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Mineralogical and geochemical characteristics of BERYL (AQUAMARINE) from the Erongo Volcanic Complex, Namibia

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ABSTRACT

The granite hosted pegmatites of the Erongo Volcanic Complex in central Namibia are well known for the wide variety of minerals present, of considerable interest to mineral collectors. These include (amongst others) often spectacular, museum quality examples of beryl, schorl, jeremejevite, fluorite, quartz, goethite and cassiterite. The locality is particularly recognized for hosting a variety of beryl types, including green, yellow (heliodor), colorless (goshenite) and blue/greenish blue (aquamarine) variants.

Comprehensive geochemical studies of the Erongo beryls are very limited. The present contribution serves to document the visual characteristics (colour, colour zoning, inclusion content) as well as the major and trace element chemistry of 42 blue, two green and one colorless beryl from Erongo, and to compare these with other localities worldwide.

The beryls from Erongo are generally subhedral to euhedral with a well-formed prismatic habit. Idiomorphic crystals, characterised by strong hexagonal prisms, are common. Beryl is commonly associated with schorl, quartz, muscovite, alkali feldspar, plagioclase feldspar, iron oxides, foitite, rossmanite and cassiterite. Aquamarines range from pale blue to deep blue or greenish blue, with marked colour zoning seen in a number of samples. One of the two green beryls examined is of a medium green colour, and is heavily included, while the other specimen has a pale yellowish green colour. The goshenite sample is colourless, clear, and transparent. Numerous cracks are present in the samples examined, and these are usually filled by iron oxides. Inclusions species encountered in the beryl samples are schorl, quartz, muscovite, feldspar, iron oxides and cassiterite, clearly reflective of the host pegmatite mineralogy.

Aquamarine and green beryl contain iron as the main chromophore while goshenite is devoid of chromophores. Fe contents in beryl increase with colour intensity, consistent with the known chromatic effects of Fe in blue, yellow and green beryl. Consistently low Cr contents in all studied beryls do not concur with Cr being a chromophore element for green beryl. Marked compositional zoning is present, with variable Fe (0.79–3.19 wt% FeO_T), Na (0.09–0.35 wt% Na₂O), Al (15.99–18.18 wt% Al₂O₃) in aquamarine. Zoning patterns range from simple core-to-rim transitions, to more complex sector and/or oscillatory zoning. Trace element contents vary amongst the beryl types examined, with the highest contents and most extreme variations observed in the aquamarines. This is probably partly due to sampling bias relating to the size of the sample set examined.

Octahedral cation substitution is dominant, with Na incorporated (over Cs) at the channels, in order to maintain charge balance. Inferences based on charge balance arguments suggest that tetrahedral Be-Li substitution in these beryls may also be present. Cs, Sc, Ga and Mn are positively correlated with Rb, consistent with the incorporation of these elements at the octahedral site (Sc, Mn and minor Ga) or the channel site (Cs, Rb), in order to preserve charge balance. In contrast, Ca, Zn and Ti do not correlate with Rb, nor with Cs. This is unexpected, as Ti and Ca are known to substitute at the octahedral site in beryl, while Ca may also enter the 2a channel site of beryl. The major and trace element chemistry of the beryls are generally similar to other worldwide beryl deposits of similar colour and do not serve to distinguish beryls from Erongo.

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1. Introduction

The cyclosilicate mineral beryl ($\text{Be}_3\text{Al}_2\text{Si}_6\text{O}_{18}$), is the most common mineral of beryllium. It has a ring structure consisting of Si tetrahedra which are linked by Be tetrahedra and Al octahedra. However, various other elements may be incorporated into the crystal lattice, resulting in structural distortion. For instance, Li may substitute for Be at the tetrahedral site, while trivalent (e.g. Fe^{3+} , Sc^{3+} , Cr^{3+} or V^{3+}) and/or divalent (Fe^{2+} , Mg^{2+} , or Mn^{2+}) cations may substitute for Al at the octahedral site. During substitution, charge balance is maintained through incorporation of monovalent cations (Na^+ , Rb^+ , K^+ or Cs^+) at the channel sites (Bakakin et al., 1969; Hawthorne and Černý, 1977). Water (in the form of OH^- or H_2O), as well as F, He, CO_2 , CH_4 , and N (in the form of N or NO_3) may also be incorporated at channel sites, owing to the large diameter (2.1–5.1 Å) of the channels in the crystal lattice (Aines and Rossman, 1984). Taking into account all possible substitutions, the formula can be represented as: ${}^c(\text{Na}, \text{Cs})_{2X-Y+Z} {}^c(\text{H}_2\text{O}, \text{He}, \text{Ar})_{\leq 2-(2X-Y+Z)} + \text{Na}^{\text{T}(2)}(\text{Be}_{3-X}\text{Li}_Y\text{O}_X\text{X}-Y) {}^o(\text{Al}, \text{Fe}, \text{Sc}, \text{Cr}, \text{V})_{2-Z} {}^o(\text{Fe}, \text{Mg}, \text{Mn})_{2+Z} \text{T}(1)\text{Si}_6\text{O}_{18}$, where $Y \leq 2$, $X \geq Y$, $Z \ll 2$ and $2X-Y+Z \leq 2$ and c represents the different channel sites (Černý, 2002).

