The Global Rare Element Endowment of Seafloor Massive Sulfide Deposits

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Abstract. Over the past three decades, a large number of seafloor hydrothermal vent sites and associated sulfide deposits have been discovered in the worlds' oceans. Geochemical analysis of samples collected from vent sites worldwide suggests that seafloor sulfide deposits may contain significant base and precious metal concentrations. The present study provides the first estimate of the global rare metal endowment of these deposits. It is shown that seafloor sulfide accumulations can contain elevated concentrations of the rare elements Bi, Cd, Ga, Ge, Hg, In, Mo, Sb, Se, Te, and Tl. Although these polymetallic deposits may represent a significant repository for some of these elements, the total endowment is regarded to be limited when compared to land-based ore deposits. Potential future deep-sea mining will not likely be a significant source of these metals.

Keywords. Rare metals, seafloor massive sulfides, deep-sea mining.

1 Introduction

The discovery of hydrothermal venting on the modern seafloor (Corliss et al. 1979; Francheteau et al. 1979; Hekinian et al. 1980) represented one of the most significant discoveries made in geosciences. It resulted in the identification of chemosynthetic vent communities and the possible link between seafloor high-temperature processes and the origin of life (Maher and Stevenson 1988; Nisbet and Sleep 2001; Martin et al. 2008). In addition, early workers already recognized that seafloor hydrothermal vent sites can be associated with significant accumulations of polymetallic sulfides and sulfates, resembling ancient massive sulfide deposits hosted by volcanic rocks emplaced in sub-marine settings (cf. Franklin et al. 2005).

Today, seafloor research and exploration has resulted in the discovery of a large number of active and inactive hydrothermal vent sites in the world's oceans. The available data is now sufficient to allow an initial assessment of the global-seafloor sulfide potential and factors controlling element enrichment in seafloor hydrothermal systems (Hannington et al. 2005, 2010, 2011; Monecke et al. 2014). In the present study, the global rare metal endowment of seafloor sulfide deposits is estimated for the first time.

2 Global distribution

Over the past decade, polymetallic seafloor sulfide accumulations have been discovered in almost all parts of the oceans (Fig. 1). The global 54,700 km of mid-ocean ridges are host to 192 known seafloor sulfide occurrences. Approximately 44 percent of these sites are hosted by fast-spreading mid-ocean ridges (spreading rate of >60 mm/yr) while 17 percent of the vent sites are associated with intermediate-rate (40-60 mm/yr) spreading centers. About 39 percent are located along slow-spreading (20-40 mm/yr) and ultraslow-spreading ridges (<20 mm/yr). Most of these sulfide deposits are hosted by mid-ocean ridge basalts although some deposits form on a substrate of ultramafic rocks (Hannington et al. 2005). As approximately 5% of the global mid-ocean ridges are covered by sediments derived from nearby continents, some of the known deposits located at divergent plate margins are hosted almost entirely by thick turbidite successions.

The neovolcanic zones in subduction-related settings host an additional 137 known seafloor hydrothermal vent sites and related polymetallic sulfide deposits (Monecke et al. 2014). Most of these vent sites are located in the western Pacific although some significant deposits have also been discovered in the Mediterranean Sea and Antarctica (Fig. 1). Approximately 40 percent of these occurrences are located on frontal arc volcanoes along the 16,000 km of submarine volcanic arcs. About 20 percent are situated in rift zones within these submarine arcs, which includes fore-arc extensional zones and back-arc rifts (de Ronde et al. 2003; Hannington et al. 2005; Monecke et al. 2014). The remaining 40 percent of these hydrothermal systems are associated with the 9,600 km of mature back-arc spreading centers.

3 Size and tonnage distribution

Hannington et al. (2010) compiled the dimensions for a test group of 62 well studied seafloor sulfide deposits. Applying the area versus tonnage relationship for the Solwara-1 deposit in the Manus basin, which is well established from detailed seafloor mapping and geophysical surveys as well as extensive exploration drilling, a first-order tonnage estimate was derived for the seafloor sulfide deposits of this test group.

Based on global heat flow data, circulation models for high-temperature vent fluids, geochemical budgets of the oceans, and the incidence of hydrothermal plumes, Hannington et al. (2010) estimated that mid-ocean ridges worldwide host a maximum of ~1,000 active vent sites. It was proposed that 500 additional vent sites may be located in the submarine volcanic arcs and associated back-arc basins.

