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壳幔岩浆混合作用与陆内环境高Sr/Y斑岩的形成及成矿：实例与探讨

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摘要：

产于陆内环境的含矿斑岩往往具有高Sr/Y特征，多数学者认为与岩浆起源于加厚或拆沉的下地壳有关。然而，目前这一模式仍存在较大争议。本文以敖仑花斑岩矿床为例，新报道了矿区内不成矿岩体的岩石学和地球化学特征，与同期成矿岩体进行对比，探讨含矿斑岩高Sr/Y原因及控制是否成矿的可能因素。相对于含矿斑岩，敖仑花贫矿黑云母花岗岩具有高SiO_2（74%~78%）、低MgO（<0.2%）和CaO（0.2%~1.1%）、贫Sr（30×10^{-6}~251×10^{-6}）和Cr（1×10^{-6}~6×10^{-6}）的特征，显示准铝质到过铝质性质（A/CNK=0.9~1.2），$Mg^{\#}$值（2~30）与玄武岩实验熔体成份相似，说明岩浆可能主要来自基性下地壳源区的部分熔融。而已有的研究表明含矿斑岩为壳幔岩浆混合成因，富集地幔起源的偏基性岩浆的加入提升了寄主长英质岩浆的$Mg^{\#}$值、大离子亲石元素（Sr、La等）含量及其氧逸度（f_{O_2}）。我们认为幔源岩浆的混合可能是导致陆内环境含矿斑岩高Sr/Y及有利成矿的根本原因；相反，来自纯壳源的花岗质熔体因缺乏富水、高f_{O_2}、幔源岩浆的参与而不利于形成斑岩Cu±Au±Mo矿床。

英文摘要：

Ore-bearing porphyries formed in non-arc environments (such as continental collision zones and intra-continents) often have high Sr/Y ratios. Most researchers advocate that intermediate to felsic magmas for these ore-bearing porphyries originated from a thickened or delaminated continental lower crust source. However, this model is still under discussion. Here we report a case study to provide new insights into this issue and give a different interpretation. The Aolunhua porphyry Mo-Cu deposit from the eastern Central Asian Orogenic Belt formed in an intra-continental extensional setting during the Early Cretaceous. Two types of granitic intrusions have been recognized in the mining area. One is the fertile monzogranite-porphyry (formed at 132Ma by zircon U-Pb dating), and the other one is the barren biotite granite (formed at 126Ma by zircon U-Pb dating). In this paper, we present new petrological and geochemical data of the barren biotite granite, and compare these data with that of the fertile monzogranite-porphyry reported by previous studies. Our results show that the barren biotite granite has relatively high SiO_2 (74.4%~78.3%), K_2O (4.3%~4.9%), Y (18.4×10^{-6}~27.6×10^{-6}) and Yb (2.4×10^{-6}~3.0×10^{-6}), but low MgO (<0.2%), CaO (0.2%~1.1%), Sr (30×10^{-6}~251×10^{-6}) and Cr (1.1×10^{-6}~5.8×10^{-6}) contents, and $Mg^{\#}$ values (2~30). They are metaluminous to peraluminous (A/CNK=0.9~1.2), and show relatively flat REE patterns and pronounced negative Eu anomalies (Eu/Eu^{*}=0.05~0.2). These compositions are comparative to those of metabasaltic experimental melts (1~4.0GPa), suggesting that magmas of the biotite granite probably derived from partial melting of a lower crust source. In contrast, the fertile monzogranite-porphyry contains plenty of mafic microgranular enclaves (MMEs), and is enriched in Sr, Ba, LREE and other LILE. They show concave REE patterns with negligible Eu anomalies, and have high Sr and La, but are low in Y and Yb concentrations, which are comparative to that of typical adakitic rocks. All samples plot in the "adakite" field in the Sr/Y vs. Y and $(La/Yb)_N$ vs. $(Yb)_N$ diagrams. Compositional and textural disequilibrium of plagioclase phenocrysts, variable $\varepsilon_{Hf}(t)$ values for zircons, together with high $Mg^{\#}$ values (45~52) and Cr abundances, indicating that the fertile monzogranite-porphyry was mainly derived from partial melting of a lower crustal source, but with remarkable addition of enriched mantle-derived materials. The mafic end-member is represented by MMEs hosted in the ore-bearing monzogranite-porphyry. They are characterized by high $Mg^{\#}$ values (56~63) and enrichment of Sr, Ba, LREE and other LILE, as well as moderate radiogenic Nd and Hf, implying that their parental magmas were derived from a fluids/melts-metasomatized mantle source. We propose that high Sr/Y ratios of the fertile monzogranite-porphyry could be caused by a process of crust-mantle magma mixing plus subsequent fractionation as follows: First, mafic magma derived from partial melting of the lithospheric mantle previously metasomatized by subduction zone fluids/melts have high LILEs (e.g., Sr, La and LREE). Mixing of such mafic magma with crustal melts in the lower crust resulted in the formation of hybrid parental magmas for the fertile monzogranite-porphyry. As revealed by the Sr abundances and $Mg^{\#}$ values, all ore-bearing porphyry and MMEs samples define a linear and positive correlated trend. By magma mixing, enriched mantle-derived wet mafic magmas could provide abundant Sr, La and other incompatible elements to the host felsic magmas, an

d meanwhile, raise the H_2O content and oxygen fugacity (f_{O_2}) of the resultant magmas. Therefore, the high Sr and high Sr/Y ratios of the porphyry are partially attributed to the addition of enriched mantle-derived mafic magma. Second, under water-rich condition, the crystal fractionation of hornblende, titanite and other accessory minerals (all these fractionated minerals have low D_{Sr} (0.03~0.516) and high D_Y) from the parental magma was earlier than that of plagioclase (because plagioclase crystallization was suppressed by the high water content of the melt), consequently leading to the enhanced high Sr/Y ratios for the evolved magmas. The Mo-Cu mineralization is attributed to the high H_2O and f_{O_2} nature of hybrid magmas. In contrast, the barren biotite granite with normal Sr/Y ratios, H_2O-deficient and low f_{O_2} signatures, are not favorable for the Mo-Cu mineralization. Therefore, the mixing of water-rich mafic magmas from an enriched lithospheric mantle with the felsic lower crustal melts is significant to the formation of high Sr/Y porphyries and related deposits in non-arc environments.

关键词：斑岩矿床 埃达克岩 壳幔岩浆混合 陆内环境

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