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Metal Contents of Ore-Forming Fluids in Magmatic-Hydrothermal Ore Deposits

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1 Introduction

As recently as the last few decades of the previous century, little was known about the actual metal contents of ore-forming fluids. Most information that was available came from laboratory-based experimental studies and from theoretical/empirical models based on experimental data. Then, starting in the 1980s a variety of analytical techniques were developed that permitted highly precise and accurate quantitative analyses of major and trace elements, including ore metals, in individual fluid inclusions as small as about 10 microns. These techniques included Particle-Induced X-ray (and Gamma ray) Emission spectroscopy (PIXE, PIGE), Synchrotron-based X-ray Fluorescence spectroscopy (SXRF) and laser ablation – Inductively Coupled Plasma – Mass Spectrometry (LA-ICP-MS). As a result of these advances in analytical techniques, we now have a much better understanding of the metal contents in ore-forming fluids in a variety of magmatic-hydrothermal ore deposits.

2 Mississippi Valley-type Deposits

Most earlier studies (pre-1990s) of MVT deposits assumed that the ore-forming fluids contained on the order of a few ppm Zn (Garven, 1985). As a result, the inferred amount of time required to form the deposits was on the order of 106 years, assuming reasonable fluid flow rates in the sedimentary basins hosting the deposits. More recently, Wilkinson et al. (2009) analyzed FI from MVT deposits by LA-ICP-MS and estimated Zn concentrations of ~2000-5000 ppm. Using these higher metal concentrations, the amount of fluid required to form the Pine Point MVT deposit is reduced from 106-107 years, and the amount of ore-forming fluid required is reduced from 102-103 km3 to 100-101 km3 (Fig. 1). These results suggest that the duration of the ore forming event and/or the amount of ore-forming fluid required are greatly reduced compared to earlier estimates.

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3 Porphyry Copper Deposits

During the middle to latter part of the last century two models evolved concerning the source of metals in porphyry copper deposits (PCDs). In one model the metals were sourced in the associated intermediate composition magma, whereas others invoked a source via leaching from surrounding host rocks.

Today, it is generally accepted that the metals are sourced in the magma, but that later circulation of externally-derived fluids may have redistributed the metals following initial deposition. Analysis of fluid and melt inclusions from PCDs and similar deposits documents that the ore-forming capacity of the system is determined early

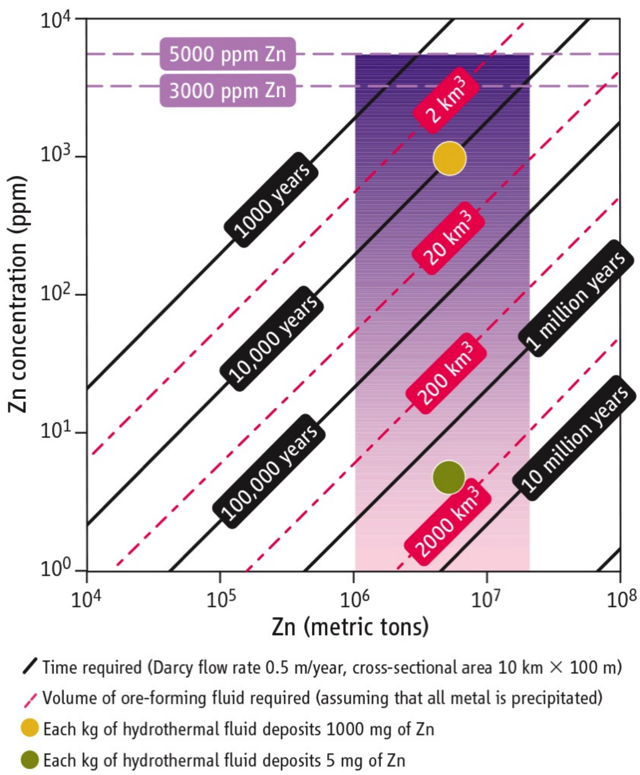

Fig. 1 Comparison of the amount of time and mass of fluid required to form an MVT deposit containing 10^6-10^7 metric tons of Zn as a function of the Zn concentration in the ore-forming fluid (from Bodnar, 2009)

on by the intruded magma (Audétat et al., 2008). A recent compilation of Cu concentrations obtained from analysis of FI from PCDs (mostly by LA-ICP-MS) shows that Cu concentrations of 10^3 to 10^4 ppm, and even up to 10^5 ppm in some cases, are typical of ore-forming fluids in PCDs (Fig. 2).

