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Micro-inclusion study in beryl: a comparison between schist type and non-schist type

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Abstract. Natural beryl can be separated into two types of geological occurrence based on their relation to the host rocks. Type I deposits: Non-schist-related beryl mineralization, type II deposits: Schist related beryl mineralization. In short term, beryl may be separated roughly by their geological setting as non-schist type and schist type. Different host rock, i.e. different forming environment may cause different inclusion set of beryl from each type. Consequently, inclusion examination is a conclusive method to differentiate between these two types of beryl. Especially, since the non-destructive method of Raman spectroscopy was applied to identify micro-inclusions this approach has been even more conclusive. Schist-type beryl could be specified by the association of quartz, mica, amphibole, and fluid inclusions while other inclusions such as carbonate minerals, apatite, fluorite, feldspars, etc., are responsive for the non-schist-type ones.
Keywords: Micro-inclusion, beryl, schist type, non schist type, Raman.

1. Material and method

For this research, 178 natural facet-cut beryl samples have been investigated for their inclusion. 96 beryl samples of non-schist-related beryl mineralizations are from Colombia (Chivor), Vietnam (Thuong Xuan), Nigeria (Gwantu). Schist related beryl mineralizations are from Kafubu (Zambia), Austria (Habachtal) including 82 samples.

The inclusions were firstly observed, described, and classified using a gemmological microscope with Zeiss optics. Then all of the different types of inclusions were photographed and determined using confocal-Raman spectroscopy. All host beryl samples were polished at two parallel sides with the thickness varying from 1 mm to 4 mm. The experiments determining inclusions of beryl were carried out on a LabRam confocal micro-Raman-system HR-800 equipped with an Olympus-BX41 by JOBIN YVON HORIBA. For searching inclusions as well as measuring a certain point, an objective with a 50 times magnifying power and green laser light (514.532 nm) were used. Raman spectroscopy is a non-destructive technique to identify not only solid but also fluid inclusions in gemstones.

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2. Results

2.1. Observation of non-schist type beryl

2.1.1. Thuong Xuan (Vietnam):

Microscopic observation revealed internal features such as growth tubes, angular or elongated two-phase (liquid and gas, as seen in figure 1a) fluid inclusions in all samples. Multi-phase (liquid, gas and crystal) inclusions were less frequently seen. By means of confocal micro-Raman spectroscopy the liquid and gas phases were examined as water and carbon dioxide respectively (Huong et al, 2011) [1].

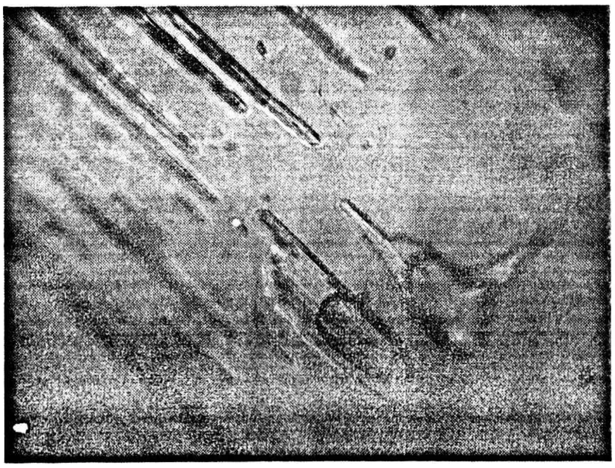

Figure 1a. Two-phase inclusion (liquid and gas) in beryl from Thuong Xuan. x50.

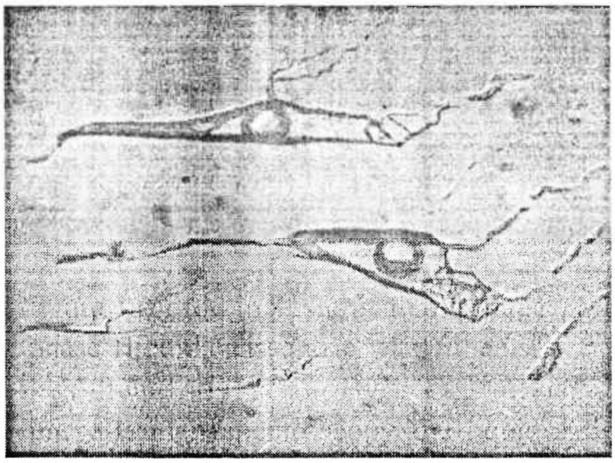

Figure 1b. Multi-phase inclusion (liquid, gas and crystals) in beryl from Thuong Xuan. x 50.

