

## Exotic pegmatite fluids: a pre-cursor for orogenic gold mineralization.

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The Alto Ligonha region of Mozambique contains economically important pegmatites in a NE-trending zone covering some 10 000 km<sup>2</sup>. The pegmatites are emplaced in schistose rocks and are thought to be related to late Pan-African syn-tectonic equigranular granites c. 500 Ma. The largest pegmatite in the region is at Muiane, which has recently been re-opened for Li and Ta exploitation, and has been estimated to be some 1600m long, 360m wide and have a thickness of over 150m (Hutchinson and Claus, 1956). The pegmatite is zoned with a central quartz core, going outwards to a lepidolite unit, a quartz plumose muscovite unit, a massive perthite unit and finally a plagioclase unit. It is essentially a Li-dominated pegmatite with significant proportions of spodumene, lepidolite, eucryptite and petallite. There are also significant concentrations of pollucite, a rare Cs mineral.

Fluid inclusions were examined in a number of samples from the quartz core using microthermometry, SEM, Raman and LA-ICP-MS. They are aqueous-CO<sub>2</sub> showing variable H<sub>2</sub>O/CO<sub>2</sub> ratios in different fluid inclusion assemblages (FIA). Within each assemblage the ratio is however quite consistent, the dominant type being, by volume fraction, ca. 0.4 CO<sub>2</sub> with lesser numbers of ca. 0.9 high density CO<sub>2</sub> inclusions. Many of the inclusions are extremely large, reaching ca. 300 µm with the CO<sub>2</sub> phase reaching ca. 100 µm. Many of the inclusions contain solid phases some of which are daughter minerals and others which are probably trapped phases.

Microthermometry reveals that  $T_m(\text{CO}_2)$  is between -57.7 and -56.6 °C (average -56.9 °C),  $T_m(\text{cla})$  is between -8.2 and -3.9 °C corresponding to an average salinity of 5 eq mass% NaCl, CO<sub>2</sub> homogenizes to liquid between 30.1 and 31.1 °C (average 30.9 °C, effectively the critical temperature). The CO<sub>2</sub> is effectively pure with little

other gases present which was confirmed by Raman analysis which did not detect any other species in the CO<sub>2</sub> liquid or vapour. Total homogenization was not always achieved in the H<sub>2</sub>O-CO<sub>2</sub> inclusions as decrepitation frequently occurred at temperatures in excess of 250 °C, a small number of inclusions did homogenize between 210 and 300 °C. Some of the solids (As-species) dissolved at 100 to 150 °C.

The composition of the solids in the inclusions was determined by opening the inclusions and analyzing the solids using the SEM. As well as the As- and Sb-phases (Fig. 1.) many other elements were detected in the solids, Bi, Sn, Cs, Ag, Mn, Zn, Cu, Ta, Ba, Ca, P, F, Cl, Br, S. Some solids could tentatively be identified as native Bi, mangano-tantalite, calcite and gypsum.

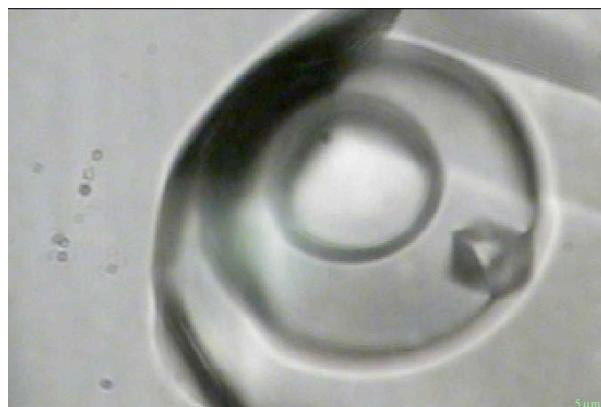


Fig. 1. Large H<sub>2</sub>O-CO<sub>2</sub> inclusion with an octahedral daughter mineral. Raman spectroscopy identified the solid as arsenolite (As<sub>2</sub>O<sub>3</sub>).

Raman identification proved to be more definitive, positively identifying two As<sub>2</sub>O<sub>3</sub> phases, arsenolite (cubic structure, low temperature phase) and claudetite (orthorhombic structure, high temperature phase) which have equivalents

as  $\text{Sb}_2\text{O}_3$  in senarmontite and valentinite, respectively (White et al., 1967). Sb-phases are found as zones within the As-oxides as well as individual minerals (Fig. 2.). In addition, we identified the rare mineral hambergite ( $\text{Be}_2\text{BO}_3(\text{OH},\text{F})$ ) in the  $\text{H}_2\text{O}-\text{CO}_2$  inclusions which was previously reported from Muine in crystals of morganite (Thomas & Davidson, 2010). Many other solids remain unidentified.

