WHAT CAN MELT AND FLUID INCLUSION TELL US ABOUT PEGMATITE-FORMING PROCESSES?

Rainer Thomas[1]

[1] Deutsches GeoForschungsZentrum Potsdam, Telegrafenberg D320, D-14473 Potsdam thomas@gfz-potsdam.de

Keywords Granitic pegmatites, melt inclusions, melt-melt immiscibility, fluid inclusions

Melt inclusions (MI) are typically small volumes of melt, mostly silicates, which are trapped within growing crystals at magmatic temperatures and pressures (Lowenstern, 2003). Due to their strength and stability the host (quartz, topaz, beryl and others) act as a natural pressure vessel. This applies analogously to fluid inclusions (FI), which have trapped fluid phases such as water-rich solutions, CO_2 or some mixtures, primarily at lower temperatures.

Since Sorby's ground-breaking studies in 1858 MI and FI have been successful used to decipher mineral-forming processes in the magmatic to low-temperature hydrothermal stages. However, even after 150 years this task is not simple. Smith (1953) demonstrated this problem on the basis of complex inclusions in pegmatitic minerals. He came to the following important conclusion: "the crystallization of at least the early pegmatitic minerals was in the presence of a hydrous silicate liquid, which became included in small amount in the minerals and crystallized there, but subsequently the pegmatite itself was crushed, healed, recrystallized, and/or decomposed by hydrothermal solutions, which left secondary inclusions in some of the minerals. In other words, I am suggesting that most of the liquid inclusions in pegmatitic minerals are of secondary (= subsequent) origin and the composition of such inclusions may bear no simple relation to the composition of the liquid present during the first crystallization." Without recognising this complexity, any subsequent interpretation must be flawed.

To be of use in deciphering their origins inclusions of mineralizing media require certain prerequisite criteria: homogeneity, volume constancy, and mass constancy. Furthermore, the effects of pressure must either be known, or can be estimated, or confidently neglected. Moreover, there is a further important point: The origin and genetic significance of the inclusions must be known – since the process of trapping is in causal connection with mineral genesis (both "primary" crystallization and recrystallization are included). We call this the "criterion of genesis".

In Thomas et al. (2008a) we have also pointed to the problem of the mimicry which can be overlooked very easily: the conversion of water-rich melt inclusions into an apparent fluid inclusions by deposition of, for example, silica epitaxially on the inclusion walls.

We demonstrate the significance of different primary inclusion types in constraining pegmatite-forming processes using examples from a variety of pegmatites. These inclusions show melt-melt immiscibility, the extreme enrichment of volatiles, semi-volatiles, especially water and alkalies, as well as a gel-sol phase, without which it is hard to imagine pegmatite-forming processes.

Furthermore we will show that the water-saturated pegmatite-forming melt begins crystallization at the wall of the pegmatite body and immediately begins second boiling and liquid immiscibility, forming a very dynamic melt-fluid system characterized by rapidly changing physico-chemical properties. Due to the low viscosity and low density at some stages turbulent convection is inevitable. Therefore the formation of a stable boundary layer is highly improbable. This can also be shown impressively by hydrothermal diamond anvil cell (HDAC) experiments.

Our studies show that the formation of pegmatites is characterized by a combination of metasomatic reactions, magmatic crystallization from extreme water-rich silicate melts and postmagmatic pneumatolytic-hydrothermal re-crystallization in a quasi closed system. It is important that pegmatite-forming melts are not in the equilibrium with the parental intrusion, and according to Thomas et al. (2008b) granite and pegmatite are decoupled at a physicochemical level, and liquidus undercooling which forms the backbone of London's theory (e.g., London 2008) of pegmatite formation, is not the driving force.

Figure 1 shows untreated natural melt inclusions in a beryl crystal from a stockscheider pegmatite in the amazonite granite Orlovka/Transbaikalia: a - Complex volatile-rich type-B melt inclusion in the (0001) plane of a large beryl crystal containing aluminosilicate glass (G), a water-rich solution (Fl), liquid carbon dioxide – (CO_2-F), and a CO_2-rich vapor bubble (CO_2-V). b and c - Type-B melt inclusions in a plane parallel to the c-axis of the same beryl crystal (G – glass, Fl –aqueous fluid, CO_2-F – liquid CO_2, CO_2-V – CO_2 - vapor). Such volatile-rich type-B melt inclusions can be considered as microscopic proxies for pegmatite systems in some high-level granite plutons. The glass volume of such inclusion, trapped near the critical point of a pseudobinary melt-water system is highly variable from 40 to 70 vol%. The cause can be traced back to pressure and density fluctuations and through this varying wetting behavior in such a dynamic melt system, and co-trapping of variable proportions of different phases in the same inclusion.

