



Seafloor massive sulfides from mid-ocean ridges: exploring the causes of their geochemical variability with multivariate analysis.

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Oceanic spreading centers ordinarily host hydrothermal systems, in which seawater-derived hydrothermal fluids precipitate metals primarily as massive sulfides (MS) on the seafloor. These MS deposits have high concentrations of base metals (Cu, Zn » Pb) and may have remarkable grades of gold and silver, making them the forthcoming target of mining industry. MS hosted on mid-ocean ridges show variable geochemistry, especially concerning the proportions of trace metals, but the causes of this geochemical variability are not fully understood. We have investigated the main factors of this compositional variability by means of multivariate statistical analysis, i.e. robust principal component analysis (rPCA) and robust factor analysis (rFA), of published and novel bulk chemical analyses of MS samples from worldwide mid-ocean ridges. We found that a large part of the observed variability is produced by two groups of anti-correlated elements, i.e. Co, Cu, Se, Mo and Zn, Sb, Pb, Ag, which most probably reflect high and low temperature mineral assemblages, i.e. chalcopyrite-pyrite dominated versus sphalerite ± galena dominated, respectively. Within the latter group, rFA reveals a good positive correlation between Ag and Zn. In addition, both rPCA and rFA well discriminate MS samples from slow-spreading ridges (Mid-Atlantic Ridge, Mid-Cayman Rise, Central Indian Ridge) from those from intermediate/fast-spreading ridges (Southern Explorer Ridge, Juan de Fuca Ridge, Gorda Ridge and Galapagos Rift); this discrimination is reflected in a principal component/factor in which Au (Ag, Sb) (highest on slow-spreading ridges) is anti-correlated with Cu and Se (highest on intermediate/fast-spreading ridges). These distinctive element associations show no apparent relationships with the nature of the MS substrate rocks (i.e. mafic vs. ultramafic). We attribute these associations to the different style of hydrothermal circulation at slow and intermediate/fast-spreading ridges. In the former, where the hydrothermal systems are typically deep and long-lasting and the fluids can undergo supercritical phase separation, Au may be leached from a deep substrate and efficiently transported as sulfur complexes together with Ag and Sb. In the latter, hydrothermal systems are shallower and ephemeral, thus less Au can be mined from the substrate; moreover, subcritical boiling can occur and the resulting vapor rich-fluids can be enriched in Se and Cu. Based on these results, we infer that MS geochemistry is mainly controlled by the temperature of precipitation and by the different hydrothermal fluid paths that characterize hydrothermal systems in slow- and intermediate/fast-spreading ridges.