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Metal transports and enrichments in iron depositions hosted in basaltic rocks: I. Case study in Mid-Lower Yangtze River Valley, China

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ABSTRACT

This study provides new information about metal transportation due to water–basaltic rock interaction experiment at temperatures from 20 °C to 550 °C and 23–34 MPa, and a case study on water–rock interactions occurred in an iron deposit. Anhydrite–magnetite–pyroxene iron deposits hosted in basaltic rocks and the accompanying alteration zones were investigated in a Mesozoic volcanic area of the mid-lower Yangtze River Valley, China. Combined with this case study, high-temperature kinetic experiments were conducted on water–rock interactions to reveal the mechanism of metal transport in hydrothermal alterations. The dissolution rates (release rates) for various metals from the rocks are temperature-dependent, causing the various metals transported at gradational temperatures along the alteration profile to form vertical trace metal zoning. The chemical compositions of the altered rocks associated with iron deposits were investigated in detail, involving the rock-forming elements, trace elements and ore elements along the alteration zone profile from the surface to a depth of 1600 m. The distribution of the metals in the altered rocks showed vertical zoning from the deep (melanocratic) alteration zone to the shallow (leucocratic) alteration zone. The locations of high metal content changes with depth, in the sequence: V, TiO_2, Cr, Ni (deepest) → Cu, Ag, Pb, Zn → Th, U → Cd, As → Sr, Sb, Ba (shallowest).

Experimental results indicated that the dissolution rates (release rate) for various metals vary with temperature. The maximum release rates (R_{MX}) for Cu, Co, Ni, Zn and Ag occurred at 550–500 °C (in some cases 400 °C); R_{MX}s for V, Ti, Cr, As, Be, Mo, Pb, U and Cd occurred at 400 °C; R_{MX} for Th at 200 °C; R_{MX} (Sr) at 100 °C (300 °C in NaCl–H_2O), and R_{MX} (Ba) at 100 °C (in some cases 400 °C).

Comparing the compositions of altered rocks along the profile with the experimentally measured release rates for various elements provided evidence that the major trace elements (most transition elements) are dissolved from basaltic rocks by upwelling fluids at temperatures around the critical-state temperature, from 300 °C to 400 °C or above. The reactive fluids transport Co, Ni, Cu, Pb, Zn, Ag, As, U, Th, Ba and Sr to shallow regions, i.e., the outer part of the alteration zones, where they are precipitated as the temperature dropped from 300 °C to 100 °C.

1. Introduction

The important topic of hydrothermal transportation of metals has been investigated many times, motivated either by a desire to understand the important role of hydrothermal processes deep in the Earth's crust, or to quantify metal transport processes derived from fluid–rock interactions. To better understand metal transport (e.g., at MORs), basaltic rock–seawater interaction experiments performed at high temperatures using static and closed experimental systems have indicated that chemical exchange of the reactive fluids produces secondary mineral formation at rock surfaces during the subcritical and supercritical hydrothermal alteration of basalt, which affects the transport of heavy metals. Data indicate that temperature plays a key role in mineral solubility and the kinetic processes that influence the compositional evolution of the circling fluid as water passed through basaltic rocks (Allen and Seyfried, 2003; Foustoukos and Seyfried, 2005).

In addition, metal transportation during the formation of Fe-oxides and Cu–Au deposition and other metals has often been investigated (Zhang et al., 2014a,b). It has been found that the composition of modern geothermal fluids varies systematically depending on their setting, and such variations directly affect the capacity for metal transport and deposition (Barton and Johnson, 2000). It has also been reported that the composition of the

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original fluid governs metal transport and deposition; for instance, metal depletion (commonly almost complete removal) has been well-documented in many instances of Fe-oxide-rich mineralization in spatially associated sodic (or calcic) and low-temperature potassic alteration (Hollocher et al., 1994; Williams, 1994; Frietsch et al., 1997; Cooke et al., 1998). It has also been reported that rock-buffering of the hydrothermal fluids dominates heavy metal transport and deposition spatially and temporally in an alteration zone (Hemley and Hunt, 1992; Hemley et al., 1992; Fisher and Kendrick, 2008).

Previously, most water–rock interaction experiments were carried out based on the mineral–fluid equilibrium model, and illustrate the chemistry of the circling fluids buffered by hydrothermal alteration minerals (Foustoukos and Seyfried, 2005; Seyfried et al., 2011; Tutolo et al., 2015). But a few experiments on water rock interactions were performed to measure the dissolution rates of the rocks at temperatures above 400 °C, and using flow through reactor at far from equilibrium conditions (Flaathen et al., 2010). Thus it is pretty difficult to illustrate the transport mechanism for the main elements and heavy metals (or trace elements) in circling fluids at high temperature hydrothermal systems (e.g., >400 °C), and thus need to perform water–rock interaction experiment in open-flow system at temperatures up to 550 °C.

