Geophysical Research Abstracts
Vol. 17, EGU2015-1781, 2015
EGU General Assembly 2015

Interpretation of fluid inclusions in quartz deformed by weak ductile shearing: reconstruction of differential stress magnitudes and pre-deformation fluid properties

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A well developed theoretical framework is available in which paleofluid properties, such as chemical composition and density, can be reconstructed from fluid inclusions in minerals that have undergone no ductile deformation. Fluid inclusions are known to reequilibrate during strong post-entrapment changes in hydrostatic confining pressure (e.g. Sterner and Bodnar 1989). The present study extends this framework to encompass fluid inclusions hosted by quartz that has undergone weak ductile deformation following fluid entrapment.

Recent piston-cylinder experiments (Griggs apparatus) made on single quartz crystals have shown that such deformation causes inclusions to become dismembered into clusters of irregularly shaped relict inclusions surrounded by planar arrays of tiny, new-formed (neonate) inclusions (Diamond et al. 2010; Tarantola et al. 2010, 2012).

Comparison of the experimental samples with a naturally sheared quartz vein from Grimsel Pass, Central Alps, Switzerland, reveals striking similarities. This strong concordance justifies applying the experimentally derived rules of fluid inclusion behaviour to nature. Thus, planar arrays of dismembered inclusions defining cleavage planes in quartz may be taken as diagnostic of small amounts of intracrystalline strain. Deformed inclusions preserve their pre-deformation concentration ratios of gases to electrolytes, but their H_2O contents typically have changed.

Morphologically intact inclusions, in contrast, preserve the pre-deformation composition and density of their originally trapped fluid. The orientation of the maximum principal compressive stress ($\sigma 1$) at the time of shear deformation can be derived from the pole to the cleavage plane within which the dismembered inclusions are aligned. Finally, the density of neonate inclusions is commensurate with the pressure value of $\sigma 1$ at the temperature and time of deformation. This last rule offers a means to estimate magnitudes of shear stresses from fluid inclusion studies. Application of this new paleopiezometer approach to the Grimsel vein yields a differential stress ($\sigma 1$ - $\sigma 3$) of $\sim$300 MPa at 390 $\pm$ 30 °C during late Miocene NNW-SSE orogenic shortening and regional uplift of the Aar Massif. This differential stress resulted in strain-hardening of the quartz at very low total strain (<5%) while nearby shear zones were accommodating significant displacements. Further implementation of these experimentally derived rules should provide new insight into processes of fluid-rock interaction in the ductile regime within the Earth's crust.

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