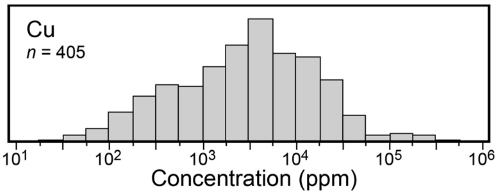

Fig. 2 Copper concentrations in ore-forming fluids in porphyry copper deposits (from Bodnar et al., 2014).

4 Epithermal Au-Ag Deposits

Compared to PCDs, less information is available on metal contents of the ore-forming fluids from analyses of individual FI because the inclusions in epithermal deposits are often small, have low salinities, and metal contents that are often below the detection limits of the analytical technique. However, epithermal precious metal deposits form in an environment similar to that which is associated with modern continental geothermal systems and associated with active volcanism, and many analyses of geothermal and hot spring waters have been published. In addition, the Au and Ag concentrations in the ore-forming fluid can be inferred from precious metal grades and tonnages in epithermal deposits (Moncada et al., 2014). As such, these data indicate average gold concentrations of 1.7 ppb (based on 241 data) and average Ag concentrations of 34 ppb (based on 213 data) in the ore-forming fluids.

5 Unconformity Uranium Deposits

Unconformity-related (Athabasca-type) uranium deposits are generally thought to have formed as brines circulated between crystalline basement and overlying sedimentary (or metasedimentary) sequences, with deposition a result of the change in redox conditions across this interface. Richard et al. (2011) analyzed individual fluid inclusions from uranium deposits in the Athabasca Basin, Canada and found U concentrations of 1 x 10^{-6} to 2.8 x 10^{-3} molal (~0.24 to 666 ppm), and noted that these concentrations are ~ 3 orders of magnitude higher than values measured in other crustal fluids. Richard et al. (2011) noted that such elevated concentrations of U are necessary in order to form giant uranium deposits in a reasonable amount of time, on the order of 0.1 to 1 Myr.

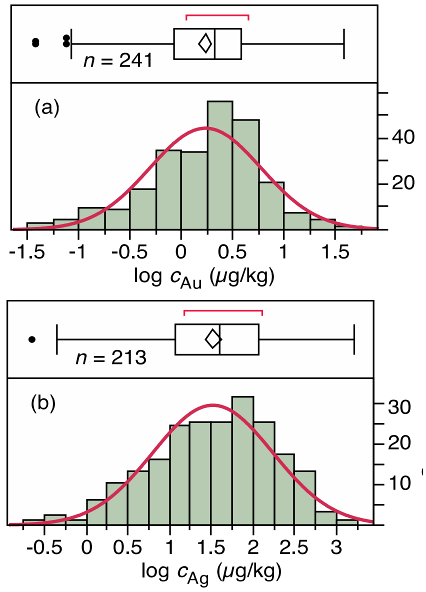

Fig. 3. Range in inferred concentrations of Au (top) and Ag (bottom) in ore-forming fluids in epithermal precious metal deposits (from Moncada et al., 2014., 2014).

6 Summary

The wealth of new analytical data that has become available in the last few decades, mostly from analyses of individual fluid inclusions in ore-forming environments, provides strong evidence that fluids that form large economic metal deposits are indeed “special”, having metal concentrations that are enriched by several orders of magnitude compared to more typical fluids in similar environments. The higher metal content of the fluids, in turn, has important implications concerning the amount of fluid and/or the amount of time required to form large deposits. The general conclusion is that world-class metal deposits can form in a much shorter period of time, and from a much smaller volume of ore-forming fluid, compared to estimates that were put forward earlier.

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