Pure beryl is colorless, and is known as goshenite. However, variations in chemistry due to element substitution in the crystal lattice, result in a variety of colored beryl minerals also being recognized. These include emerald (green; due to Cr and/or V in the crystal lattice), aquamarine (blue; Fe), heliodor (yellow; Fe) andmorganite (pink; Mn). Investigations into the mineral chemistry of aquamarine have been conducted on a number of localities worldwide including Argentina (Sardi and Heimann, 2014), Brazil (Vianna et al., 2002), Canada (Mihalynuk and Lett, 2003; Adamo et al., 2008; Beal and Lentz, 2010; Groat et al., 2010), China (Wang et al., 2009), Czech Republic (Novák et al., 2011; Příkryl et al., 2014), Italy (Auricchio et al., 1988; Bocchio et al., 2009), Mozambique (Auricchio et al., 1988; Neiva and Neiva, 2005); Nigeria (Schwarz et al., 1996); Pakistan (Auricchio et al., 1988), Slovakia (Uher et al., 2010), Vietnam (Huong et al., 2011; Fridrichova et al., 2015), and Zimbabwe (Auricchio et al., 1988; Černý et al., 2003). However most of these studies were only focussed on major element chemistry, and were typically conducted on a limited number of samples (± 3), with comprehensive studies which

include minor and trace element data being rare. Aquamarine is unusually abundant at the Erongo Volcanic Complex in Namibia (Cairncross and Bahmann, 2006). An availability of a substantial number of samples from the Complex presented an opportunity to not only investigate chemical variations, but to also link the observed variations in major and trace element chemistry to colour and colour zoning, and this is therefore the purpose of the present contribution.

2. Background

The Erongo Volcanic Complex is located in central Namibia, approximately 270 km north-west of the capital, Windhoek (Fig. 1). It forms part of the Damaraland Alkaline Province, one of three large alkaline igneous provinces in Namibia, with the other two being the Lüderitz Alkaline Province and the Kaboos-Bremen Province (Pirajno, 1990). Previous studies of the Complex include investigations into its age, geology, and associated mineralization (Cloos, 1911; Emmermann, 1979; Blümel et al., 1979; Pirajno, 1990, 1994; Pirajno and Schlögl, 1987; Menzies, 1995; Milner, 1997; Pirajno et al., 2000; Wigand et al., 2004; Trumbull et al., 2000, 2004, 2008; Pirajno, 2015). The Complex comprises a mixture of intrusive granite and extrusive mafic and felsic lavas, which form a caldera 30 kms in diameter, with an age of approximately 132 Ma (Pirajno et al., 2000). It is recognized as a famous mineral locality, with spectacular specimens of beryl (Fig. 2), tourmaline, jermenejevite, and many others, having been collected at the site for almost a century (Cairncross and Bahmann, 2006). The occurrence of aquamarine, as well as other beryl varieties, appear to be restricted to miarolitic cavities in the granite (Hirsch and Genis, 1992; Roesener and Schreuder, 1992; Cairncross and Bahmann, 2006).

Geochemical studies of the aquamarines at Erongo are rare, with only Boudreaux (2014) reporting on the chemistry of 16 pale blue aquamarines, with major and minor element chemical data acquired using electron microprobe analysis, and limited trace element data acquired using direct current plasma emission spectrometry. In the current contribution, we report on a detailed investigation into the beryls (particularly aquamarines) from Erongo, with the aim of supplementing the existing, very limited

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