Characterizing a new type of nelsonite recognized in the Damiao anorthosite complex, North China Craton, with implications for the genesis of giant magmatic Fe-Ti oxide deposits

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ABSTRACT

Nelsonite (Fe-Ti oxide-apatite rock) devoid of silicates offers a rare opportunity to investigate the magma processes for the formation of magmatic Fe-Ti oxide deposits. Both fractional crystallization and silicate liquid immiscibility have been put forward, but the lack of robust evidence has hindered unambiguously distinguishing the role of these two processes in Fe-Ti mineralization. The nelsonite and associated Fe-Ti-P-rich rocks hosted in the Proterozoic Damiao anorthosite complex represent a typical example for studying Fe-Ti ore-forming processes. We recognized a new type of nelsonite (type-I) in the Damiao complex, which is distinct from the two known types of nelsonite (type-II and type-III) from the same complex. The type-I nelsonite is characterized by its coexistence with oxide-apatite gabbronorite and granite in the same dike, and all these rocks have identical emplacement ages (1740 ± 7 Ma), subparallel REE patterns, and major-element compositions lacking intermediate compositions, suggesting derivation from conjugate Fe- and Si-rich melts generated by silicate liquid immiscibility. The large type-II nelsonite bodies form irregular dikes along fractures in anorthosite and constitute the major ore type. The type-III nelsonite occurs as conformable layers or pods within oxide-apatite gabbronorite and pyroxenite, and occupies the end part of the type-II dike. The latter two types of nelsonites formed by extensive fractional crystallization of residual magma with crystal accumulation and subsequent hydrothermal replacement. During residual magma evolution, silicate liquid immiscibility was crucial for Fe-Ti-P enrichment, fractional crystallization was responsible for enhancing oxide-apatite concentrations, and hydrothermal replacement was effective for mobilizing oxide-apatite concentrations. Our newly recognized nelsonite provides an unambiguous, outcrop-scale, field evidence for the operation of silicate liquid immiscibility process. We show that giant magmatic Fe-Ti oxide orebodies can form by a combination of processes involving silicate liquid immiscibility, fractional crystallization and hydrothermal mobilization.

Keyword: Fe-Ti oxide deposits, nelsonite, silicate liquid immiscibility, fractional crystallization, anorthosite

INTRODUCTION

Magmatic Fe-Ti oxide deposits associated with mafic layered intrusions and Proterozoic anorthosite complexes are important sources of iron, titanium, and vanadium. Large Fe-Ti oxide orebodies represent extreme differentiation products of tholeiitic basalt magma, but the magmatic processes responsible for producing these oxide concentrations have been an enduring problem in economic geology and igneous petrology (Bowen 1928; Ashwal 1993; Duchesne 1999; Veksler 1999; Namur et al. 2012; Charlier et al. 2015; Bai et al. 2021). Nelsonite (Fe-Ti oxide-apatite rock) (Watson and Taber 1910) devoid of silicates constitutes an important ore type of the Fe-Ti oxide deposits, and has been regarded as a unique rock type critical for understanding the magma processes leading to Fe-Ti mineralization (Philpotts 1967; Kolker 1982; Tollari et al. 2008; Duchesne and Liégeois 2015).

Most nelsonite occurs in close association with Proterozoic anorthosite complexes and generally form veins or dikes crosscutting surrounding anorthosite, but sometimes also occurs as conformable layers within Fe-Ti oxide-rich silicate rocks (Ashwal 1993; Duchesne 1999; Zhang 2018). The origin of nelsonite remains enigmatic. The cross-cutting relationship and experimental results have led many researchers to consider an origin from crystallization of Fe-Ti-P-rich melt segregated from its Si-rich immiscible conjugate (Philpotts 1967; Kolker 1982; Van Tongeren and Mathez 2012; Zhou et al. 2013; Wang et al. 2018; Coint et al. 2020), whereas others attribute the formation of such ore bodies to extensive fractional crystallization associated with crystal sorting and accumulation from a homogenous melt on the basis of their conformable occurrences (Dymek and Owens 2001; Pang et al. 2008; Song et al. 2013; Lindsley and Epler 2017). This discrepancy is largely due to the difficulty in distinguishing the role of fractional crystallization and silicate liquid immiscibility in Fe-Ti mineralization (Veksler et al. 2006; Van Tongeren and Mathez 2012; Charlier et al. 2015).