Figure 2 show two different volatile-rich inclusions in the same growth zone: a - This inclusion was probably a type-B melt inclusion, similar to Figs. 1a to 1c, however the melt has crystallized to stable mineral phases: cristobalite Crs, REE-rich fluorite CaF_2, muscovite Mu and trilithionite Tri, Fl – water-rich solution, CO_2-L – liquid carbon dioxide, CO_2-V carbon dioxide-rich vapor. b - A large supercritical water- and CO_2-rich fluid inclusion in beryl with a small amount of silicates (mostly polylithionite) and native sulfur (S_0) determined with Raman spectroscopy.

The inclusion assemblage found in the Orlovka beryl are very important for deciphering pegmatite-forming processes, especially the significance of liquid-liquid immiscibility processes, since they demonstrate the coexistence of two discrete silicate melts as well as a supercritical aqueous phase during beryl crystallization (see Thomas et al., 2009).

REFERENCES

London, D. 2008. Pegmatites. Can Mineral, Special Publication 10

Lowenstern, J.B. 2003. Melt inclusions come of age: volatiles, volcanoes, and Sorby's legacy. In: De Vivo, B. and Bodnar, R.J. (eds) Melt inclusions in volcanic systems – methods, applications and problems. Elsevier Amsterdam, 1- 21

Smith, F.G. 1953. Complex inclusions in pegmatitic minerals. Am. Mineral. 38: 559 - 560

Sorby, H.C. (1858) On the microscopical structure of crystals, indicating the origin of minerals and rocks. Proceedings of the Geol. Soc., London, Quart. Journ., Vol. 14, 1: 453 – 500

Thomas R, Davidson P., Hahn A. 2008a. Ramanite-(Cs) and ramanite-(Rb): New cesium and rubidium pentaborate tetrahydrate minerals identified with Raman spectroscopy. Am. Mineral. 93: 1034-1042

Thomas R., Davidson P., and Badanina E. 2009. A melt and fluid inclusion assemblage in beryl from pegmatite in the Orlovka amazonite granite, East Transbaikalia, Russia: implications for pegmatite-forming melt systems Min. & Petrol. DOI 10.1007/s00710-009-0053-6

Thomas, R., Davidson, P., Rhede, D. and Leh, M. 2008b. The miarolitic pegmatites from the Königshain: a contribution to understanding the genesis of pegmatites. Contrib. Mineral. Petrol. 157: 505-523

