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Research paper

Corundum formation by metasomatic reactions in Archean metapelite, SW Greenland: Exploration vectors for ruby deposits within high-grade greenstone belts

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ABSTRACT

Corundum (ruby-sapphire) is known to have formed *in situ* within Archean metamorphic rocks at several localities in the North Atlantic Craton of Greenland. Here we present two case studies for such occurrences: (1) Maniitsoq region (Kangerdluarssuk), where kyanite paragneiss hosts ruby corundum, and (2) Nuuk region (Storø), where sillimanite gneiss hosts ruby corundum. At both occurrences, ultramafic rocks (amphibole-peridotite) are in direct contact with the ruby-bearing zones, which have been transformed to mica schist by metasomatic reactions. The bulk-rock geochemistry of the ruby-bearing rocks is consistent with significant depletion of SiO_2 in combination with addition of Al_2O_3, MgO, K_2O, Th and Sr relative to an assumed aluminous precursor metapelite. Phase equilibria modelling supports ruby genesis from the breakdown of sillimanite and kyanite at elevated temperatures due to the removal of SiO_2. The juxtaposition of relatively silica- and aluminum-rich metasedimentary rocks with low silica ultramafic rocks established a chemical potential gradient that leached/mobilized SiO_2 allowing corundum to stabilize in the former rocks. Furthermore, addition of Al_2O_3 via a metasomatic reaction is required, because Al/Ti is fractionated between the aluminous precursor metapelites and the resulting corundum-bearing mica schist. We propose that Al was mobilized either by complexation with hydroxide at alkaline conditions, or that Al was transported as K-Al-Si-O polymers at deep crustal levels. The three main exploration vectors for corundum within Archean greenstone belts are: (1) amphibolite- to granulite-facies metamorphic conditions, (2) the juxtaposition of ultramafic rocks and aluminous metapelite, and (3) mica-rich reactions zones at their interface.

1. Introduction

Corundum (Al_2O_3) is a relatively rare metamorphic mineral that requires unusual geochemical conditions of low silica activity combined with high aluminum contents of the host rock. Corundum in its purest form is colorless, but when trace element impurities of Cr, Fe or V enter the structure, corundum can become the colored gem ruby (red) or sapphire (blue), although other colors are also possible (e.g., Simonet et al., 2008). High quality gem ruby can be as expensive as diamond (e.g., Shor and Weldon, 2009); hence it is of economic interest for mineral exploration companies, as well as for small-scale miners.

A major concern for gemologists is to identify the origins of gem quality corundum in order to control the trade of ruby and sapphire to avoid illegal activities. In recent years, several analytical methods have been employed with the aim of fingerprinting the origins of cut gem stones, including oxygen isotope analysis, Raman spectroscopic analysis (for inclusions), and *in situ* trace element analysis (e.g., Porto and Krishnan, 1967; Giuliani et al., 2005, 2014; Pornwilard et al., 2011). It has been demonstrated that corundum from Greenland has a rather unique composition in a global context, including mantle-like O-isotope compositions and elevated Cr and Si, which allows for precise fingerprinting of cut gems originating from the North Atlantic Craton (Thirangoon, 2008; Keulen and Kalvig, 2013). This specific signature reflects

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the unusual geologic conditions in which Greenlandic ruby has formed, as we will give examples of in this paper.

One of the fundamental issues relevant for corundum prospecting is to identify the combination of rock types and metamorphic environment that favors its formation. Many of the most economic ruby occurrences are placer deposits sourced from marbles hosting corundum or alkaline dykes containing corundum xenocrysts (e.g., Sutherland et al., 1998; Garnier et al., 2008; Groat et al., 2014). In metamorphic terranes, proposed mechanisms for corundum stabilization include hydrothermal alteration (e.g., Bottrill, 1998), metasomatic exchange of silica with the ultramafic rocks (e.g., Riesco et al., 2005), and anatexis of aluminous protoliths accompanied by melt loss (e.g. Cartwright and Barnicoat, 1986; Palke et al., 2017).

In the present study, we highlight a less common primary geological environment of corundum formation, namely high-grade Archean greenstone belts. We present two case studies from southern West Greenland, where ruby corundum is hosted by aluminous Archean metapelite. Thermodynamic modelling is used to show under which pressure, temperature and geochemical conditions such rocks can stabilize corundum, and we demonstrate the critical importance of associated ultramafic rocks, which act as chemical buffers to maintain a low silica activity in the system. We summarize our findings by proposing several exploration vectors for corundum deposits within Archean greenstone belts, which may have applications for similar geological environments globally.

