The genesis of mantle-derived sapphirine

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ABSTRACT

Sapphirine, a typical ultrahigh-temperature metamorphic mineral, is rarely found in mantle xenoliths. Here we report the occurrence and characteristics of sapphirine in a mantle-derived xenolith from the Cenozoic basalts of Hannuoba in the North China Craton. The xenolith consists of a clinopyroxene, spinel, and sapphirine assemblage, with the sapphirine occurring as the reaction rim surrounding spinel. The mineral compositions of this sample are all characterized by high Mg contents, similar to those of minerals from other sapphirine-bearing rocks reported from high-Mg-Al granulites elsewhere in the world. Clinopyroxene is relatively rich in Al and Ca in comparison to pyroxene in peridotite and pyroxenite xenoliths in the Hannuoba basalts, as well as in global mafic and felsic granulites in other terranes, a feature that is consistent with the bulk composition. The P-T compilations from both experimental and natural rock data show a restricted stability field for the coexisting clinopyroxene + spinel + sapphirine assemblage of around 8–15 kbar and 800–900 °C. The rare occurrence of sapphirine in a mantle-derived xenolith therefore suggests specific bulk composition, restricted P-T range and possible melt-peridotite interaction. Such conditions are best satisfied in a tectonic setting with basaltic magma underplating and interaction between the infiltrating melts and the wall-rock peridotite.

Keywords: Sapphirine, pyroxenite, P-T condition, North China Craton

INTRODUCTION

Experimental studies and P-T estimates from natural assemblages and mineral phase equilibria modeling have constrained the stability of sapphirine under ultrahigh-temperature (UHT) and medium- to high-pressure conditions of 900–1100 °C and 10–18 kbar, corresponding to lower crustal and upper mantle depths (e.g., Ackerman et al. 1975; Sills et al. 1983; Powell and Holland 1985; Griffin and O’Reilly 1986; Christy 1989; Das et al. 2006; Sato et al. 2006; Brigida et al. 2007; Podlesskii et al. 2008; Kelsey 2008). Sapphirine has been reported in Mg-Al granulites subjected to extreme crustal metamorphism under UHT conditions in various regions of the world (e.g., Lal et al. 1987; Okay 1994; Santosh et al. 2007, 2009; Galli et al. 2011; Jiao and Guo 2011). The stability of sapphirine-bearing assemblages in metamorphic orogens exhumed from depth has been a topic of wide interest in characterizing metamorphic P-T conditions, tectonic architecture, and crustal evolution (e.g., Sills et al. 1983; Christy 1989; Okay 1994; Mattielli et al. 1996; Grecoire et al. 2001; Harley 2004; Santosh et al. 2007, 2009, 2012; Tsunogae and Santosh 2011; Tsunogae et al. 2011; Xiang et al. 2012).

Mantle-derived sapphirine has been rarely reported, such as in pyroxenite xenoliths from Stockdale, Kansas (Meyer and Brookins 1976), from Delegates, New South Wales, Australia (Griffin and O’Reilly 1986), the Beni Bousera massif, Morocco (Kornprobst et al. 1990), and the Ronda massif, Spain (Morishita et al. 2001). Sapphirine in these pyroxenites exhibits diverse textural relationships despite the relatively consistent mineral assemblages, suggesting that sapphirine occurs in a wide range of P-T conditions and bulk compositions. Griffin and O’Reilly (1986) suggested that sapphirine is stable under upper-mantle conditions in Ca-Al-Mg-rich bulk compositions, whereas Okay (1994) suggested that the vast majority of sapphirine-bearing rocks are rich in Mg and Al and poor in Ca, consistent with the composition of the mineral. Sapphirine occurs as relics of a low-P mafic granulate assemblage preserved in garnet in Okay’s (1994) study. Christy (1989) suggested that sapphirine might be a widespread constituent of basic rocks with high Mg/(Mg+Fe) ratio. The models proposed to explain the origin of sapphirine in such rocks include recycling of crustal material (Morishita et al. 2001) and exsolution of clinopyroxene (Kornprobst et al. 1990; Mattielli et al. 1996).

The Cenozoic Hannuoba basalts occur along the northern part of the Trans-North China Orogen, a Paleoproterozoic suture that amalgamates the Western and Eastern Blocks in the North China Craton. Abundant lower crustal and upper mantle xenoliths are found in the basalts and have been studied by various workers (Fan et al. 2001; Liu et al. 2010; Rudnick et al. 2004; Zhang 2009; Zheng et al. 2009; Zhang et al. 2011, 2012). However, the present study is the first report of sapphirine-bearing rocks from Hannuoba. We present detailed petrologic and geochemical data on the sapphirine-bearing clinopyroxenite from Hannuoba and compare our results with other occurrences in an attempt to characterize the origin of mantle-derived sapphirine, as well as suggest possible chemical discriminants between sapphirines of crustal and mantle origins.