Geochemistry characteristics and emplacement mechanism of the Cenozoic magma in Baoxingchang area, Yunnan Province, SW China

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Abstract. Alkali-rich intrusions associated with Cu-Mo mineralization in Baoxingchang district, displaying both felsic and mafic rock series, can be divided into four evolution stages. LA-ICP-MS zircon U-Pb ages of the four stages intrusions 36.5~34.6 Ma, 38.0~33.5 Ma, 36.0~34.5 Ma and 34.0 Ma, respectively. All the studied rocks have similar magma sources and tectonic setting. The $\varepsilon_{Hf}(t)$ values indicate that they were reworked by ancient lithospheric mantle and crustal materials via subduction. Formation of the alkaline-rich intrusions in Baoxingchang area may be involved in the processes of partial melting of mantle rocks, crust-mantle materials and fractional crystallization. It appears an increasing tendency from felsic intrusions, to enclaves and then to early-stage lamprophyre to late-stage lamprophyre.

1. Objective
Cenozoic alkali-rich intrusions are widely distributed along the Jinshajiang-Red River tectonomagmatic belt[1,2,3]. Numerous alkaline porphyries were closely associated with Cu-Mo-(Au) deposits, such as Yulong in north, Beiya and Baoxingchang in centre, and Tongchang in south[4,5]. Baoxingchang Cu-Mo deposit is a typical Cenozoic porphyry deposit, which is structurally controlled by NW-trending Red River and NE-trending Chenghai faults[6,7]. Alkali-rich intrusions in the Baoxingchang deposit district include syenite porphyry, porphyritic granite, granite porphyry, alkali-feldspar granite porphyry and lamprophyre. Cu-Mo mineralization is spatially and temporally associated with granite porphyry and porphyritic granite. This paper describes geology of Baoxingchang Cu-Mo deposit and reports zircon U-Pb geochronology, whole-rock geochemistry and Sr-Nd-Hf isotopes data to discuss its genetic mechanism and built magmatic emplacement model.

2. Methods
Whole-rock major and trace elements were determined by Axios Model PW4400 X-ray fluorescence (XRF) and ELAN 6000 ICP-MS, respectively, at the State Key Laboratory of Ore Deposit Geochemistry, Institute of Geology, Chinese Academy of Sciences. Cathodoluminescence (CL) images and U-Pb dating of zircon grains were subsequently performed by Agilent 7500a LA-ICP-MS with 213 nm (a spot size of 32 μm) and Geolas 2005 laser ablation system at the State Key Laboratory of Geological Processes and Mineral Resources, China University of Geosciences (Wuhan). Whole-rock Sr, Nd and Hf isotopes were analyzed by Thermo Fisher Science Neptune-Plus MC-ICP-MS at the State Key Laboratory for Mineral Deposits Research, Nanjing University. Whole-rock samples...
were completely dissolved in a mixture of HF + HClO\textsubscript{4} for Sr-Nd isotope analysis and in mixture of HF + HNO\textsubscript{3} for Hf isotope analysis[8,9,10].

3. Results

1. Alkali-rich intrusions in Baoxingchang Cu-Mo deposit have felsic and mafic two series, which can be divided into four evolution stages: (I) syenite porphyry or quartz syenite porphyry, (II) porphyritic granite and early lamprophyre, (III) granite porphyry and late lamprophyre, and (IV) alkali-feldspar granite-porphyry. The four stages were formed gradually towards silica-rich and alkali-rich, especially to K-rich.

2. Whole-rock geochemical results of felsic series rocks suggest that their SiO\textsubscript{2} contents become higher, whereas Al\textsubscript{2}O\textsubscript{3}, CaO, Fe\textsubscript{2}O\textsubscript{3}, MgO and P\textsubscript{2}O\textsubscript{5} contents decreased from Stage I to Stage IV. Meanwhile, the evolution process of the composition of mafic rocks, such as enclaves, early lamprophyre and late lamprophyre, is very obvious. Particularly, there are same or similar characteristics between enclaves and the early lamprophyre. The SiO\textsubscript{2}, MgO, K\textsubscript{2}O and (K\textsubscript{2}O+Na\textsubscript{2}O) contents were increased gradually from enclaves and early-stage lamprophyre to late-stage lamprophyre, whereas Al\textsubscript{2}O\textsubscript{3} content was decreased gradually.

