Interaction of seawater with (ultra)mafic alkaline rocks—Alternative process for the formation of aegirine

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ABSTRACT

Submarine mafic and relatively Na-poor alkaline rocks in the Outer Carpathians often contain aegirine, a sodic pyroxene usually found in differentiated alkaline rocks. Its presence in rocks that are too basic and Na-poor for its conventional magmatic appearance is linked to sodic alteration of submarine alkaline rocks. Aegirine crystals grow on altered rims of diopside, commonly with crystallographic unconformity, suggesting that their growth was related to alteration and that aegirine does not represent a late stage of continuous clinopyroxene crystallization. The U-shaped REE patterns in the studied aegirine lack Eu anomaly, characteristic for aegirine from differentiated alkaline rocks. Therefore, the involvement of chemically more evolved magma is unlikely to have played any role in the formation of aegirine in ijolites and essexites. Formation of aegirine in submarine alkaline rocks may thus represent an alternative process to spilitization. However, this process is strongly limited by the availability of Fe³⁺ oxidized and mobilized by hydrothermal alteration, which may explain a relative scarcity of aegirine observed in submarine alkaline rocks compared to near-complete albitionization of spilites, and its absence in high-MgO rocks (>10 wt%). Due to the blocking effect related to Fe²⁺ unavailability, ijolites, and essexites do not display significant Na enrichment. We posit that Na incorporated in aegirine was mainly sourced from the zeolitized interstitial glass.

Keywords: Aegirine, sodic metasomatism, pyroxene recrystallization, submarine alkaline rocks, teschenite

INTRODUCTION

Aegirine (nominally NaFe³⁺SiO₄) is a member of the clino-pyroxene group and forms green to greenish-black zoned crystals displaying strong green to brown pleochroism. It mainly occurs in differentiated alkaline rocks (alkaline granites/rhyolites, foid syenites, phonolites, leucocratic foidites, and related pegmatoid rocks) in association with sodic amphibole, alkali feldspar, and nepheline or quartz (e.g., Yagi 1966; Larsen 1976; Pazdernik 1997; Piilonen et al. 1998; Baudouin et al. 2016). Aegirine was also frequently reported in high-pressure, low-temperature metamorphic rocks such as greenschist, blueschist, and epidote-amphibolites (e.g., Banno and Yamada 2012; Flores et al. 2015; Ghose et al. 2022), as a product of sodic metasomatism–fenitization (e.g., Sutherland 1969; Cooper et al. 2016; Weidendorfer et al. 2016), as an authigenic phase resulting from diagenesis/anchimetamorphism of marine sediments (e.g., Fortey and Michie 1978; McSwiggen et al. 1994), and in Na-rich magmatic rocks including carbonatites (e.g., Woolley et al. 1995; Chakhmouradian and Mitchell 2002; Ackerman et al. 2021). Its hydrothermal origin at temperatures around ~200 °C was experimentally proven as well (Decarreau et al. 2004). In magmatic systems, it usually crystallizes at lower magmatic temperatures, close to the solidus of differentiated alkaline melts at a high oxygen fugacity (e.g., Yagi 1966; Mann et al. 2006). The presence of aegirine in (ultra)mafic alkaline rocks may imply: (1) extensive differentiation during the crystallization of mafic magma (e.g., Weidendorfer et al. 2016), or (2) a mingling/mixing process involving a batch of a differentiated alkaline melt (e.g., Chakhmouradian and Mitchell 2002). Neither of these modes of the formation of aegirine is likely applicable to (ultra)mafic alkaline rocks, considering no other signs of differentiation or mixing with chemically evolved melts and the relatively limited contents of Na₂O.

In the Bohemian Massif and the Outer Carpathians (Central Europe), aegirine was found in Mesozoic alkaline mafic to ultramafic rocks (e.g., Ulrych et al. 1996; Dolníček et al. 2010), although it normally crystallizes from differentiated alkaline melts. Aegirine occurs in the so-called Teschenite Association Rocks (TAR; Menčík et al. 1983), submarine alkaline rocks of the Outer Carpathians, but is much less frequent compared to diopside. Aegirine was, for the first time in the TAR, reported by Pacák (1926) from several localities. He mentioned continuous compositional mixing series between both aegirine–aegirine-augite and aegirine–augite. However, such observations were solely based on optical microscopy with no in situ micro-analytical technique.