Modeling of fluid infiltration in low-permeable rocks, Dronning Maud Land, Antarctica

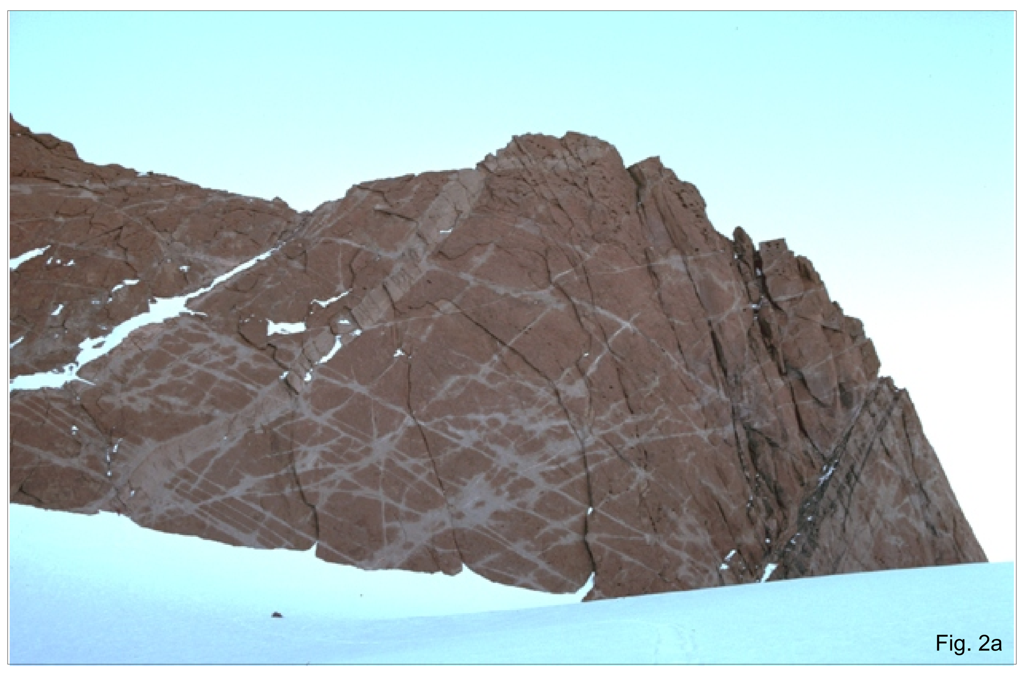
Ane K. Engvik[1], Håkon Austrheim[2], Synnøve Elvevold[3], Lars Engvik[4] and Bernhard Stöckhert[5]

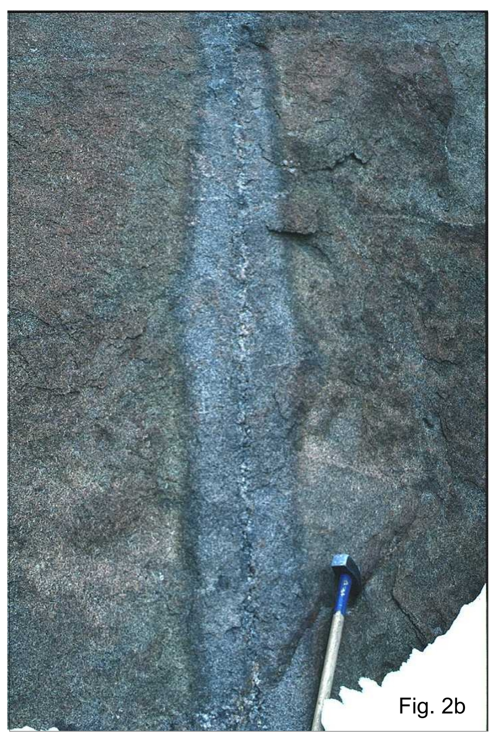
[1]Norges Geologiske Undersøkelse, Trondheim, Norway (ane.engvik@ngu.no)
[2]Physics of Geological Processes, Universitetet i Oslo, N-0316 Oslo, Norway (h.o.austrheim@geo.uio.no)
[3]Norsk Polarinstitutt, N-9296 Tromsø, Norway (elvevold@npolar.no)
[4]Avdeling for teknologi, Høgskolen i Sør-Trøndelag, N-7004 Trondheim, Norway (lars.engvik@hist.no)
[5]Institut für Geologie, Mineralogie und Geophysik, Ruhr-Universität Bochum, D-44801 Bochum, Germany (bernhard.stoeckhert@rub.de)