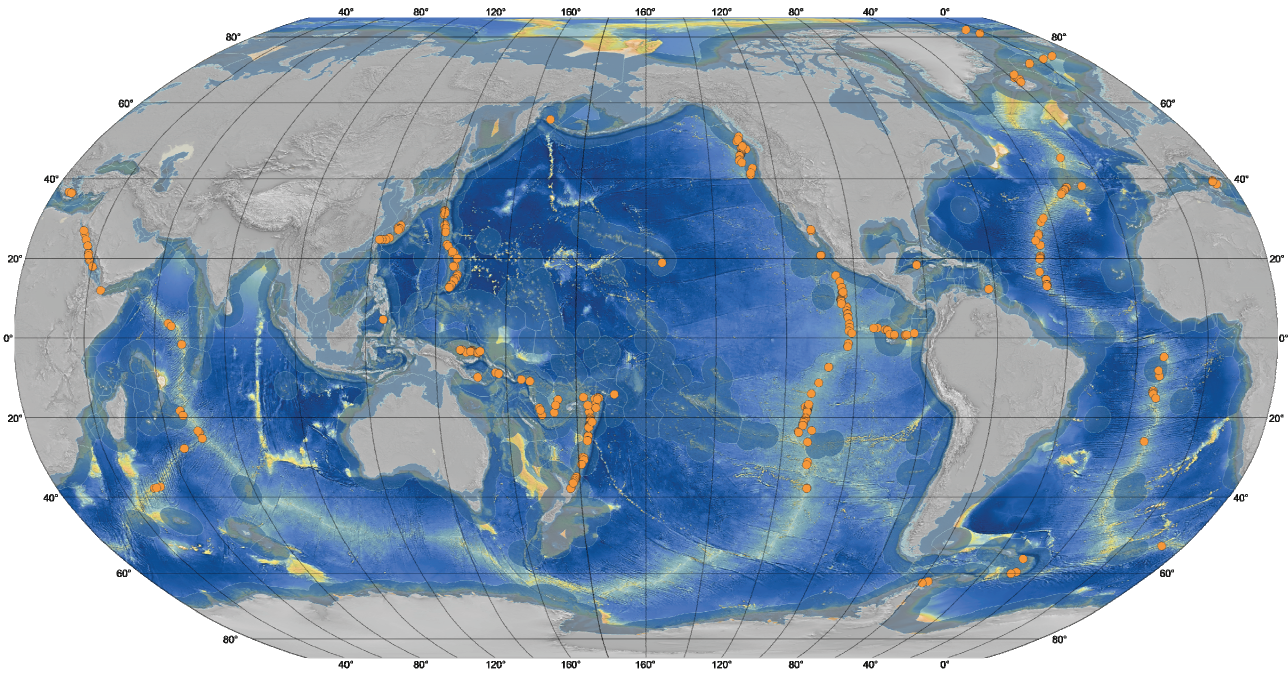

Figure 1. Global distribution of seafloor hydrothermal vent sites with associated sulfide deposits (modified from Hannington et al. 2005, 2011; Monecke et al. 2014).

If the size distribution of the test group of the 62 well-studied deposits is representative of what remains to be discovered, the total tonnage of seafloor massive sulfide deposits located in the neovolcanic zones of the world's oceans would be ~600 Mt (this estimate excludes sulfide accumulations associated with continental rifting in the Red Sea).

4 Rare metal content

Samples collected from polymetallic seafloor sulfide occurrences worldwide indicate that these deposits can contain significant concentrations of Cu, Zn, Pb, and the precious metals Au and Ag (Hannington et al. 2005, 2010, 2011; Monecke et al. 2014). Analyses of over 4,900 sulfide samples collected from vent sites in different tectonic settings has revealed that seafloor sulfides can contain enrichment of rare metals such as Bi, Cd, Ga, Ge, Hg, In, Mo, Sb, Se, Te, and Tl (Fig. 2).

The concentrations of these elements vary over orders of magnitude between samples. On average, the samples collected contain 14 ppm Bi, 362 ppm Cd, 64 ppm Ga, 30 ppm Ge, 105 ppm Hg, 21 ppm In, 74 ppm Mo, 518 ppm Sb, 116 ppm Se, 6 ppm Te, and 39 ppm Tl. It is important to note that these average concentrations cannot be directly compared to grade data of ancient massive sulfide deposits on land. Sampling of seafloor sulfides is inherently difficult and commonly only yields chimney fragments or other surface samples from the sulfide accumulations. As drilling of modern seafloor sulfide accumulations has only been conducted at a small number of sites, it is currently unknown how representative such surface samples are for the deposits as a whole.