Figure 2a. Hematite inclusion in beryl from Thuong Xuan. x10

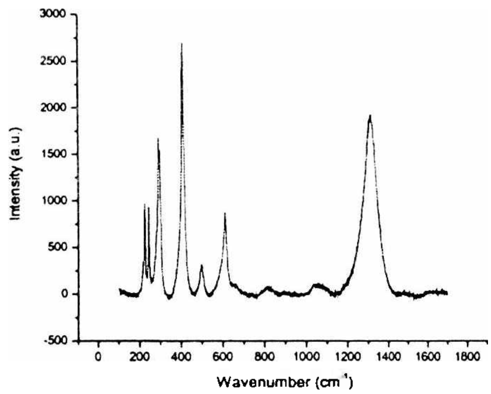

Figure 2b. Raman-spectrum obtained from hematite inclusion in Thuong Xuan beryl.

Multi-phase inclusions with liquid, gas and multi crystals/aggregates were also seen (figure 1b). Confocal micro-Raman spectroscopy revealed that the transparent crystals in one multi-phase inclusion were calcite and the aggregates in other multi-phase inclusion in the same sample were albite. Hematite were also found as mineral inclusions in aquamarine samples from Vietnam (figure 2a).

2.1.2. Chivor (Colombia)

Observations in beryls from Chivor lead to conclude that the main mineral inclusion is pyrite (figure 3a). Other frequently observed inclusions are carbonate crystals (calcite, dolomite) and albite. The appearance of pyrite crystals is the very characteristic feature of these berylsas pyrite is not a frequent inclusion in beryl.

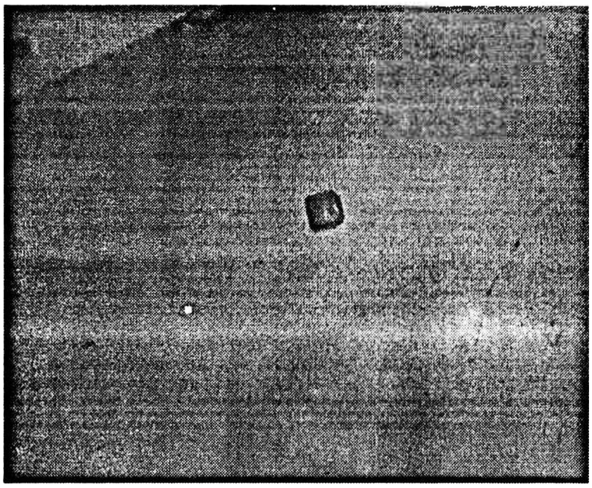

Figure 3a. Pyrite (FeS_2) as well-formed cube in Chivor beryl. x50.

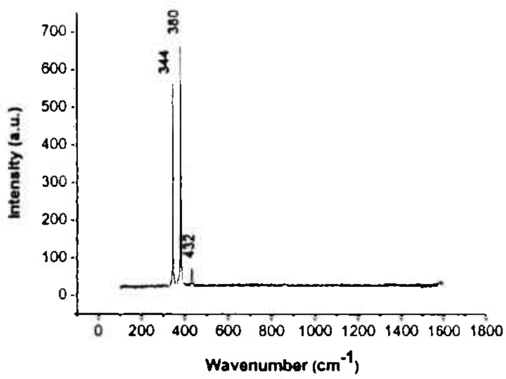

Figure 3b. Raman-spectrum obtained from pyrite inclusion in one Chivor beryl sample.

Figure 4a. Feldspar inclusions in Chivor beryl. x50.

