Mantle-Derived Primary Sulphide Melt Inclusions in Amphibole Megacrysts

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1 Introduction

Sulphide deposits in mafic and ultramafic igneous rocks are of considerable economic importance, but the ultimate origin of the metals and sulphur in these deposits is often ambiguous and raises wide concerns. Two main aspects are discussed in this debate: the origin of mantle metasomatism and the origin of crust assimilation. Recently, much attention has been focused on the alternatives of a primary mantle origin for sulfides after extensive research on sulphide melt inclusions (SMI) in mantle-derived xenoliths in basaltic or kimberlitic rocks. Most studies treated the evolution of magma and SMI separately; whether by the numerical simulations based on isotopic geochemistry, petrochemistry or laboratory simulation experiment. Few models have attempted to use detailed chemical analysis and petrographic evidence for the origin of the sulphide, let alone describing how the SMI evolves in mantle-derived magmas. In this work, we report and describe the direct evidence for the mantle origin of the sulphide, let alone describing how the SMI evolves in mantle-derived magmas. In this work, we report and describe the direct evidence for the mantle origin of metals and sulphur of the middle and lower reaches of the Yangtze River (MLYR) large-scale mineralization. MLYR large-scale mineralization belt is situated in the middle segment of the Yangtze River Deep Fault Belt and located in the foreland of the Dabie Orogenic Belt, being one of the most famous iron-copper ore province in East Asia with relevant economical and political impact. We present new petrographic observations, geochemical data, and Time of Flight- Secondary Ion Mass Spectrometer (ToF-SIMS) analyses of the SMI trapped within Amp-M in this area. Results provide new insights into the mantle metasomatism processes and the origin of primary SMI.

2 Petrology

The Amp-M are unevenly distributed within the host diorite porphyry. This diorite porphyry is green with typical porphyritic texture. Phenocrysts are mainly plagioclase (40–45%), pyroxene (8–10%), amphibole (4–5%), biotite (1–2%), and feldspar (~1%) with accessory quartz. The plagioclase are mainly euhedral or subhedral in shape, 0.20–3.00 mm wide. The matrix is mainly composed of plagioclase and accessory magnetite, apatite, and sphene. The SMI generally occur as droplets in the amphibole crystals, are mainly ellipsoidal to rounded in shape, and 2–20 mm in size. They distribute regularly in a radial disposition or as clusters. The SMI are mainly composed of pyrrhotite, chalcopyrite and pyrite.

3 ToF-SIMS Analysis

The ToF-SIMS spectra were obtained on an ION-TOF TOF-SIMS IV (ION-TOF GmbH, Münster, Germany) located at the Surface Interface Ontario at the University of Toronto. With ToF-SIMS we have analyzed the detailed element composition, obtaining positive and negative ion maps of the SMI and surrounding host Amp-M.

The SMI are characterized by high Int Mn, Fe, Cu, Sr, Zr, Cs, Nd144, Nd145, Sm, Ho, Yb and relatively low Si, As, Se, La, Ce, Nd142, Tb intensity. The positive and negative ion maps clearly manifested that: ① Positive, Amp-M containing Si, Na, Mg, Al, K and Ca; SMI composed of Fe, Mn, Co, Ni, Cu, Rh, Sr, Ba, Nd and Sm.② Negative, Amp-M consisting mainly C, H and O; SMI with S³², S³⁴ and Cl. The enrichment of Si in Amp-M probably implies significant crustal sima contamination. Relatively to the SMI, there are two major element systems:

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Previous studies indicate large-scale mantle metasomatism and crust mantle interaction in Mesozoic. There is a significative number of published literature on the pyroxene amphibolites of the upper mantle in Eastern China, Western America and localities elsewhere. It is generally accepted the occurrence in the upper mantle of pyroxene amphibolites at a depth of 30~32km(Tang et al., 1998), and deep-level crustal magma chambers at a depth of 22~27km (Du et al., 2004). The calculated pressure, temperature and the depth during formation of the amphibole megacrysts is 6.86~8.32kb, 850℃~950℃ and 22.64~27.47km. It corresponds to Qin(2007) reported pressure, temperature and depth of the hornblende cumulates 6.8~ 8.5kb, 835℃~950℃, 22.8~27.1km. Previous studies indicate large-scale mantle metasomatism and crust mantle interaction in Mesozoic.

We suggest that the Amp-M were formed from the recrystallization of altered mantic pyroxene amphibolite located in magma chambers at the base of continental crust. These materials experienced strong alteration and metasomatism by mantle fluids during interaction between pyroxene amphibolite and basaltic magma in the upper mantle. The basaltic magma resulted from previous partial melting of the upper mantle and basaltic magma in the upper mantle. The existing experimental data and research findings provide petrological and geochemical evidence for the existence of partial melting in the upper mantle and underplating of mantle-derived basaltic magma within the lower crust to form a deep-level magma chamber at a depth of 22~27km, and the basaltic magma had previously been produced by partial melting of the upper mantle (~32km) (Du et al., 2004). When the basaltic magma began to fractionate in the deep-level chamber, large amounts of S (Ni, Cu, Cr, etc.) were released concomitantly with decreasing sulphur solubility, as part of the general process of mantle metasomatism. There are several possible mechanisms for the decrease of the sulphur solubility: ① Magma mixing; ② Magma rapid cooling; ③ Liquation and differentiation of magma or ④ Contamination of crust and lithospheric mantle. We believed that the last view is regarded as the most viable explanation. In a Fe-O-S or Fe-Ni-S deep system, the solubility of sulphur is proportional to the temperature and inversely to the pressure; under the condition of atmospheric pressure it is in proportion to the content of SiO₂, and has the inverse ratio with the content of FeO. Crust material rich SiO₂ may decrease the solubility of sulphur in the magma. Previous studies have shown that there are pyroxene and plagioclase-bearing amphibolites and felsic and mafic granulites at depths of 18~32 km in MLYR, and upper mantle below 32 km. In agreements it is the contamination of the sima (Si-Mg) at lower crust causing the decrease of the sulphur solubility in mixed magma at the deep-level magma chamber.

During the underplating of mantle-derived basaltic magma, the altered pyroxene amphibolite was carried to the lower crust in the form of xenoliths, and recrystallized to Amp-M. Then the SMI were trapped as droplets of immiscible sulphide melt, nucleated on the surface of growing Amp-M. These melts would remain fluid for some cooling interval after their trapping, and could easily be redistributed due to fracturing or recrystallization of the Amp-M. Nevertheless, the ultimate origin of these
sulphides was through liquid immiscibility. This may be the source of most sulphur observed in mantle xenoliths. After an extended magmatic episode, this could lead to a significant concentration of sulphur and chalcophile elements in the lowermost crust, and these components were available for remobilization during episodes of crustal thinning at 140 Ma (Li et al., 2011), resulting in the MLYR large-scaled mineralization belt.

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