Therefore the case study focused on understanding ore and trace metal transportation in terms of water–rock interactions, which result in ore deposition and accompanying alteration zones in the Luzong Mesozoic continental volcanic basins in the Middle–Lower Yangtze River Valley, China (Figs. 1 and 2). Those iron deposits are dominated by pyrite–anhydrite–magnetite ores and formed mainly at temperatures from 550 to 300 °C (for a brief, Py-Anh-Mt refers to the pyrite–anhydrite–magnetite assemblage) (Zhang, 1982, 1983, 1986; Zhang et al., 1997, 2002, 2010). Lots of investigations have been focused on the geological comparisons of the mineral assemblage characters for different types of ore deposits in those volcanic areas and their geological settings in the Middle–Lower Yangtze River valley, but it is not will known that mechanisms of metal transport of main and trace elements during the ore formations (Dong et al., 2009, 2010; Zhang et al., 2014b). That is the existing problem for scientists to resolve later on. A few studies were concentrated to the transports of ore metal and trace elements along the alteration profile and ore metal origin (Chang, 1974; Zhang et al., 1979; Zhang and Lu, 1982). Those investigations indicated that ore metal such as Fe, Ti, V, Cu and trace elements, Co, Ni, Pb, Zn, Ag, Ba, Sr, As were distributed in the different altered rocks along alteration profile. The Ti, V are mainly distributed in melanocratic alteration zone; Cu, Ag, Zn, Pb, As, Ba, etc. are present in the leucocratic alteration zone, which show

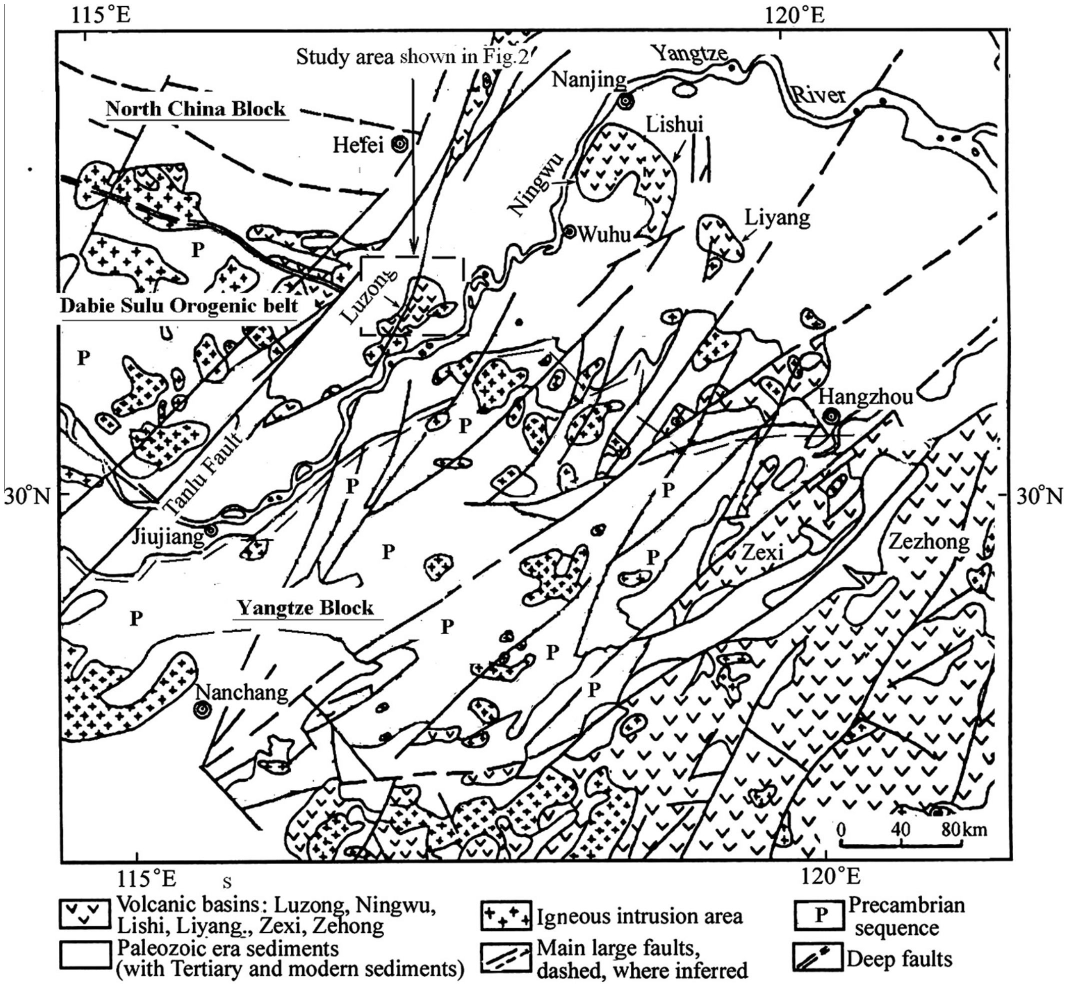

Fig. 1. Regional geological map showing the geological setting of the Middle–Lower Yangtze River Valley metallogenic belt. The northwestern and southern parts of the Precambrian sequence are represented by the North China and Yangtze Blocks, respectively. Between the two blocks, Paleozoic era sediments and Mesozoic volcanic sediments are distributed along Yangtze River valley. Box shows the study area detailed in Fig. 2. (Part of this figure is quoted from Guo, 2002, China Endogenetic metallogenic map, Chinese Academy of Geological sciences, Institute of Geology, 2012.)