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Metasomatic silicate chemistry at the Bayan Obo Fe–REE–Nb deposit, Inner Mongolia, China: Contrasting chemistry and evolution of fenitising and mineralising fluids

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Abstract

Fenite aureoles around carbonatite dykes, and alteration associated with Fe–REE–Nb ore bodies at Bayan Obo, Inner Mongolia, China, show alkali silicate assemblages containing aegirine–augite, (magnesio-)riebeckite, (magnesio-)arfvedsonite, and phlogopite, accompanied by varying amounts of apatite, albite and quartz. In both fenites and orebodies simple thermodynamic constraints indicate mineral parageneses are consistent with rock buffered cooling accompanied by the infiltration of a range of externally buffered hydrothermal fluids. Statistical analysis of amphibole chemistry indicates that even in apparently texturally well constrained paragenetic stages wide variations in chemistry occur in both the ore bodies and fenites. Much of this variation is attributable to the Mg and F content of amphibole, and is therefore interpreted as a result of variation in externally controlled variables (*P*, *T*, initial fluid composition) rather than internally controlled variables such as protolith composition. Similarities in chemistry exist between fenite and some ore body amphiboles. Thermodynamic analysis of the composition of biotite and apatite allows constraints to be placed on the F-content of hydrothermal fluids, and indicates relatively consistent compositions in fenites and orebodies ($\log a_{HF}/a_{H_2O} = -3.8$ to -3.6 at 300 °C and 1 kbar). Amphibole and biotite associated with niobate mineralization are both enriched in fluorine relative to the rest of the paragenesis, and biotite compositions indicate significantly higher HF activities in the hydrothermal fluid ($\log a_{HF}/a_{H_2O} = -2.6$ at 300 °C and 1 kbar). The data presented here reinforce previous interpretations of the complex, multistage nature of mineralisation at Bayan Obo, but are still consistent with a direct involvement of carbonatite derived fluids during ore genesis.

Keywords: Amphibole; Biotite; Fenite; Bayan Obo; Fluid chemistry

1. Introduction

The Fe–REE–Nb deposit at Bayan Obo, Inner Mongolia, China, is the world's largest known rare-earth element (REE) resource, and formed by multiple episodes of hydrothermal activity (Drew et al., 1990; Yuan et al., 1992; Chao et al., 1992, 1993, 1997). Much interest has been focused on the deposit because of its extraordinary metal concentrations, and its similarities to both carbonatitic deposits and the broad group of igneous-related Fe-oxide–(Cu–U–Au–REE) deposits (Hitzman et al., 1992). Various origins have been proposed (reviewed by Wu et al., 1996; Smith and Wu, 2000), with models involving fluids derived

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from carbonatite or alkaline magmatism (Drew et al., 1990; Yuan et al., 1992; Campbell and Henderson, 1997), subduction (Chao et al., 1992, 1997; Wang et al., 1994), or A-type granite magmatism (Chao et al., 1997). Unequivocal carbonatites do occur in the Bayan Obo area, but no previous attempts have been made to compare the associated fenitisation with the alteration within and surrounding the ore bodies.

This paper presents new textural descriptions and analyses of alteration phases from both fenites and ore bodies, carried out in order to examine links between the carbonatite dykes and the hydrothermal alteration within the orebodies. These data are examined in terms of their implications for fluid compositions. Using an internally consistent thermodynamic database allows fluid compositions to be calculated in terms of species activities, which can then be more easily related to fluid compositions (Zhu and Sverjensky, 1991), than halogen acid fugacities (e.g. Munoz, 1984). New data from Bayan Obo are important in the further development of models for ore genesis in the area, and are relevant to problems relating to the hydrothermal mobility of the high field strength elements (HFSE), particularly the REE and niobium, and understanding the processes involved in alkaline alteration.

