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Pb and other ore metals in modern seafloor tectonic environments: Evidence from melt inclusions

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Abstract

Many modern seafloor tectonic environments are host to hydrothermal systems and associated polymetallic sulfide deposits. Metal transport and precipitation are controlled by magmatic processes such as pre-eruptive degassing and the hydrothermal cycle. The original availability of Pb and other ore metals in a given setting is dependent on concentrations in the original magmatic source or additional enrichment processes. We have examined the Pb budget of melt inclusions from nine modern seafloor settings representing back-arcs, mid-ocean ridges and seamounts. Melt inclusions provide information on the characteristics of parental magmas, including insights into metal budgets. Trace element data in melt inclusions hosted in plagioclase, olivine and pyroxene were obtained by laser-ablation inductively-coupled mass-spectrometry.

Results from back-arcs emphasize the impact of slab-subduction and dehydration processes on the chemical characteristics of generated magmas. Volatile- and fluid-mobile element-rich melt inclusions at Manus basin and Okinawa trough reflect a robust contribution of elements from the subducting slab as evidenced by relatively low Ce/Pb ratios. At Bransfield strait, on the other hand, melt inclusions are volatile poor, and fluid-mobile element ratios are similar to mid-ocean ridge values indicating little or no contribution from the slab. High Cu concentrations at Manus basin and Okinawa trough can be explained by fluxing of ferric iron from the subducting slab benefiting the production of sulfate over sulfide.

Metal budgets for seamounts located on and nearby the axis of mid-ocean ridge segments appear to be independent of any input of mantle plume material. Results from the southern Explorer ridge (strong lower mantle influence, transitional- and enriched-MORBs), Pito and Axial seamounts (moderate lower mantle influence, transitional-MORBs) and a Foundation near-ridge seamount (little to no mantle influence, normal-MORB) show that, despite similar tectonic environments and varying contributions of mantle plume material, Cu, Zn and Pb values do not vary significantly between the enriched and non-enriched magma components of a given setting.
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Keywords: Pb; melt inclusions; LA-ICP-MS; back-arcs; mid-ocean ridges; seamounts

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1. Introduction

Melt inclusions have emerged as a significant tool for the study of magma genesis in modern seafloor environments. They are commonly used to provide insight into the characteristics of magmas prior to the influences of processes such as mixing and degassing. Melt inclusion chemistry can be used to reconstruct the evolution of host magmas through the interpretation of various element patterns (Sobolev and Shimizu, 1994; Sours-Page et al., 1999). These patterns define the compositions of erupted lavas including the concentration of metals that may be a potential source of hydrothermal sulfide deposits.

Many recent studies have examined melt inclusions in specific tectonic settings with an emphasis on the relationships between spreading rate and chemical variability, mantle temperature and crustal thickness (e.g., Sobolev et al., 1992; Sinton et al., 1993; Sobolev and Shimizu, 1993; Sobolev et al., 1994; Sobolev and Shimizu, 1994; Nielsen et al., 1995; Sours-Page et al., 1999; Shimizu et al., 2000; Michael et al., 2002). This study compares melt inclusion compositions from 9 different modern seafloor sites representing 4 different tectonic settings in an examination of magma ore metal budgets and their viability to be a metal source for hydrothermal sulfide deposits.

Attention is given to Cu, Zn and in particular Pb and the potential of a parent magma to be a source of the metals. Melt inclusion studies in the Manus basin back-arc have emphasized a magmatic contribution of metals in the formation of volcanogenic massive sulfide-type hydrothermal deposits (Yang and Scott, 1996; Kamenetsky et al., 2001; Yang and Scott, 2002, 2005, 2006). The ore metals Cu, Zn, Au, Ag and Ni have been observed and to some extent quantified in pre-eruption trapped inclusions. Pb has been less studied due to its low concentration in melt inclusions requiring detection limits previously unavailable by conventional microbeam analytical techniques except for SIMS. Pb behavior in modern seafloor systems has therefore remained poorly understood. This study focuses on determining the availability of Pb and other ore metals in parental magmas for settings that host sulfide deposits but does not attempt to consider the transfer of metals from the magmatic to the hydrothermal system. It is an attempt to put into context on-going work involving the potential for the direct magmatic contribution of Pb and other metals to metallic sulfide ores in volcanic terrain.

2. General geology of study sites

Site locations are numbered as in Fig. 1. Specific characteristics for each site are briefly presented below. Except where indicated, average Pb, Zn and Cu analyses of the hydrothermal deposits are for random samples as tabulated by Scott (1997).

2.1. Mid-Atlantic Ridge (MAR): TAG and Snake Pit hydrothermal areas

Basalt samples from two sites along the MAR were included in this study as representatives of a typical mid-ocean ridge spreading system having a slow rate of spreading. Both sample locations are characterized by N-MORB volcanism (Petersen et al., 2000).

The Trans-Atlantic Geotraverse (TAG) ridge segment extends from 25°55′N to 26°17′ N along the MAR slowly spreading asymmetrically at 1.3 cm to the east and 1.1 cm to the west (Purdy et al., 1990; Sempéré et al., 1990; McGregor et al., 1977). The hydrothermally active TAG mound (approximately 200 m in diameter) located at 26°08′ N latitude is at a juncture between the MAR valley floor and the eastern wall (Rona et al., 1986; Thompson et al., 1988).

Deposits at TAG are dominated by Cu- and Zn-sulfide assemblages. Fifty-nine samples averaged 0.04 wt.% Pb, 25.2 wt.% Zn and 6.3 wt.% Cu. Numerous studies of active and fossil sulfide deposits at, and in the vicinity of, the TAG field have described in detail the compositions and morphology of both low and high temperature systems (e.g., Rona et al., 1986; Thompson et al., 1988; Lisitsyn et al., 1989; Rona et al., 1993a,b; Bogdanov et al., 1995; Rona et al., 1996; Petersen et al., 2000).

The Snake Pit hydrothermal field is located at 23°22′ N latitude on the Mid-Atlantic Ridge. In contrast to the TAG field, Snake Pit occurs in the center of the axial valley on a north–south trending neovolcanic ridge (Fouquet et al., 1993). The main sulfide mound covers a 150 m by 300 m area. The surface of the mound is dominated by Zn-rich assemblages and the core by Cu-rich assemblages (Fouquet et al., 1993). Thirty-one samples from the mound averaged 0.07 wt.% Pb, 7.0 wt.% Zn and 12.4 wt.% Cu.

2.2. Southern Explorer Ridge (SER)

Located approximately 200 km west of Vancouver Island, SER is a moderately fast-spreading ridge with an estimated asymmetrical spreading rate of 7 mm/yr to the east and 21 mm/yr to the west (Botros and Johnson, 1988). It is defined by a single 65 km long, 5–8 km wide segment flanked by deep, flat-floored valleys with an abnormally high standing culmination area (Michael et al., 1989; Scott et al., 1990; Beaudoin, 2007).

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