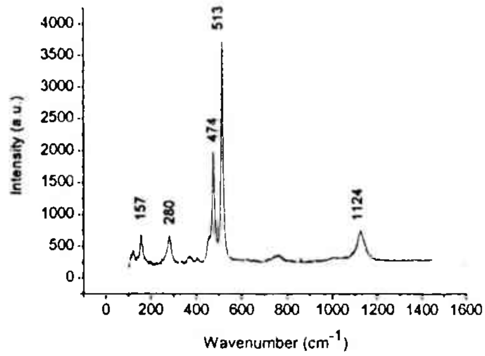

Figure 4b. Raman-spectrum obtained from feldspar (albite) inclusion.

Carbonate inclusions (calcite, dolomite, etc) are transparent, colourless to brown, forming either rhombohedral crystals or irregular bordered grains, and in general, they are small. Albite crystals show yellowish-brown colour in triclinic crystal form (figure 4a). Other mineral inclusions are sometimes found, including clinochlore and quartz which are considered as atypical inclusions of Chivor beryls. Another frequent feature of Chivor beryls is aggregates of tiny, dark grains which are thought to be particles of the wall rocks that may be carbonaceous shale.

2.1.3. Gwantu (Nigeria)

Gwantu beryls show a large variety of fluid inclusions with tubular or irregularly shaped forms. The tubular shaped ones are orientated with the c-axes of the beryl host crystal, and therefore, they are considered as the primary filled cavities. Most of the fluid inclusions in the Gwantu beryls have strong relief and appear almost opaque in the transmitted light. This is due either to the difference between the refractive index of the cavity filling and the surrounding beryl or to the irregular walls of the cavities. The most abundant type of inclusion in Gwantu beryl is one containing a liquid, a gas bubble and one or two crystals.

Minerals contained in multi-phase inclusions show very well-formed cubic or rectangular crystals. The gas bubbles are identified as carbon dioxide by this study. According to Schwarz and others (1996) [2] the minerals are probably halite. Such multiphase inclusions are also found in beryls from Chivor, Columbia. The ratios of gas bubble to the volume of solid substances are relatively high in comparison with other localities. In addition to the large liquid inclusions, fingerprints were also frequently observed in Gwantu beryls. By studies of Lind et al. (1984, 1986) [3,4] two different types of two-phase inclusions were described. The first type forms irregular feathers, in most cases in the core of the crystals. The second type was generally observed at the rims of crystal and forms elongated, often jagged cavities parallel to the prism face.

Beside the liquid inclusions, growth structures are also common in Gwantu beryls. The most frequent observed structures are the bands parallel to the basal-pinacoid, prism and pyramidal faces. One can observe that during the growth of the crystal, many fluid inclusions have been incorporated. In comparison with liquid, mineral inclusions are much less frequent. There were samples in which even only liquid inclusions were observed. The most common minerals, according to Schwarz and others (1996) [2] are fluorite (figure 5a) and albite (however, they were found in less than 10 percent of 1000 samples).

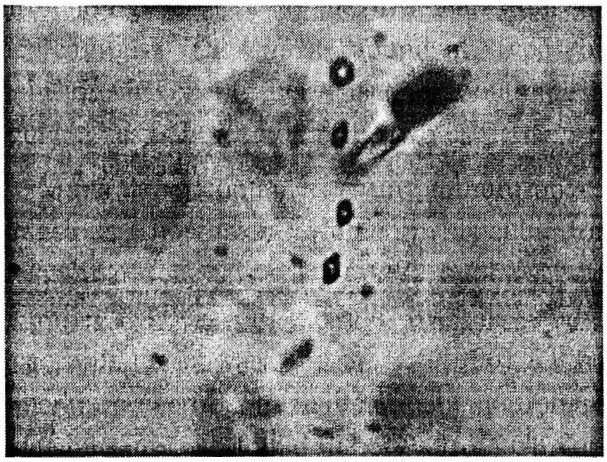

Figure 5a. The appearance of euhedral fluorite in Gwantu beryl. x50.

