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The Permian–Triassic granitoids in Bayan Obo, North China Craton: A geochemical and geochronological study

Ming-Xing Ling [a,*], Hong Zhang [b], He Li [c], Yu-Long Liu [c], Jian Liu [d], Lin-Qing Li [e], Cong-Ying Li [c], Xiao-Yong Yang [f], Weidong Sun [c,*]

[a] State Key Laboratory of Isotope Geochemistry, Guangzhou Institute of Geochemistry, Chinese Academy of Sciences, Guangzhou 510640, China
[b] State Key Laboratory of Continental Dynamics, Department of Geology, Northwest University, Xi'an 710069, China
[c] CAS Key Laboratory of Mineralogy and Metallogeny, Guangzhou Institute of Geochemistry, Chinese Academy of Sciences, Guangzhou 510640, China
[d] Zhejiang Institute of Geological Survey, Hangzhou 311203, China
[e] Hebei Institute of Regional Geology and Mineral Resources Survey, Langfang 065000, China
[f] CAS Key Laboratory of Crust–Mantle Materials and Environments, School of Earth and Space Sciences, University of Science and Technology of China, Hefei 230026, China

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ABSTRACT

Granitoids near the Bayan Obo giant rare earth element (REE) deposit at the north margin of the North China Craton (NCC), the world's largest light REE (LREE) deposit, have been taken by some authors as the key factors that controlled the mineralization. In contrast, others proposed that the REE deposit has been partially destructed by these granitoids. Here we report systematic studies on geochronology and geochemical characteristics of granitoids of different distances from the orebodies, to investigate the genesis and their relationship to the giant Bayan Obo deposit. Granitoids studied here, including granites and quartz monzonites, are peraluminous with A/CNK = 0.99–1.11, LREE enriched and heavy REE (HREE) depleted, with variable REE concentrations (total REE = 54–330 ppm) and large negative Eu anomaly (δEu = 0.19–0.70). The REE patterns are distinct from those of ore-bearing dolomites. Some samples have slightly higher LREE concentrations, which may have been contaminated by the orebodies during intrusion. Trace elements of the granitoids are characterized by positive Pb anomaly, strong negative Ti anomaly and Nb, Ta and Sr anomalies. The granites exhibit negative Ba anomaly. The granitoids plot within the post-collision granite field in the Pearce diagram, which is consistent with the tectonic regime. The quartz monzonites and one granite have A-type granite characteristics and belong to the A_2 subgroup. Zircons in these granitoids have high Th/U values, which are typical for magmatic zircons. High precision U–Pb dating for these zircons by secondary ion mass spectrometry (SIMS) and laser ablation inductively coupled plasma mass spectrometry (LA–ICP-MS) yields Permian–Triassic $^{206}Pb/^{238}U$ ages ranging from 243.2 to 293.8 Ma. The formation of the granitoids is >55 Ma later than the latest ore forming age. The zircons have low La concentrations (0.02–12 ppm), high $(Sm/La)_N$ (0.8–685) and Ce/Ce^* (1.4–80). The Ti-in-zircon temperature of the granitoids ranges from 590 to 770 °C. All these evidences suggest that the granitoids have no contribution to the formation of the Bayan Obo deposit. Granitoids that are close to the orebodies had limited interaction with it and gained some LREE-enriched characteristics during magmatisms. Nevertheless, their effects to the orebodies are subtle. All the granitoids formed in a post-collisional tectonic regime at convergent margins, which is consistent with plate subduction during the closure of the Palaeo-Asian Ocean, which started in the Neoproterozoic and lasted until the Carboniferous/Permian.