2. Geologic setting

The main portion of the North Atlantic Craton occurs along the SW coast of Greenland (Fig. 1). It is dominated by high-grade grey orthogneiss of the tonalite-trondhjemite-granodiorite (TTG) suite, although greenstone belts and fragmented anorthosite complexes also comprise an important component (e.g., Windley and Garde, 2009). Given that the Archean greenstone belts in this region have all experienced amphibolite- to granulite-facies metamorphism (e.g., McGregor and Friend, 1992; Garde, 1997), the neutral term 'supracrustal belt' has traditionally been preferred for such rock associations, and we therefore use this 'local' nomenclature here.

The geodynamic environment of formation for Archean crust is debated and still controversial within the geologic community. Some researchers argue that uniformitarian principles can be applied back into the Eoarchean (e.g., Polat et al., 2002; Komiya et al., 2015) or even the Hadean (Harrison et al., 2005; Watson and Harrison, 2005; Hopkins et al., 2008), while others argue that modern-style plate tectonics did not operate until the Mesoarchean (Smithies et al., 2007; Dhuime et al., 2012) or perhaps even the Neoproterozoic (Brown, 2008; Stern, 2008; Hamilton, 2011). There are several Archean cratons which clearly did not form by uniformitarian processes, one such example being the East Pilbara Craton (Collins et al., 1998; Van Kranendonk et al., 2004). However, the North Atlantic Craton may represent the opposite case, in which even the oldest component potentially formed via geologic processes resembling those of modern-style subduction zone systems. The currently favored model for the formation of the Archean continental crust in Greenland is by subduction (e.g., Nutman et al., 1996, 2015; Garde, 1997), and it is also the preferred interpretation for the formation of supracrustal belts (e.g., Garde, 2007; Polat et al., 2008; Jenner et al., 2009; Szilas et al., 2012, 2013, 2017a), as well as for the associated anorthosite complexes of the North Atlantic Craton (Polat et al., 2009, 2012; Hoffmann et al., 2012; Huang et al., 2014). Although the question of the overall geodynamic environment is not the main topic of the present contribution, it does have some implications for the interpretation of the metamorphic evolution of the rocks describe and investigated in the present study.

Corundum is a high-grade metamorphic mineral that has been reported from several localities within Archean rocks in southern West Greenland. The best-known example is the extensive ruby

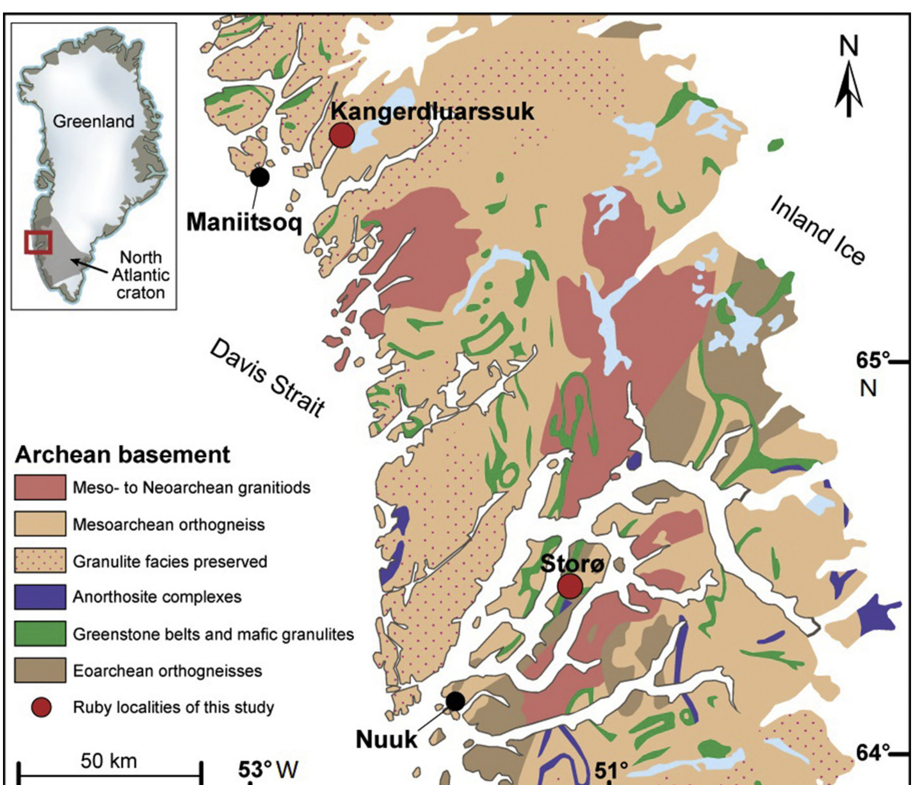

Figure 1. Geological map of the Maniitsoq and Nuuk regions of southern West Greenland. Based on mapping by the Geological Survey of Denmark and Greenland (GEUS).

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