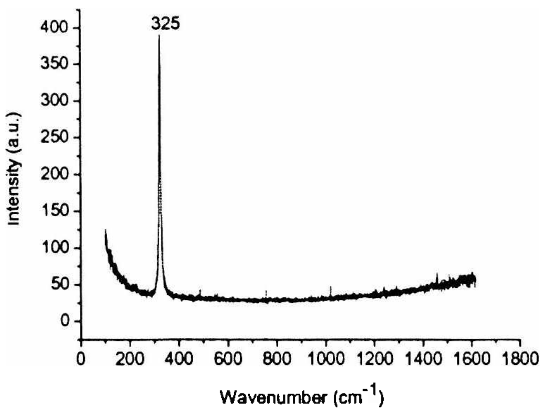

Figure 5b. Raman-spectrum obtained from a fluorite inclusion in Gwantu beryl.

Other minerals such as mica, ilmenite, quartz and tourmaline were found in less than a few percent of the samples. By the present study, biotite, fluorite, albite and tourmaline were found among which fluorite seemed to be the most common; the others were all found only occasionally.

Figure 6a. Amphibole inclusions in Habachtal beryls. x10.

The most recognizable feature of Habachtal beryls is the image which is teeming with masses of amphibole needles (figure 6a). They rarely occur solitaire but often congregate in clusters and bundles. Their colour is always green and varies from pale to dark shades. The picture of an amphibole cluster as shown in figure 24 is absolutely unique for Habachtal beryls. Thus this is the most distinguishable character of beryl in this locality. Less abundant than biotite and amphibole are apatite, albite, quartz, hematite and lepidocrocite. Quartz is found as small grains associated with liquid inclusions. According to Zwaan et al. (2005) and Koivula (1982), tourmaline is a mineral inclusion in Kafubu beryls as well; and this is in agreement with one of the host rock types of Kafubu beryl which is tourmaline-bearing mica schist.

2.2. Observation of schist type beryl

2.2.1. Habachtal (Austria)

Being one of the typical schist-hosted types, Habachtal beryls show their typical inclusions as amphibole (tremolite, actinolite), biotite and liquid, as expected.

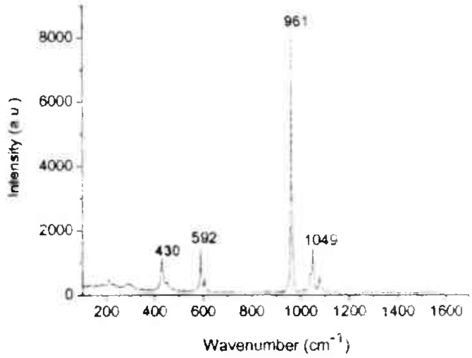

Figure 6b. Raman-spectrum obtained from apatite inclusion in Kafubu beryl.

2.2.2. Kafubu (Zambia)

The microscopic in situ observation in Kafubu beryls leads to the conclusion that the most significant inclusions are liquids. In general, the features of liquid inclusions in Kafubu beryls are more or less alike with those in Gwantu (Nigeria) or Itabira beryls: they all display wide variations in shape and appearance. Nevertheless, the features of fluid inclusions in Kafubu beryls allow this locality to be discriminated from the others. The well shaped forms of negative crystals which are very common in Gwantu or Itabira beryls were found less frequent in Kafubu beryls.

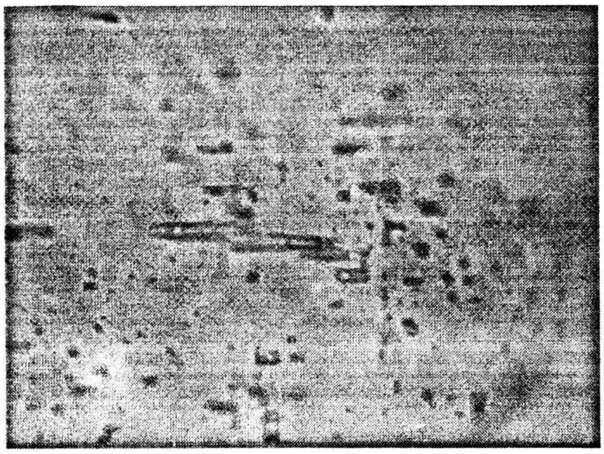

Figure 7. Fluid inclusions in Kafubu beryl. x10.

Figure 8. Amphibole and mica occasionally found singly but usually in groups in beryls from Zambia. x50.