1. Introduction

Bayan Obo, located at the northern margin of the North China Craton (NCC) (Fig. 1), is the largest light rare earth element (REE) deposit in the world, the largest niobium (Nb) and thorium (Th) deposit, and a major iron (Fe) deposit in China (Chao et al., 1992; Kynicky et al., 2012; Lai and Yang, 2013; Ling et al., 2013; Y.L. Liu et al., 2008; Tu, 1998; Yang and Le Bas, 2004; Yang et al., 2009; Yuan et al., 1992). Granitoids are widespread near the Bayan Obo deposit (Fig. 1), which have been studied by several groups (Chao et al., 1997; Fan et al., 2009; Ling et al., 2013; Wang, 1980; Wang et al., 1973, 1994; Yang et al., 2000; Yuan et al., 1992). These granitoids were taken by some authors as the key factors that controlled the mineralization (IGCAS, 1988; Wang et al., 1973), while others proposed that the REE deposit has been partially transformed and further metasomatized by the granitoid intrusion (Yuan et al., 1992), but little REE ore-forming material was brought into the orebodies (Yuan et al., 1992). Recent studies favor that there is no connection between the granitoids and the formation of the REE deposit (Fan et al., 2009; Ling et al., 2013; Yang et al., 2000). Nevertheless,

* Corresponding authors.
E-mail addresses: mxling@gig.ac.cn (M.-X. Ling), weidongsun@gig.ac.cn (W. Sun).

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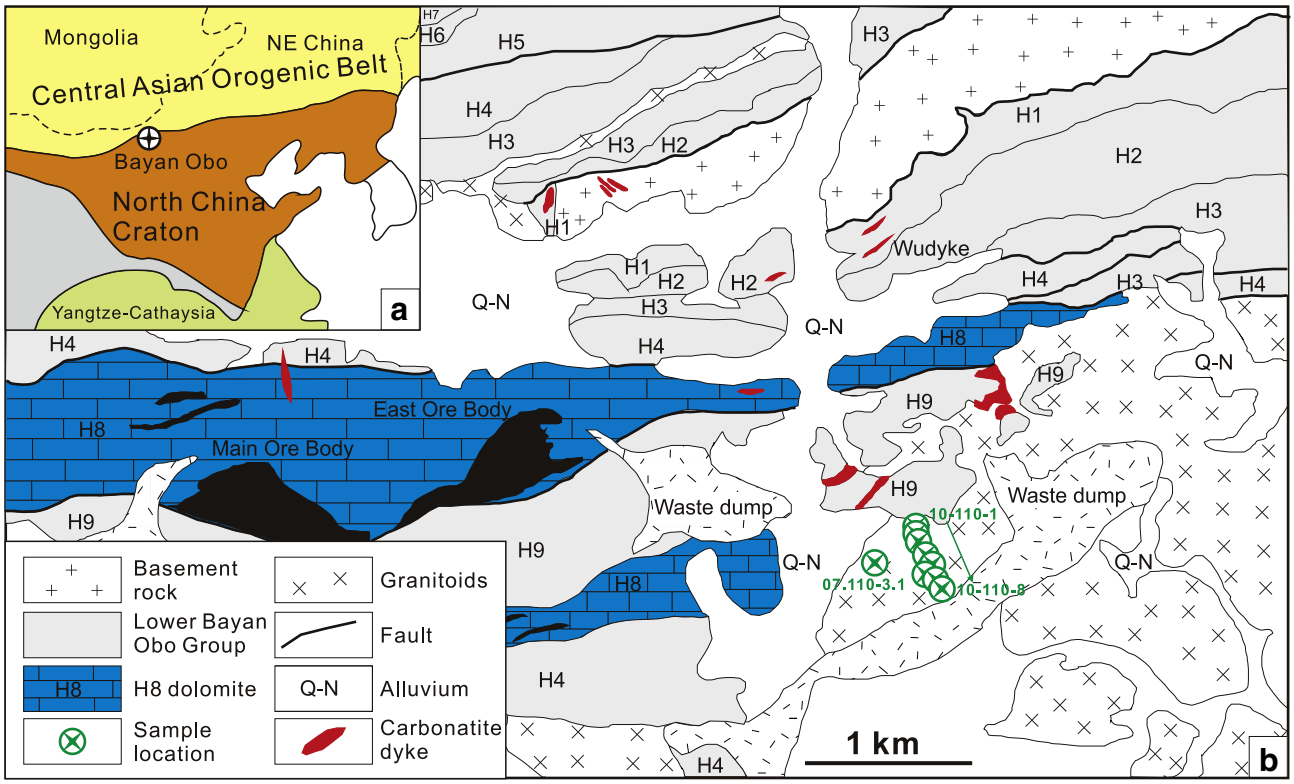