The presently available data suggests that rare element enrichment in seafloor sulfides varies to some extent by tectonic setting. For instance, samples from sulfide deposits hosted by mid-ocean ridge basalts on average only contain 4 ppm Bi, while average concentrations of 26 ppm were noted for samples from sedimented ridges and 48 ppm for samples from arc hydrothermal systems. In comparison, samples from sulfide deposits hosted by sedimented ridges appear to have low average concentrations of 86 ppm Cd and 8 ppm Ge. Sulfide samples from arc volcanoes have comparably high Hg concentrations, averaging 698 ppm. In general, the lowest In concentrations (average of 5 ppm) are encountered in samples from sulfide occurrences hosted by mid-ocean ridge basalts. Sb in seafloor sulfides are highest in hydrothermal systems located along convergent plate margins.

In 2014, the world's refinery production of these rare metals was estimated to be 8,500 t Bi, 22,200 t Cd, 440 t Ga, 165 t Ge, 1,870 t Hg, 820 t In, 266,000 t Mo, 160,000 t Sb, >2,275 t Se, >95 t Te, and >10 t Tl (U.S. Mineral Commodity Summaries 2015). Comparison of these production figures with the estimated global metal endowment of seafloor sulfide deposits shows that seafloor sulfide occurrences forming around active hydrothermal vents only represent a significant repository for selected rare elements, especially Ga, Ge, and Tl.

The first-order approximation of the present study demonstrates that the rare element endowment of seafloor massive sulfide deposits is limited when compared to land-based mineral resources. The currently available data suggests that polymetallic seafloor massive sulfides are not an economically significant or strategic source for rare elements. Although these elements could potentially be recovered, they will not likely become an economic driver for deep-sea mining operations in the foreseeable future.

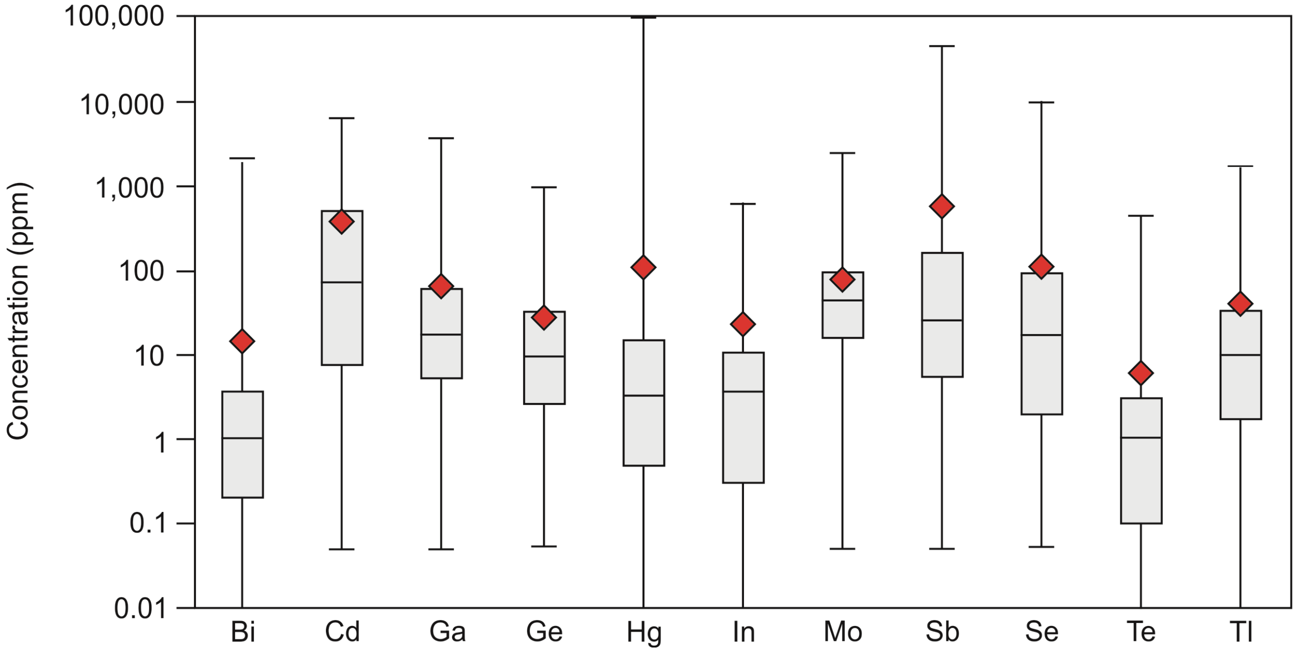

Figure 2. Box-and-whisker plot representing the abundance of rare metals in over 4,900 sulfide samples collected from modern seafloor hydrothermal vent sites. The box encloses the interquartile range with the median displayed as a horizontal line. The vertical lines extending outside the box mark the minimum and maximum values that fall within the acceptable range. The average rare metal concentrations are highlighted by the red diamonds.

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