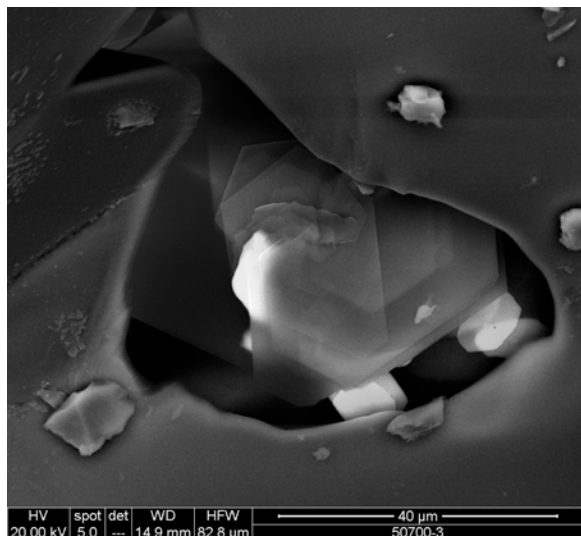


Fig. 2. SEM image of opened inclusion. The inclusion contains a zoned Al-Si polymorph, with additional As and Sb (brightest phase) daughter(?) minerals.

LA-ICP-MS analysis was carried out on the different FIA's and the composition of the inclusion fluids strongly reflects the mineralogy of the pegmatite. The maximum concentrations of Li (6,000 ppm), B (18,000 ppm) and Cs (5,000 ppm) are reflected in the presence of spodumene, lepidolite, eucryptite, petallite, tourmaline and pollucite. However, the extremely high maximum concentrations of As (210,000 ppm) and Sb (2,000 ppm) are not reflected in the bulk mineralogy of the pegmatite. Relatively low concentrations of Mn (50 ppm) and Fe (300 ppm) may be due to unusually oxidising conditions. Based on the K/Na ratios the fluid inclusion compositions can be placed in two groups. Fluids with a high K/Na ratio have low concentrations of Li, Rb, Sb, As and B and higher concentrations of Zn, Bi and Cs compared to the fluid with the lower K/Na ratios. Sr, Cu, Pb, P, Mn, Mo and Ag did not correlate with K/Na. It is likely that this represents

a fluid evolution controlled by the precipitation sequence of minerals within the pegmatite. As Muiane is a Li-pegmatite it is reasonable to assume the low K/Na, high Li, B, Cs, Sb and As fluid was the parental fluid and a decrease in Li was due to precipitation of the Li-minerals in the pegmatite. It is also likely that precipitation of pollucite and tourmaline are related to decreasing Cs and B.

Many of the inclusions are large enough that the  $\text{CO}_2$  phase can be sampled relatively independently of the aqueous phase. The significance of this is that high concentrations of Au are associated with the release of  $\text{CO}_2$  and subsequent analysis of the aqueous portion reveals no detectable Au. However it is not clear how the Au is transported in these fluids as there is no  $\text{H}_2\text{S}$ , as would be expected if Au was transported as a bi-sulphide complex. There is also no association with the presence of  $\text{As}_2\text{O}_3$  in the inclusions as inclusions without a daughter mineral also have a significant Au signal in many instances. An alternative is that Au nano particles are in effect stuck to the  $\text{CO}_2$  phase when they precipitated during  $\text{H}_2\text{O}-\text{CO}_2$  phase separation.

The compositions of these pegmatite fluids show many of the characteristics associated with orogenic Au-deposits, the typical enrichment of As, Sb, B, Bi, only a slight enrichment in Pb, Zn and Cu, low salinity and substantial  $\text{CO}_2$  concentrations. Mineralizing fluids derived from oxidised granitic magmas have been considered as possible sources of Au-bearing fluids for this type of mineralization and the presence of As and Sb oxides as daughter crystals, cassiterite and mangano-tantalite plus the lack of any reduced gas species indicates that these pegmatite fluids were oxidising. Therefore, these evolved granitic fluids may be the precursors of fluids that transport and precipitate ore metals in orogenic Au deposits.

## REFERENCES

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