

## **Late magmatic crystallization in the tourmaline-bearing miarolitic granitic pegmatites (by example of Shakhdarinskaya and Leskhozovskaya veins, SW Pamir, Tajikistan)**

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### **Introduction**

Late stages of granitic magma crystallization are frequently accompanied by separation of aqueous fluids, which assist in ore deposit formation. Miarolitic granitic pegmatites are natural laboratories that allow to study this process in detail. However, some features of the late-stage magmatic crystallization should vary depending on initial magma composition. This should lead to different P-T paths and various styles of phase transitions.

### **Pegmatites of SW Pamirs**

Pegmatite veins Shakhdarinskaya (ShV) and Leskhozovskaya (LeV) are located within 1.5 km from each other on the right bank of the Shakhdara river in the SW Pamir. Both veins consist of quartz-two-feldspar pegmatite with schorl and contain small miarolitic cavities with elbaitic coloured tourmaline. Some of miarolitic cavities are surrounded by quartz-tourmaline plagioclase or quartz-lepidolite-plagioclase paragenesis with abundant apatite and accessory phenakite (near-miarolitic assemblage). Quartz-two-feldspar pegmatite is a major constituent of the veins. Mineralogy and texture make it similar to tourmaline-rich coarse-grained granite. In the majority of models this mineral paragenesis is attributed to magmatic crystallization. Miarolitic cavities contain well formed quartz and feldspar crystals and are believed to form from hydrothermal solution. Thus, miarolitic mineralization corresponds to hydrothermal crystallization stage. The mineral paragenesis surrounding the miarole thus may represent the transitional stage from magmatic to hydrothermal crystallization. This work represents the features of late magmatic crystallization in two tourmaline

bearing granite pegmatites on the basis of fluid and melt inclusion studies in quartz from magmatic, transitional and hydrothermal assemblages. This study was focused on phase transitions and chemical compositions of coexisting phases, which participated in pegmatite crystallization and formed mineralogically different mineral assemblages.

### **Fluid and melt inclusion study**

Fluid and melt inclusions in quartz were studied by microthermometry, Raman spectroscopy, SEM EDS, EMPA and LA-ICP-MS methods. Quartz from quartz-two-feldspar pegmatite contains rare primary fluid and extremely scarce melt inclusions both in ShV and LeV. However, the amount and size of inclusions increase in quartz of quartz-two-feldspar pegmatite in vicinity of miarolitic cavities in LeV. Primary fluid inclusions from quartz-two-feldspar pegmatite of ShV consist of H<sub>2</sub>O-CO<sub>2</sub> fluid, while in LeV primary fluid inclusions contain aqueous solution with daughter sassolite. These inclusions were found to accompany silicate melt inclusions that are composed mostly of mica and feldspar, and aqueous fluid. In contrast to quartz-two-feldspar pegmatite quartz from near-miarolitic assemblage of both veins contains numerous fluid and melt inclusions. In quartz from LeV these inclusions have much in common with those from quartz-two-feldspar pegmatite, while in quartz from ShV both types of inclusions are larger and more abundant. Primary fluid inclusions in quartz from ShV similarly to quartz-two-feldspar assemblage contain large CO<sub>2</sub> bubbles with an aqueous rim. The aqueous rim contains daughter crystals of sassolite and an unidentified phase. Fluid inclusions in quartz of LeV also represent

aqueous solution with daughter sassolite and unidentified phase. Mirolitic quartz also contains fluid and melt inclusions. Melt inclusions are less numerous than in the near-miarolitic assemblage and confined to root part of crystals. Mirolitic fluid inclusions from veins consist of gas, aqueous solution and daughter sassolite, Cs and Rb pentaborates (ramanite) and an unidentified phase, similar to that of inclusions from the near-miarolitic assemblage. Melt inclusions in quartz of magmatic and transitional stage were heated in the autoclave at 2.5 kbar. Their homogenization temperatures were 600 to 615 °C for both veins. Quenched glasses of inclusions are depleted in SiO<sub>2</sub>, compared to evolved granite (62 mass% for ShV and 67.8 mass% for LeV) and have elevated Al<sub>2</sub>O<sub>3</sub> contents (14.0 mass% for ShV and 13 mass% for LeV). Unlike to the evolved granite the studied glasses from ShV are depleted in Na and K but strongly enriched in Cs (up to 3.4 mass %Cs<sub>2</sub>O). The glasses hosted in the quartz from LV have K and Na contents at the level of evolved granite but are less enriched in Cs (up to 0.16 mass% of Cs<sub>2</sub>O). Similarly to glasses of melt inclusions in pegmatitic quartz from tourmaline-bearing pegmatites of other regions of the world, melt inclusions from ShV and LeV are enriched of B<sub>2</sub>O<sub>3</sub>, F and H<sub>2</sub>O. H<sub>2</sub>O contents were estimated at 10 to 15 mass%. Fluid compositions recorded by fluid inclusions change from quartz-two-feldspar to mirolitic assemblage. Fluid inclusions in quartz of ShV show a strong decrease in the CO<sub>2</sub> contents and an increase in boron concentrations, which is manifested in the appearance of sassolite daughter phases (up to 14 mass% of H<sub>3</sub>BO<sub>3</sub>). The concentration of boron in the fluid of LV increases from 16 to 19 mass% H<sub>3</sub>BO<sub>3</sub> in quartz-two-feldspar pegmatite to 22 to 25 mass% H<sub>3</sub>BO<sub>3</sub> in the mirolitic quartz. LA-ICP-MS studies of individual fluid inclusions showed that they are enriched in B, Na (up to 3.4 mass%), K (up to 0.6 mass%), Cs (up to 0.4 mass%), Li (up to 0.3 mass%), W (up to 0.1 mass%), As (up to 2.3 mass%) and Sb (up to 0.1 mass%). Elevated amounts of Be, Ta, Sn and Nb were recorded. SEM EDS measurements of dry residues of opened fluid inclusions indicate the presence of trace amounts

of Cl in the solution. Trace element compositions of fluid inclusions from both veins are similar. On the basis of the study one can conclude that the fluid have tendency to increase concentrations of B, As, Sb, Na, W and probably Li.

### Discussion and conclusion

Classic models, based on examination of the P-Q type system silicate – H<sub>2</sub>O and granite – H<sub>2</sub>O, envisage pegmatite formation through three subsequent stages: magmatic, where silicate melt and aqueous fluid are present; pneumatolytic, where supercritical fluid is a major mineral forming medium; and hydrothermal, where crystallization proceeds from subcritical aqueous fluids. This suggests that quartz from the first stage should contain coeval fluid and melt inclusions, from the second stage only crystal-rich fluid inclusions, and from the third stage two or three-phase fluid inclusions. Our study showed that besides mineralogical and textural difference quartz from three subsequent mineral assemblages contain both fluid and silicate melt inclusions. The study of fluid and melt compositions showed that silicate melts and aqueous fluids changed systematically their compositions from quartz-two-feldspar pegmatite to mirolitic quartz. From the data obtained in this study one can conclude that three phases, i.e. silicate melt, aqueous fluid and crystallizing minerals, coexisted in the course the magmatic crystallization. The compositions of fluid and melt evolved due to element re-distribution between all three phases.

According to Valyashko (1990) and Ravich (1974) this way of phase transformations is possible when volatiles of flux components are added to the system with P-Q type phase diagram transforming it into the diagram without critical phenomena on the saturation curve.

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