Fig. 1. Geological setting in Bayan Obo, North China Craton. (a) Simplified map showing the location of Bayan Obo, the North China Craton, and the Central Asian Orogenic Belt, modified after Jahn et al. (2000) (b) Sketch geological map of Bayan Obo, showing the Triassic–Permian granitoids and the sample locations, modified after Y.L. Liu et al. (2008) and Ling et al. (2013).

granitoids contacting with the orebodies do have higher REE content than others (Wang, 1980). Given that most previous dating of the granitoids gives Permian ages, e.g., K–Ar age 246–270 Ma (IGCAS, 1988), Rb–Sr isochron age 264 ± 91 Ma or 249 ± 35 Ma (Zhang et al., 2003), Rb–Sr isochron age 255.2 ± 8.2 Ma (Wang et al., 1994, and references therein), 263–273 Ma by LA–ICP-MS zircon U–Pb dating (Fan et al., 2009), and 267.4 ± 2.2 Ma by SIMS zircon U–Pb dating (Ling et al., 2013), it has been argued that the granitoids made no contribution to the mineralization (Ling et al., 2013). Nevertheless, there are large volumes of granitoid intrusions near the Bayan Obo region. Only a few have been dated, and there is no systematic geochemical data yet reported. In addition, many of the previously reported ages were not done using suitable methods, and the ages varied dramatically with large uncertainties. Moreover, these granitoids may have negative effects in the form of remobilization and grade reduction on the Bayan Obo deposit, which have not been previously studied.

To test these possibilities, we sampled a granitoid profile of ~800 m from the southeast boundary of the Bayan Obo deposit outward, and carried out a detailed geochemical study, aiming at better constraints on the genesis of these granitoids and their relation to the Bayan Obo deposit.

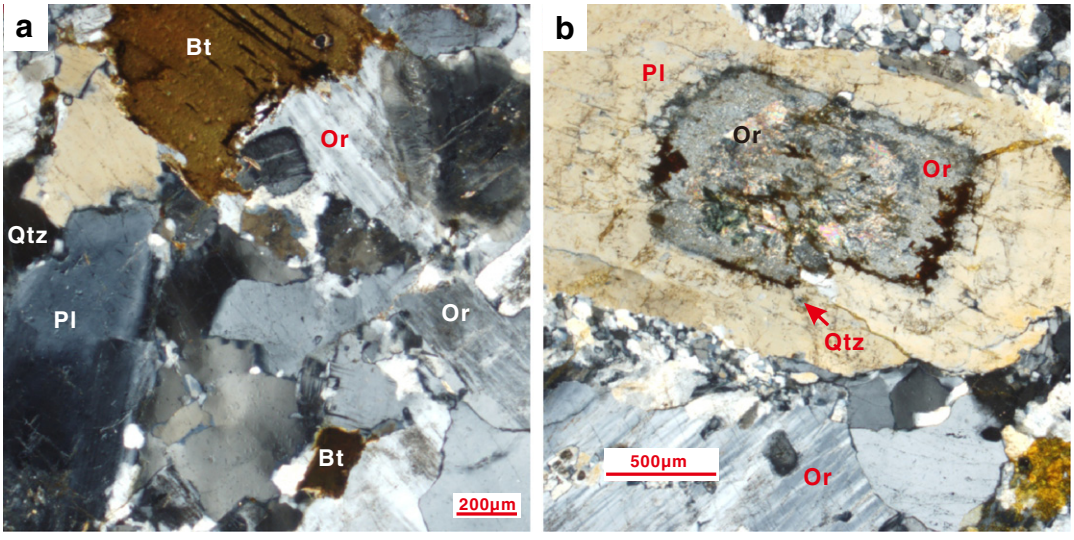

Fig. 2. Cross-polarized microscopic photos of the granitoids. Qtz = quartz, Pl = plagioclase, Or = orthoclase, Bt = biotite.