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The role of fluids in the formation of a clinopyroxene-rich pegmatoid vein in a migmatised granitic gneiss: Söndrum Stenhuggeriet, Halmstad, SW Sweden

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A clinopyroxene-rich pegmatoid vein along the eastern wall of the Söndrum stone quarry, Halmstad, SW Sweden has been investigated. The quarry is located in the Eastern Segment of the Sveconorwegian Orogen in SW Sweden. The study is accomplished by investigating the petrology, mineralogy, mineral chemistry, and fluid inclusions from a series of samples collected along a 1080 cm symmetrical traverse centred on the clinopyroxene-rich pegmatoid vein and including the surrounding coarsened granitic gneiss and subsequent surrounding regional migmatised gneiss. The obvious structural and geometric relationship between these three rock types makes this association ideally suited for the study of fluid-rock interaction under high-grade conditions.

The zone consists of a 0.5 m-wide, dark green, orthopyroxene-absent clinopyroxene-rich pegmatoid vein, which is characterized by an intergrown mass of megacrystic, semi-euhedral to anhedral clinopyroxene crystals up to 5-10 cm in size. This pegmatoid vein is surrounded on either side by a 0.5 meter-wide, coarsened overprint of red-pink, granitic gneiss, which grades into the unaltered regional migmatised granitic gneiss. Similar but smaller clinopyroxene-rich pegmatoid veins as well as clinopyroxene-bearing coarse patches in the migmatised granitic gneiss are also found in other parts of the Halmstad area.

EMP analysis of garnet, clinopyroxene, biotite, amphibole, and fluorapatite across the traverse indicates various mineral chemical trends including high Cl and low F values, low Fe and Ti values, and high Mn values in the pegmatoid dyke relative to the surrounding coarsened granitic gneiss and migmatised granitic gneiss. With the exception of Cl, diffusive trends are seen for these elements in the coarsened granitic gneiss. All minerals, with the exception of clinopyroxene are ubiquitous showing the same modal mineralogy both in the coarsened gneiss zone as well as in the surrounding granitic gneiss with the proviso that in the case of those samples containing clinopyroxene, modal amounts of hornblende and biotite are relatively less than in samples devoid of clinopyroxene.

Garnet-clinopyroxene and garnet-biotite geothermometers suggest an approximate temperature for the formation of the clinopyroxene-rich zone of 650-700°C. Subsequently, garnet-clinopyroxene-plagioclase-quartz barometry indicates a mean pressure of 750-820 MPa.

The fluid inclusions show a series of striking differences along the traverse. The regional migmatized granitic gneiss contains only aqueous inclusions, whereas the clinopyroxene-rich vein contains dominantly carbonic inclusions (ca. 76% of the fluid inclusion inventory) and subordinate water inclusions. The transitional coarse-grained granitic gneiss between the two contains carbonic and aqueous inclusions, but the aqueous inclusions are more abundant here compared to the clinopyroxene-rich vein (ca. 41% instead of ca. 22% of the fluid inclusion inventory).

The fluid inclusions can be grouped in (1) low-salinity solutes (ca. 8 mass% NaCl), (2) essentially pure water, (3) high-salinity $CaCl_2$-rich brines (20-21 mass% $CaCl_2$), (4) pure CO_2, and (5) aqueous-carbonic fluids. Mixtures between all types occur. CO_2 is found only in the clinopyroxene-rich and red gneiss zones, with the largest quantity in the clinopyroxene-rich zone, where it also has the highest densities.

The carbonic inclusions are always closely associated with the H_2O-NaCl inclusions with salinities of ca. 78 mass% NaCl, suggesting that these fluids were derived from one H_2O-NaCl-CO_2 fluid, which may have been present during granulite-facies metamorphism. This would concur with the finding of primary, peak-metamorphic fluid inclusions of the same composition in Opx-Cpx-Bt-Amph-Gt dehydration zones in the western wall of same quarry (Harlov et al. 2006). In the present Cpx-rich pegmatoid vein however, the original fluid seems to be poorly preserved. Rare aqueous-carbonic inclusions found in the pegmatoid vein are interpreted as samples of the original fluid. These inclusions show water volume fractions of 0.7 to 0.8 and have an estimated composition of $H_2O(87)CO_2(10)NaCl(3)$. The corresponding isochores cross-cut the peak-metamorphic conditions. Rock deformation (shearing) must have resulted in secondary pure carbonic inclusions trapped in healed microfractures (Fig. 1), whereas aqueous inclusions remained as clusters.

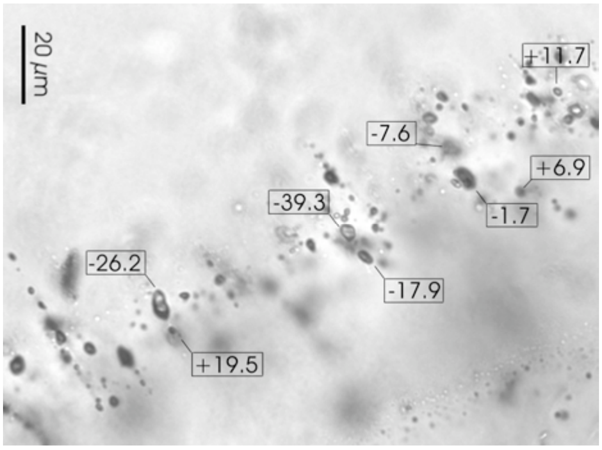

Fig. 1. Sheared carbonic inclusions in quartz from the Cpx-rich pegmatoid vein. Note highly scattering homogenization temperatures (°C).

In the clinopyroxene-rich vein the pure CO_2 inclusions are not only most abundant, but also best preserved. The homogenization temperatures of these inclusions concentrate between ca. –10 and 0°C, whereas homogenization temperatures in the reddish gneiss concentrate between ca. +12 and +24°C. The fluid inclusions in the clinopyroxene-rich vein are assumed to be trapped during an early stage of uplift, the ones with highest density of 1.114 g/cm^3 (T_h –39.3°C) must originate from conditions close to the metamorphic peak and survived uplift. Most of the carbonic inclusions in the reddish gneiss are likely to be re-trapped at low temperatures. This is also in accordance with the general lower total homogenization temperatures found for the aqueous inclusions in the reddish gneiss, which points to retrograde re-equilibration.

The homogenization temperatures of the migmatized granite are generally low $T_h$total <220°C. This is the only rock which contains $CaCl_2$-bearing brines. The homogenization temperatures of these brine inclusions are the lowest found (ca. 98 to 123°C) or the inclusions are monophase, suggesting re-equilibration below ca. 200°C 200 MPa. The $CaCl_2$ brines are considered the result of extreme retrograde rock alteration.

It can be concluded that the Cpx-rich pegmatoid vein must have formed at granulite-facies conditions in a tectonic fracture flushed with CO_2-rich fluids. The differences in the fluid inclusion inventory observed for the different rock types was strengthened by the different retrograde developments: the "dry" Cpx-rich vein best preserved the carbonic fluid inclusions, together with the aqueous inclusions with highest homogenization temperatures, and also some peak-metamorphic H_2O-NaCl-CO_2 inclusions. The fluid inclusions in the surrounding "wet" rocks were most intensively equilibrated at low temperatures.

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