Furthermore, the ratios of volume of gaseous phase (bubble) to liquid phase in multi-phase inclusions of Kafubu beryls are smaller than those in Gwantu or in Itabira beryls. As mentioned, the rectangular bordered cavities or the well-formed negative crystals were found less frequent than the elongated filled fractures (figure 7). Usually, elongated fluid inclusions are orientated parallel with the c axis. The small tiny fractures were partially filled and marked by planar groups of wispy or irregularly shaped fluid inclusions that often show optically a low relief.

Mineral inclusions are also common in beryls from Kafubu; biotite, and amphibole were found to be most common. Biotite and amphibole (Raman spectroscopy indicated amphiboles are both actinolite and tremolite) were occasionally found solitaire but always grouped together. In some cases amphiboles are practically abundant and they knit together to form clusters, this makes Kafubu beryls more or less alike with those from Habachtal. Amphibole appeared colourless to a light green colour, and either typical straight needles or bamboo-like forms (figure 9a).

Figure 9a. Apatite crystal with amphibole needles in Kafubu beryls.

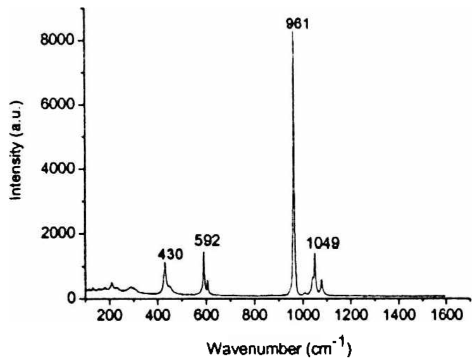

Figure 9b. Raman-spectrum obtained from apatite inclusion in Kafubu beryl.

Less abundant than biotite and amphibole are apatite, albite, quartz, hematite and lepidocrocite. Quartz is found as small grains associated with liquid inclusions. According to Zwaan et al. (2005) [4] and Koivula (1982) [5], tourmaline is a mineral inclusion in Kafubu beryls as well; and this is in agreement with one of the host rock types of Kafubu beryl which is tourmaline-bearing mica schist. Furthermore, pyrite and talc are identified as rare mineral inclusions. Another widespread feature in Kafubu beryls is parallel growth lines with a fine lamellar appearance. These exhibited moderate to strong narrow zoning of straight, alternating light green to green bands which are oriented parallel to the prism faces of crystal.

4. Discussion and Conclusion

For the schist-hosted type end-members, the inclusion suit of quartz, mica, amphibole, fluid inclusions are normally abundant and considered as the typical inclusions for beryls of all of these localities. And, because the localities have the same inclusion suit, then, the appearance of these inclusions has only a little value in distinguishing each locality from the others. Nevertheless, in the mean of association with other types of inclusions, or by some special appearances of typical inclusions themselves, and especially, with increasing personal experiences, the possibility of proper discrimination is growing. For instances, the cluster of amphibole in Habachtal beryls is one distinguishable feature. In the contrary, beside the typical mineral suit, there are the individual minerals that exist only in certain localities and could be a great value to limit the range of beryl location, for instance, pyrite inclusion in Chivor beryl.

Furthermore, those beryls coming from a geological environment that is characterized by the association of different metamorphic schists, with principally biotite/phlogopite schists and subordinately amphibole-bearing or amphibole schist, and pegmatite veins, probably show the typical inclusions such as quartz, biotite, phlogopite, rods or needles of actinolite, tremolite, crystal grains of chromite, feldspar.

For the non-schist-hosted branch of beryl deposits, such as Gwantu and Chivor beryls, mineral inclusions are not characterized by mica or amphibole, but different suits instead. A great part of fluid inclusions together with the less frequent mineral inclusions in beryls from Gwantu can be used to separate this locality from the others. Carbonate minerals, feldspars and pyrite are minerals characteristic for beryls from Chivor. Mica and amphibole are even considered as rare mineral inclusions in non-schist-hosted beryls. Briefly, good knowledge on the host rocks of beryls as well as on the forming conditions is a good base for research on provenance discrimination based on inclusions or internal features of beryls.

Acknowledgments

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