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Marble-hosted ruby deposits of the Morogoro Region, Tanzania

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ABSTRACT

The ruby deposits of the Uluguru and Mahenge Mts, Morogoro Region, are related to marbles which represent the cover sequence of the Eastern Granulites in Tanzania. In both localities the cover sequences define a tectonic unit which is present as a nappe structure thrusted onto the gneissic basement in a north-western direction. Based on structural geological observations the ruby deposits are bound to mica-rich boudins in fold hinges where fluids interacted with the marble-host rock in zones of higher permeability. Petrographic observations revealed that the Uluguru Mts deposits occur within calcite-dominated marbles whereas deposits in the Mahenge Mts are found in dolomite-dominated marbles. The mineral assemblage describing the marble-hosted ruby deposit in the Uluguru Mts is characterised by corundum-dolomite-phlogopite ± spinel, calcite, pargasite, scapolite, plagioclase, margarite, chlorite, tourmaline whereas the assemblage corundum-calcite-plagioclase-phlogopite ± dolomite, pargasite, sapphirine, titanite, tourmaline is present in samples from the Mahenge Mts. Although slightly different in mineral assemblage it was possible to draw a similar ruby formation history for both localities. Two ruby forming events were distinguished by textural differences, which could also be modeled by thermodynamic $T-X_{CO2}$ calculations using non-ideal mixing models of essential minerals. A first formation of ruby appears to have taken place during the prograde path (M1) either by the breakdown of diaspore which was present in the original sedimentary precursor rock or by the breakdown of margarite to corundum and plagioclase. The conditions for M1 metamorphism was estimated at ~750 °C at 10 kbar, which represents granulite facies conditions. A change in fluid composition towards a CO_2 dominated fluid triggered a second ruby generation to form. Subsequently, the examined units underwent a late greenschist facies overprint. In the framework of the East African Orogen we assume that the prograde ruby formation occurred at the commonly observed metamorphic event around 620 Ma. At the peak or during beginning of retrogression the fluid composition changed triggering a second ruby generation. The late stage greenschist facies overprint could have occurred at the waning stage of this metamorphic episode which is in the range of ~580 Ma.

1. Introduction

1.1. Regional geology

The continent-continent collision between West and East Gondwana in Neoproterozoic to Early Palaeozoic eras created an extensive collision zone, the East African Orogen, which transects the eastern part of Africa from the Arabian-Nubian shield in the north to the Mozambican coast in the south (Stern, 1994; Collins and Pisarevsky, 2005). Related to this major thermotectonic event several orogenic phases were identified accordingly. In a first phase island arcs were accreted starting as early as ~750 Ma ago. The subsequent East African Orogeny (EAO) including an active suture zone with a length of more than 1000 km and peak metamorphism at ~640-580 Ma led to the formation of large high-grade metamorphic complexes in East Africa (Stern, 1994; Meert et al., 1995; Appel et al., 1998; Meert, 2003; Sommer et al., 2003; Fritz et al.,

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2005; Tenczer et al., 2006; Hauzenberger et al., 2007). Whether the collision between the Tanzania Craton and the Bangweulu Block can be related to the observed tectono-metamorphic events in the Eastern Granulites is still subject to an ongoing debate. However, results from the Usagaran-Ubendian Belt showed matching ages linked to subduction metamorphism at 580 Ma (Boniface and Schenk, 2012). Finally, the later Kuunga-Malagasy Orogeny at ~570-500 Ma was responsible for another metamorphic episode affecting the continental block of East Africa (Collins and Pisarevsky, 2005; Rossetti et al., 2008; Hauzenberger et al., 2014).

In a simplified manner, the EAO incorporates two granulitic terrains in Kenya and Tanzania, the Western and Eastern Granulites (Fig. 1), which are characterised by westward thrusting onto the Tanzania Craton (Fritz et al., 2005; Rossetti et al., 2008; Viola et al., 2008; Fritz et al., 2009).

The Eastern Granulites which contain the investigated marble-hosted ruby deposits consist mainly of juvenile crust with meta-igneous rocks indicating formation ages of 986-800Ma (Möller et al., 2000; Kröner et al., 2003; Fritz et al., 2005; Tenczer et al., 2006; Hauzenberger et al., 2007). As a particularity, the basement of both the Uluguru and Mahenge Mts as a part of the Eastern Granulites was intruded by anorthosites with intrusion ages between 880 and 820 Ma (Tenczer et al., 2006). Further, the banded pyroxene-bearing granulitic basement described as enderbitic gneiss (Coolen, 1980; Appel et al., 1998) is overlain by nappe structures consisting mainly of meta-carbonates (Rossetti et al., 2008). The nappe structures of the Uluguru and Mahenge Mts were thrusted onto the basement in a north-western dislocation direction (Fritz et al., 2005; Rossetti et al., 2008; Viola et al., 2008; Fritz et al., 2009) and were cut in their root zones by a major fault structure with a north-eastern trending strike (Sampson and Wright, 1964; Schlüter, 1997).

