these deposits precipitated at T = 200°–330 °C and high fS_2. The negative $\delta^{34}S$ values (−8.58 to −3.70‰) of the enargite-luzonite are best explained by disproportionation reactions of magmatic SO_2 and suggest that the high fS_2 is likely provided by direct magmatic input of SO_2 into the hydrothermal system. Fractionation of Cu stable isotopes during the precipitation of enargite-luzonite ($\delta^{65}Cu$ ranges from −0.20 to +0.35‰) is inferred to be associated with either Rayleigh-type fractionation, or redox processes (Cu^+ oxidation to Cu^{2+}) and the mass balance of dissolved Cu^+ and Cu^{2+} species in the hydrothermal fluid. The trace element composition of enargite and luzonite indicates a temporal fluctuation of the chemistry of the ore-forming fluid with an increase of Fe, Ga, Tl, Au, Hg, Pb and Ag, and decrease of Sb, Sn, Te, Ge and V concentrations with time and points out that this type of deposits is the richest in Au (average 11.9 ppm) and Te (average 169 ppm) among all other types of seafloor metal deposits.

In addition to the widespread inorganic precipitation of enargite and luzonite in this setting, there is evidence that this mineralization may be biogenically mediated on the external surfaces of the active vents. Fungi-like filaments mineralized by luzonite imply that the fungi (Dikarya subkingdom) may be implicated in a mechanism of bio-sequestration of As, S and Cu, and provide the initial substrate for luzonite precipitation.

The studied enargite-luzonite deposits have characteristics similar to those of subaerial high-sulfidation epithermal mineralization: back-arc basin setting; acid-sulfate and boiling ore-forming fluids; altered (advanced argillic stage) dacitic host rocks; major enargite-luzonite and minor pyrite, barite and S^0; $\delta^{34}S < 0‰$. Therefore, they may be considered as submarine analogues of subaerial high-sulfidation epithermal deposits with the potential for concealed porphyry Cu(—Au) mineralization at depth.

1. Introduction

The mineralogical composition of seafloor hydrothermal deposits has been increasingly well characterized (e.g., Haymon and Kastner, 1981; Oudin, 1983; Koski et al., 1984, 1988; Fouquet et al., 1988, 1993a,b, 2010; Hannington et al., 1991; Iizasa et al., 1999; Rouxel et al., 2004a; Webber et al., 2015). Although these investigations recognize distinct mineralogical differences among hydrothermal deposits formed at mid-ocean ridges (MOR) (sedimented and unsedimented), volcanic arcs and back-arc spreading centers, they show that most seafloor hydrothermal deposits are composed of relatively simple mineral assemblages. Iron-, Cu- and Zn-sulfides, and Ca- and Ba-sulfates are the main constituents of these deposits, whereas silicates,

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http://dx.doi.org/10.1016/j.chemgeo.2016.05.021
0009-2541/

oxyhydroxides, carbonates and sulfosalts are minor phases (Herzig and Hannington, 1995). Therefore, hydrothermal chimneys and mounds composed almost entirely of one mineral considered to be minor in seafloor hydrothermal deposits, like native sulfur (Chen et al., 2005), silica (Herzig et al., 1988) or talc (Hodgkinson et al., 2015), attract special scientific interest because this type of deposits testifies for uncommon conditions of precipitation (T, P, pH, Eh, ion activity and speciation) over time. Enargite (Cu_3AsS_4) and its polymorph luzonite are minor minerals in seafloor hydrothermal deposits mainly reported from volcanic arc and back-arc settings (Halbach et al., 1993; Lüders et al., 2001; Dekov and Savelli, 2004; Petersen et al., 2004, 2014; Rouxel et al., 2004b; de Ronde et al., 2005; Suzuki et al., 2008; Fouquet et al., 2010; Alfieris et al., 2013).

We investigated the mineralogy and geochemistry (including S- and Cu-isotope composition) of active and inactive hydrothermal vents composed almost entirely of the Cu-sulphosalt (enargite-luzonite) assemblage from a back-arc basin (BAB) setting and address their conditions of precipitation and potential importance in terms of both the genesis and mineral exploration of seafloor hydrothermal deposits.