3. Transitional elements of all whole-rock samples show roughly coincident with "W" type pattern with relatively depleted Cr and Ni, and enriched V, Co, Cu and Zn. All bulk-rock samples are enriched in large-ion lithophile elements (LILE: Rb, Sr, Ba, U, Th) and LREE, depleted in high field strength elements (HFSE: Ti, Nb, Ta) and HREE. This indicates that all the studied rocks have similar magma sources or formation in the same tectonic setting.

4. High initial \(^{87}\text{Sr}/^{86}\text{Sr}\) ratios and low \(\varepsilon_{\text{Nd}}(t)\) values of all the studied samples suggest a similar- EM II type- mantle source for their origin. The \(\varepsilon_{\text{Nd}}(t)\) values of mafic rocks are higher than that of the felsic rocks, imply that the former includes more mantle-derived components than the latter. The \(\varepsilon_{\text{Hf}}(t)\) values of felsic intrusions are positive (0~1.84), while mafic rocks have negative \(\varepsilon_{\text{Hf}}(t)\) values (-0.07 and -0.30, respectively), indicating that they were reworked by ancient lithospheric mantle and crustal materials via subduction.

5. LA-ICP-MS zircon U-Pb ages of the four stages intrusions are 36.5~34.6Ma, 38.0~33.5Ma, 36.0~34.5Ma and 34.0Ma, respectively, which are similar to the reported peak ages (45~30Ma) of alkali-rich intrusions in the Jinshajiang-Red River tectonic belt and are also consistent with the formation age of the porphyry-related Cu-Mo deposit (37~32Ma). This suggests that these intrusions were formed under the post-collision intraplate setting.

4. Conclusion

Formation of the alkaline-rich intrusions in Baoxingchang area may be involved in the processes of partial melting of mantle rocks, crust-mantle mixing and fractional crystallization. Our research suggests that felsic rocks and late lamprophyre were derived from the partial melting of EM II mantle-type, and the melting degrees are 15% and 10% respectively. Both enclaves and early lamprophyre were originated from the partial melting of EM II mantle, with degree of ~3%. Besides, the intrusions show significant crust-mantle mixing source, with crust-mantle mixed proportion from 0.44 to 0.60, which indicates more remarkable continental crust contamination during the formation of felsic rocks than lamprophyres. Although there is no sign of significant fractional crystallization, it appears an increasing tendency form felsic intrusions, to enclaves and then to early lamprophyre to late lamprophyre.

On the basis of analysis above for time-space evolution of magma, source characteristics and magmatic genesis, a model of the four-stage magma with fluid pulsatile aroused was built in this paper (Figure 1). It indicates that mantle heat flow from Eastern Margin of Tibetan Plateau underplated to the bottom of the mantle lithosphere to constitute a magmatic circulatory system with low pressure and heterogeneous temperature, which occurred endless crust-mantle mixed. The crust-mantle mixation zone provides primary magma for alkaline-rich intrusions which experiences partial melting, crust-mantle mixed as well as fractional crystallization during the ascend processes of magma
along a dilation centre between Red River fault and Chenghai fault to emplace multi-stage and multi-type intrusions. In this evolution process, the first (Ⅰ) stage syenite porphyry rocks are higher depth of magma source, higher partial melting degree, lower SiO$_2$ components and weaker crystallization differentiation. The second-third (Ⅱ-Ⅲ) stage granite rocks, as a main intrusion, have shallower depth and weaker partial melting degree of magma source, but larger scale outcrop, stronger crystallization differentiation and more crustal contamination than the first (Ⅰ) stage rocks, which consists of porphyritic granite and granite porphyry with contaminations of old basement of Yangtze Craton. The IV stage alkali-feldspar granite-porphyry has similar depth of magma source and crystallization differentiation, while it is smallest outcrop and lowest partial melting degree. Furthermore, early- and late-stages lamprophyres, with the deepest magma source and reduced scale, intruded following porphyritic granite and granite porphyry, respectively.

![Figure 1. The magmatic emplacement model in Baoxingchang area.](image)

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