The sedimentation age of the precursor marbles is not well constrained but may be linked to a similar unit in the Cabo Delgardo Nappe Complex in northern Mozambique (Viola et al., 2008; Fritz et al., 2013). The Cabo Delgardo Nappe Complex is characterised by a comparable structural composition to the Eastern Granulites divided into crystalline basement and a meta-sedimentary cover sequence. For marbles belonging to the Cabo Delgardo Nappe Complex covering a sedimentary sequence, ages between 800 and 750 Ma were determined by Melezhik et al. (2008). Finally, there are two generations of late- and post-orogenic pegmatites found in the Eastern Granulites (Fritz et al., 2005; Tenczer et al., 2006; Rossetti et al., 2008; Fritz et al., 2013).

By applying a finite element “hot fold nappe model” after Beaumont et al. (2006) and Fritz et al. (2009) were able to visualise a possible scenario for the tectonic development of the Eastern Granulites in Central Tanzania describing an isobaric cooling P-T path, which was already described by Appel et al. (1998) based on mineral textures. In addition, the proposed model was also capable to explain the different histories of metamorphism found in the Eastern and Western Granulites respectively (Fritz et al., 2005).

1.2. Literature review related to the marble-hosted deposits in the Uluguru and Mahenge Mts

The marble-hosted ruby deposits in Eastern Africa formed during the Neoproterozoic East African Orogen (Malisa and Muhongo, 1990) when parts of Eastern and Western Gondwana collided and experienced granulite facies metamorphic overprint (Appel et al., 1998; Hauzenberger et al., 2014; Tenczer et al., 2012). All other marble-hosted ruby deposits of economic importance are related to the much younger collision of India with Eurasia when the Himalayan and related orogens and structures developed (Balmer, 2011; Giuliani et al., 2014; Rossovskiy et al., 1982).

Until today, most studies and mining activity on primary corundum deposits in East Africa focused on none marble-hosted deposits from sources in the Mangari area, Kenya (Mercier et al., 1999) or from Longido (Keller, 1992), the Umba Valley (Solesbury, 1967), and Winza (Schwarz et al., 2008), the latter three located in Tanzania.

In contrast to these deposits, the marble-hosted ruby deposits in the Morogoro Region did not catch much attention in the past. Although the occurrence of rubies was briefly mentioned in a report following the mapping campaign in the Uluguru Mountains in the early 1960's by Sampson and Wright (1964), their economic importance was not recognised until the 1970's when rubies and spinels from the Morogoro Region started to reach the gem market (Dirlam et al., 1992).

During the same time Malisa and Muhongo (1990) published a general study focusing on regional tectonics related to the Pan African orogeny and the possible connection to the genesis of gem deposits in the Mozambique Belt. Altherr et al. (1982), Hänni and Schmetzer (1991) as well as Msolo (1992) worked specifically on ruby occurrences in the Morogoro Region, Tanzania. Altherr et al. (1982) published a study on a migmatite (or anatexite, as mentioned in the publication) related occurrence in the south of the Uluguru Mts near Ngon'horo (Fig. 2) whereas Hänni and Schmetzer (1991) focused on the gemmological aspects of the rubies produced from this region. Msolo (1992) was concentrating on the geology of one particular mine in the Uluguru Mts, the Visakazi Mine (Fig. 2). Finally, a more exploration orientated work about the ruby occurrences in the Uluguru Mts, Tanzania was published by Muhongo and Errera (1993).

1.3. Primary ruby deposit types

Ruby as one of the most prominent gemstones occurs in a range of different geological settings. Following the classification introduced by Giuliani et al. (2014) primary ruby deposits can be divided into two major groups according to their geological setting: (1) magmatic or igneous deposits are predominantly found in relationship with alkaline basalt volcanism such as the ruby deposits in Thailand, Cambodia, and Laos (Jobbins and Berrangé, 1981; Levinson and Cook, 1994; Guo et al., 1996; Sutherland et al., 1998, 2002; Sutthirat et al., 2001). Only in rare cases, and without any economic importance for rubies as a gem material, rubies can also be found as inclusions in diamonds mined from kimberlites (Hutchinson et al., 2004). (2) The second group of deposit types is related to metamorphic rocks. Where corundum derives from a metamorphic environment the situation is more diverse. Major deposits are related to either metasomatism (e.g. in contact with plumasitic intrusions or skarns) or to metamorphism sensus strictus (e.g. in mafic to ultra-mafic rocks, marbles, gneissic rocks, or in migmatites) (Altherr et al., 1982; Hunstiger, 1990; Mercier et al., 1999; Rakotondarazafy et al., 2008; Schwarz et al., 2008; Nguyen Ngoc Khoi et al., 2016). The best quality of rubies however derives from marble-hosted deposits. Marble-hosted gem quality ruby deposits occur typically in high-grade metamorphic environments preconditioned that the precursor sedimentary rock is distinguished by aluminium enriched layers (e.g., bauxite or Al-enriched marls) (Rossovskiy et al., 1982; Hunstiger, 1990; Garnier et al., 2008; Giuliani et al., 2014).

Within this study we describe ruby bearing mineral assemblages from marbles which were discovered from small scale mining activities in the Uluguru and Mahenge Mountains, Tanzania. Field observations, structural data, observed mineral textures and assemblages as well as mineral reactions calculated in T-X_{CO2} diagrams are used to present a model of ruby formation within the framework of the regional geological situation.