2. Geologic setting

Hydrothermal deposits were recovered from two seafloor hydrothermal fields (North Su and Kaia Natai) situated in an intra-oceanic back-arc spreading setting: East Manus Basin (Fig. 1, Table 1). The Manus Back-Arc Basin is structurally bound by the inactive Manus-Kilinailau and active New Britain subduction zones and floored by North and South Bismarck microplates (Fig. 1). The active spreading in the Manus Basin occurs at three successive ridge segment offsets by the Willaumez, Djaul and Weitin transform faults (from west to east) (Fig. 1). Recent hydrothermal activity has been documented at the Manus spreading center and in the East Manus Basin (Scott and Binns, 1995; Bach et al., 2003; Roberts et al., 2003; Vanko et al., 2004; Binns, 2006; Binns et al., 2007; Craddock et al., 2010; Reeves et al., 2011). East Manus Basin (between the Djaul and Weitin transform faults) is an active transform zone within island-arc crust formed during previous subduction of the Pacific Plate under the New Ireland Arc (Taylor, 1979; Binns and Scott, 1993; Martinez and Taylor, 1996). Magmatic activity associated with the incipient rifting of felsic crust has produced a series of volcanic ridges composed of a wide range of lavas (from basalts to rhyodacites) showing strong geochemical arc affinities (Binns and Scott, 1993; Sinton et al., 2003). Several large hydrothermal systems have been discovered in the East Manus Basin (Binns and Scott, 1993; Scott and Binns, 1995; Gamo et al., 1997; Ishibashi et al., 1997; Bach et al., 2003; Roberts et al., 2003; Vanko et al., 2004; Binns, 2006; Binns et al., 2007; Craddock et al., 2010; Reeves et al., 2011). Three porphyritic dacite domes, known as the SuSu Knolls comprising three vent fields (Suzette, North Su and South Su), are situated in the East Manus Basin. The middle seamount of this series, North Su, is hydrothermally active with many black and white smokers, diffuse venting and numerous relict chimneys (Fig. 1). Kaia Natai is another submarine volcano, which is situated ~10 km east of the SuSu Knolls (Fig. 1). An inactive hydrothermal field covers its summit and upper part of the southeastern slope.

3. Samples and methods of investigation

3.1. Samples

We investigated three samples consisting dominantly of enargite and luzonite from three vent sites at two seafloor hydrothermal fields: North Su and Kaia Natai (Table 1). The samples were collected during the R/V *L'Atalante* cruise Manaute (2000) using the Deep Submersible Vehicle (DSV) *Nautile* (two samples) and during the R/V *Melville* cruise MGLN06MV (2006) using the Remotely Operated Vehicle (ROV) *Jason* (one sample) (Table 1). One of the samples was a part of an active flange with pooled fluid (buoyant hydrothermal fluid entrapped beneath the flange, underlain by colder and denser seawater) with a temperature

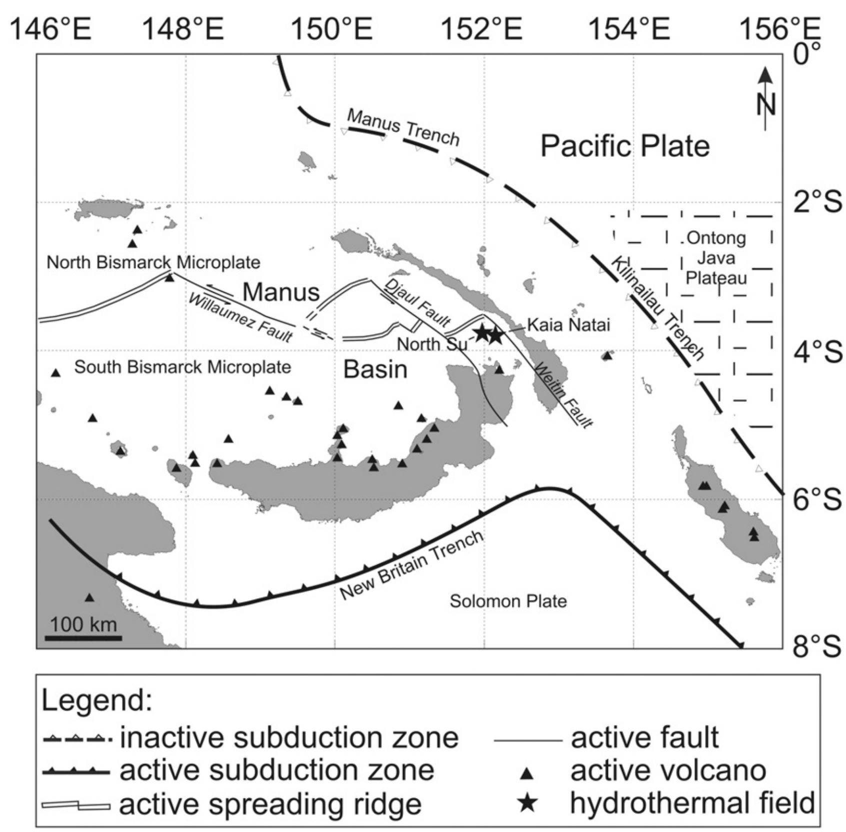

Fig. 1. Schematic map of the Manus Back-Arc Basin (SW Pacific) with North Su and Kaia Natai hydrothermal fields.