Indonesian mineralization event in the Wulashan District, Northwest China: Evidence of isotopic geochronology

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The Wulashan district has a great economic potential for Mo–Au mineralization and attracted wide attentions of geologists. More than thirty ore deposits have been discovered in this region since the late 1980s. Representative deposits mainly include the medium-sized Xishadegai porphyry Mo deposit and the superlarge-sized Hadamengou-Liubagou alkaline-related Mo–Au ore field. Previous opinion of mineralization epoch was Hercynian, however, Indonesian ages have been recognized recently. Re-Os isotopic dating on seven molybdenites from the Xishadegai Mo deposit defines model ages of 223.2-232.6 Ma and an isochron age of 225.4 ± 2.6 Ma, whereas LA-ICP-MS dates on zircon from the Xishadegai host granite yield an age of 245.3 ± 9.6 Ma. Stepwise ^{40}Ar-^{39}Ar dates on K-feldspar of auriferous quartz-K feldspar vein (ores) give a plateau age of 217.9 ± 3.1 Ma in the Liubagou deposit, in accordance with the previously reported ^{40}Ar-^{39}Ar data (239.8 ± 3.0 Ma) for sericite separated from ores in the Hadamengou deposit. Considering that the dating minerals showed clear co-existing textures with ore-stage mineral assemblages, the mineralization process mainly occurred during early Indonesian. In addition, LA-ICP-MS dates on zircon from associated granitoid (Shadegai granite) give an isochron age of 231.4 ± 3.1 Ma. The geochronological data, together with the regional geological setting, suggest that the early Indosinian (231-245 Ma) magmatic activities induced a coeval magmatic hydrothermal mineralization (218-240 Ma) under a post-collisional extensional setting. This magmatism-mineralization event is significantly recorded and should be highly valued in the north margin of the North China Craton.

The research was funded by the National Natural Science Foundation of China under grants of 40930423 and the Specialized Research Fund for the Doctoral Program of Higher Education (SRFDP, 20130022120016).

Superchondritic Mantle Is Partially Depleted MORB Mantle

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The composition of the bulk silicate Earth (BSE) is often modeled by the "chondritic" model, in which the refractory and lithophile elements such as REEs in BSE are assumed to have chondritic ratios (Jagoutz *et al*., 1979; Sun, 1982; Zindler and Hart, 1986; Allegre *et al*., 1995; McDonough and Sun, 1995; Palme and O'Neill, 2004). Recently, high-precision measurements reveal that $^{142}Nd/^{144}Nd$ ratios in terrestrial samples are higher than those in chondrites by about 0.2 epsilon units (Boyet and Carlson, 2005, 2006). The results were interpreted to mean that the primordial Sm/Nd ratio in BSE was higher than chondritic ratio, namely superchondritic. Since then, there has been much discussion about the "superchondritic" mantle (Caro *et al*., 2008, Caro and Bourdon, 2010, Campbell and O'Neill, 2012), although the jury is still out (e.g., Huang *et al*., 2013; Gale *et al*., 2013).

If BSE is indeed superchondritic, it is necessary to estimate the SuperChondritic BSE (SC-BSE) composition, to distinguish it from previous BSE composition based on the "chondritic" assumption. The latter is hereafter referred to as chondritic BSE (C-BSE). To estimate SC-BSE composition, isotopic constraints can be converted to the following elemental ratio constraints (Caro and Bourdon, 2010):

$(Sm/Nd)_{SC\text{-}BSE} \approx 1.06(Sm/Nd)_{C\text{-}BSE}$;

$(Lu/Hf)_{SC\text{-}BSE} \approx 1.12(Lu/Hf)_{C\text{-}BSE}$;

$(Rb/Sr)_{SC\text{-}BSE} \approx 0.70(Rb/Sr)_{C\text{-}BSE}$.

The more incompatible elements are depleted in SC-BSE compared to C-BSE, consistent with depletion of the mantle. To quantitative examine whether the SC-BSE is partially depleted MORB mantle (DMM), it is necessary to quantify the incompatible element sequence (Sun and McDonough, 1989): **Rb** > Th > U > La > Ce > **Sr** > **Nd** > *Pm* > **Sm** ≈ **Hf** > Eu > Gd > Tb > Dy > Ho > Er > Tm > Yb > **Lu**. The quanfication is achieved by comparing DMM composition (Salters and Stracke, 2004; Workman and Hart, 2005) with C-BSE composition (McDonough and Sun, 1995) to define the Compatibility Index (CoI) calculated as $\ln(C_{DMM}/C_{C\text{-}BSE})$. It was found that the Sm/Nd, Lu/Hf, and Rb/Sr ratios in SC-BSE over those in C-BSE are well related to the difference in CoI between the numerator element and the denomenator element, implying that SC-BSE can be regarded as partially depleted DMM. The concentrations of other elements in SC-BSE are then obtained. SC-BSE likely formed by some early depletion event in Earth. The complementary subchondritic material might be in D" layer or in the lower crust.

DOI:10.1180/minmag.2013.077.5.26