2. Geological setting

The Bayan Obo Fe–REE–Nb deposit is located in Inner Mongolia, China (109° 59′ E; 41° 48′ N), and has estimated total reserves of 600 Mt of iron oxides (Yuan et al., 1992) and in excess of 100 Mt REE–oxide (Ren, 1985). The deposit is contained within the sediments of the Proterozoic Bayan Obo Group (Fig. 1), which consists

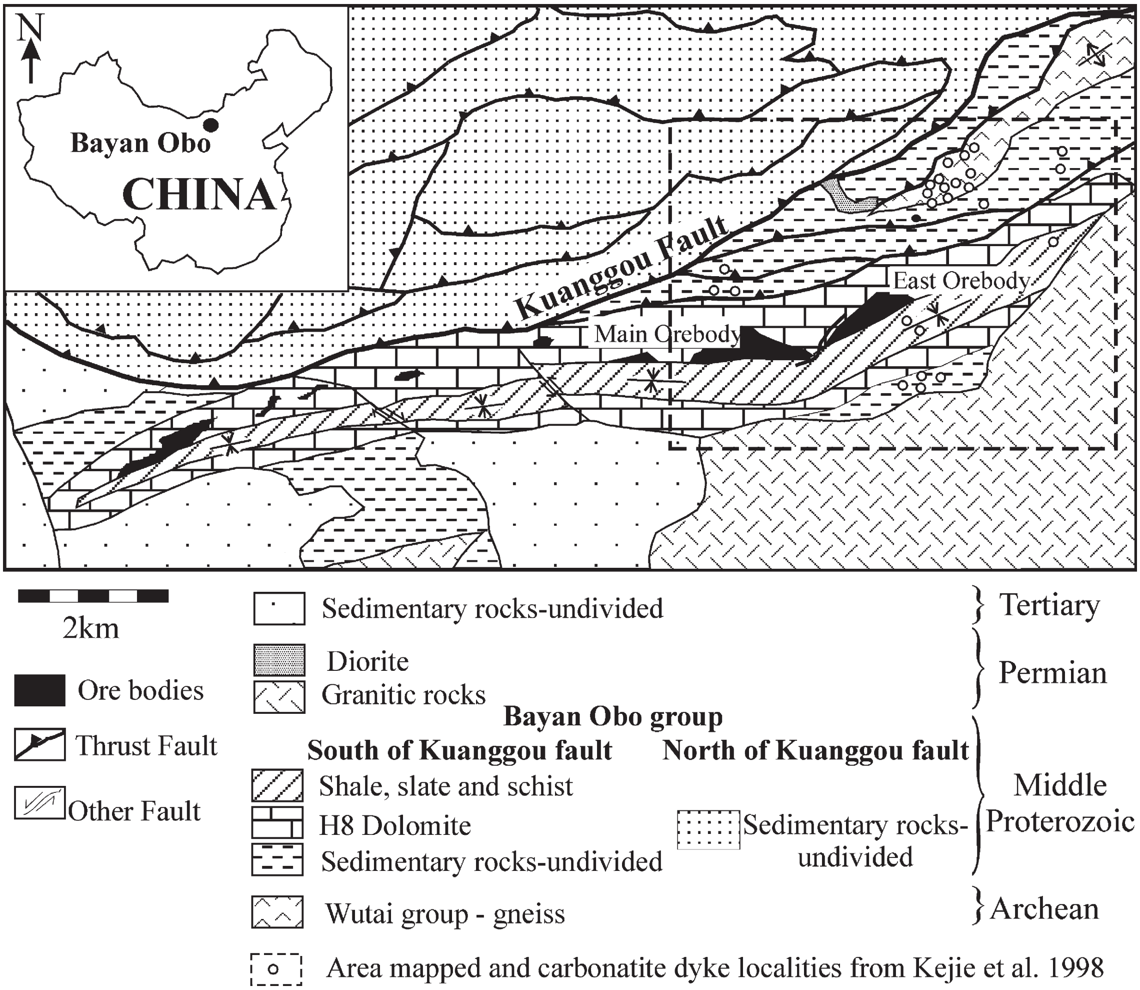

Fig. 1. Sketch map of the geology surrounding the Bayan Obo ore deposits, adapted from Chao et al. (1992). Also shown are the area mapped and locations of carbonatite dykes from Tao et al. (1998).