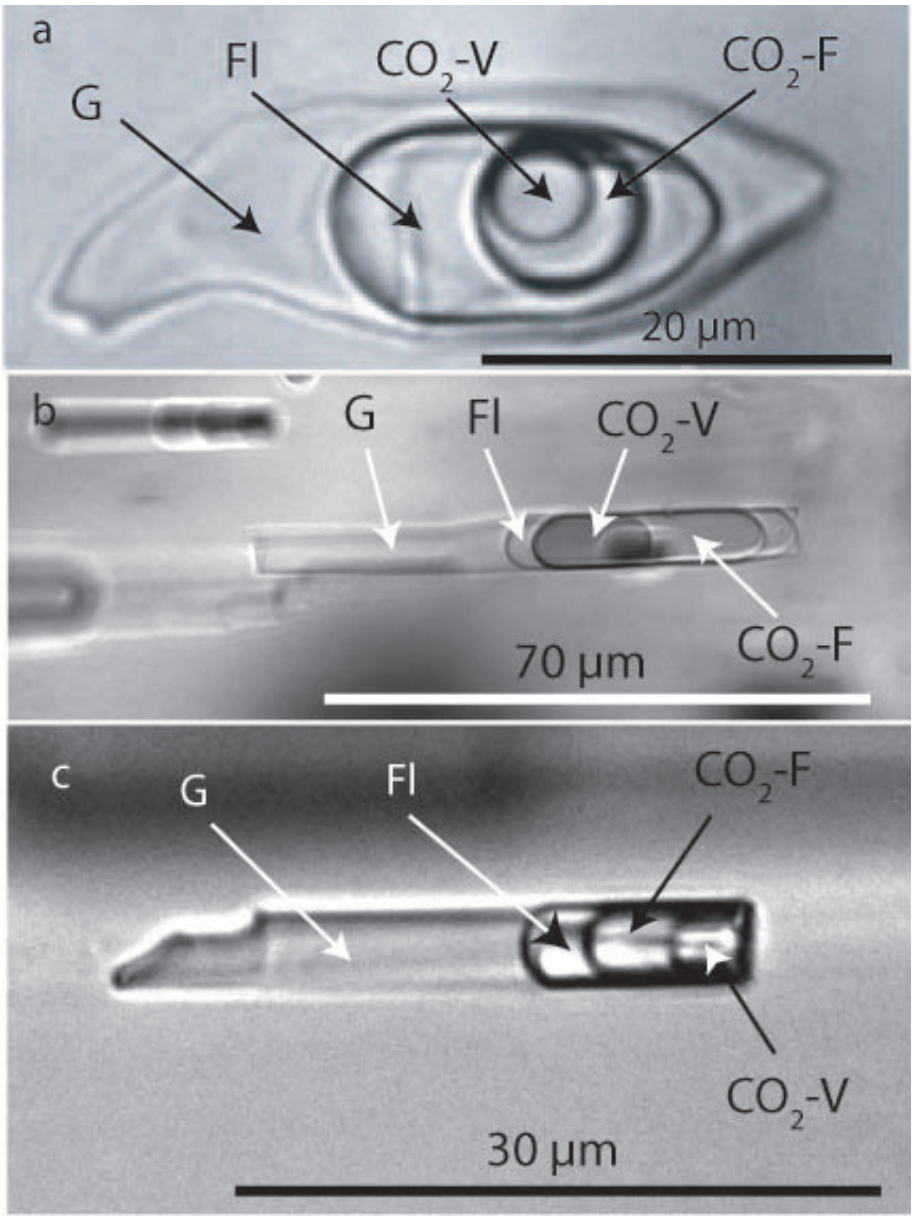

Figure 1 - Untreated natural melt inclusions in a beryl crystal from a stockscheider pegmatite in the amazonite granite Orlovka/Transbaikalia: a - Complex volatile-rich type-B melt inclusion in the (0001) plane of a large beryl crystal containing aluminosilicate glass (G), a water-rich solution (Fl), liquid carbon dioxide – (CO_2-F), and a CO_2-rich vapor bubble (CO_2-V). b and c - Type-B melt inclusions in a plane parallel to the c-axis of the same beryl crystal (G – glass, Fl –aqueous fluid, CO_2-F – liquid CO_2, CO_2-V – CO_2 - vapor)

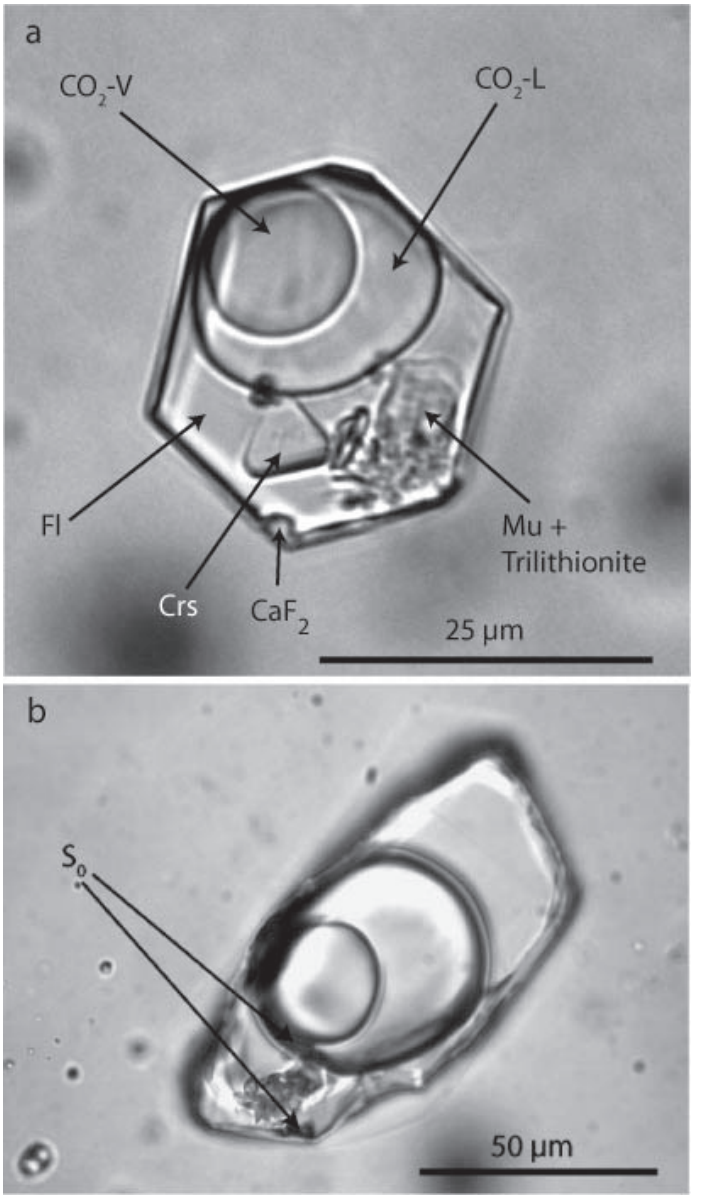

Figure 2 - Two different volatile-rich inclusions in the same growth zone: a - This inclusion was probably a type-B melt inclusion, cristobalite Crs, REE-rich fluorite CaF_2, muscovite Mu and trilithionite Tri, Fl – water-rich solution, CO_2-L – liquid carbon dioxide, CO_2-V carbon dioxide-rich vapor. b - A large supercritical water- and CO_2-rich fluid inclusion in beryl with a small amount of silicates (mostly polylithionite) and native sulfur (S_0) determined with Raman spectroscopy.