NGU Geological Survey of Norway · Norsk Polarinstitutt · HiST Trondheim · PGP Physics of Geological Processes · Ruhr-Universität Bochum

Excellent outcrops in Dronning Maud Land, Antarctica, provide unique insights into the mode and extent of fluid infiltration into metamorphic and plutonic rocks in the middle crust. The nunataks of Mühlig-Hofmannfjella and Filchnerfjella comprise a deep-seated metamorphic-plutonic rock complex, dominated by a dark colour due to anhydrous, charnockitic and granulitic mineral assemblages including perthite, plagioclase, orthopyroxene and garnet. The area was affected by a late-magmatic fluid infiltration outcropping as conspicuous light alteration halos around granitoid veins, probably originating from underlying magma chambers. The alteration halos were formed by CO_2-H_2O volatiles emanating from the veins into the host rock causing hydration of the granulite facies assemblage such as breakdown of orthopyroxene to biotite and sericitisation of plagioclase. The marked colour change is caused by the transformation and microcracking of feldspar, and the spread of dusty opaques and fluid inclusions.

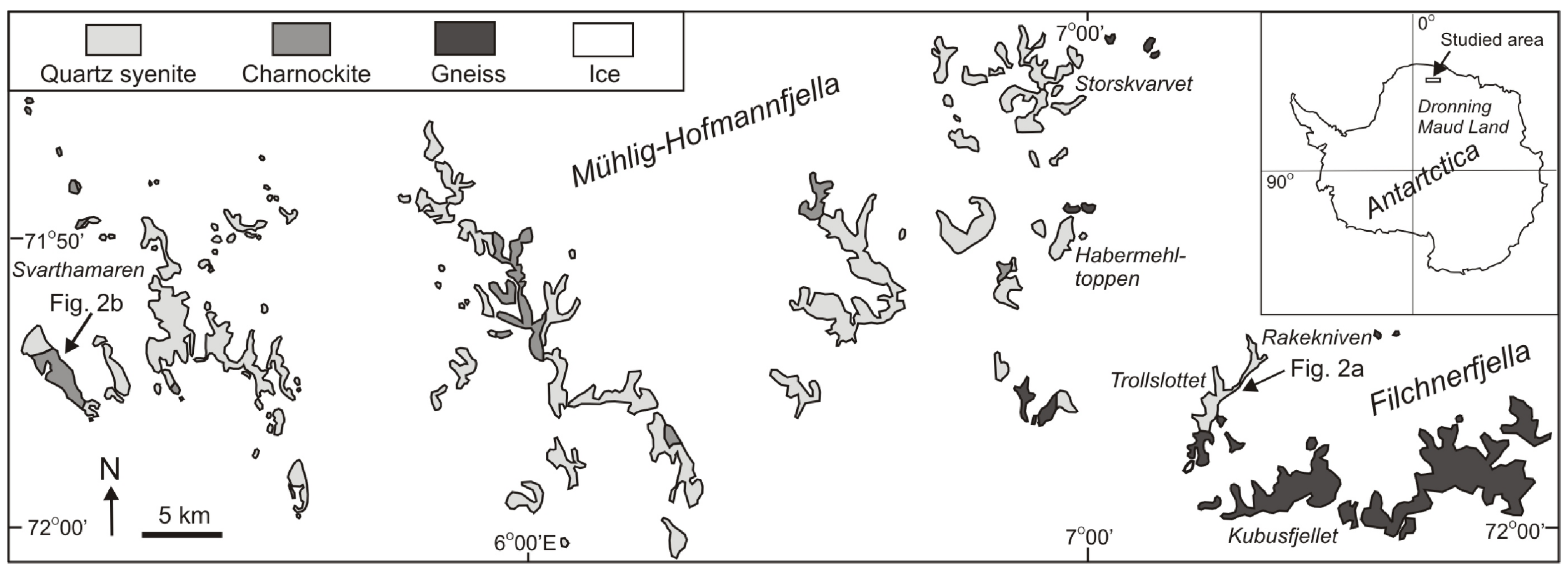
Field examples





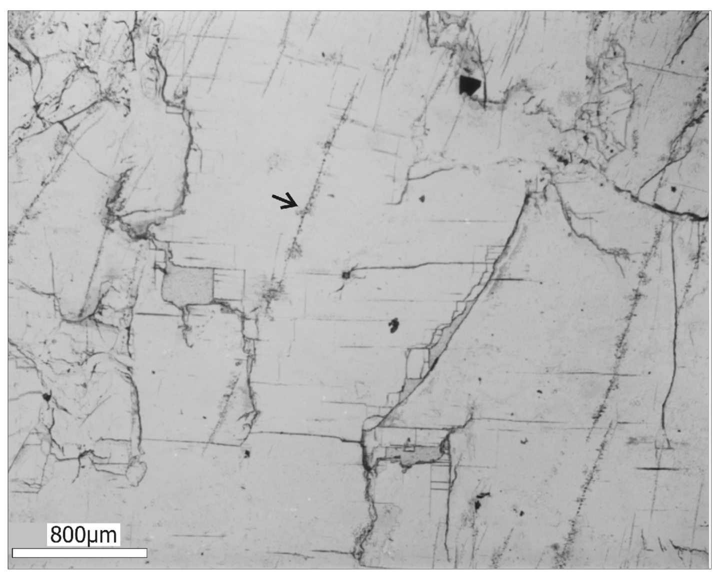
Light alteration halos around pegmatitic and aplitic veins cutting dark quartz syenites and charnockites.

Dronning Maud Land, Antarctica

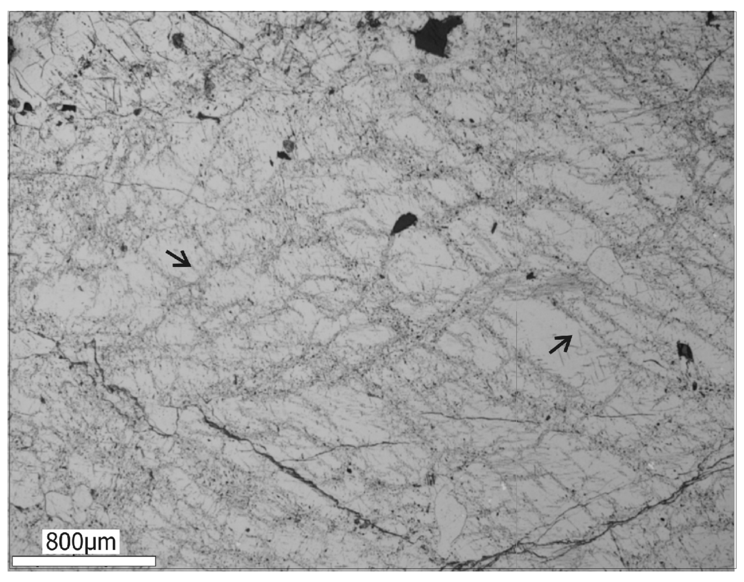


Geological map of Mühlig-Hofmann- and Filchnerfjella of Dronning Maud Land, East Antarctica.

Microcracking

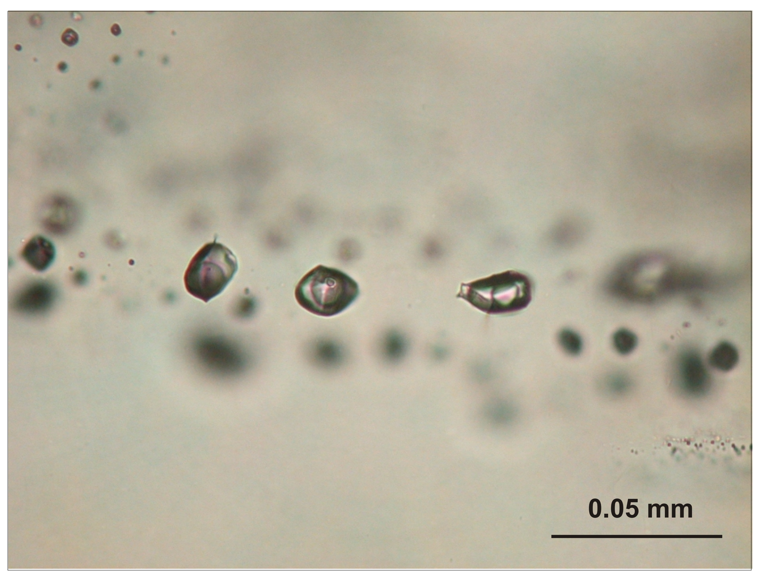


Photomicrograph of perthite in dark coloured quartz syenite showing only few microcracks.

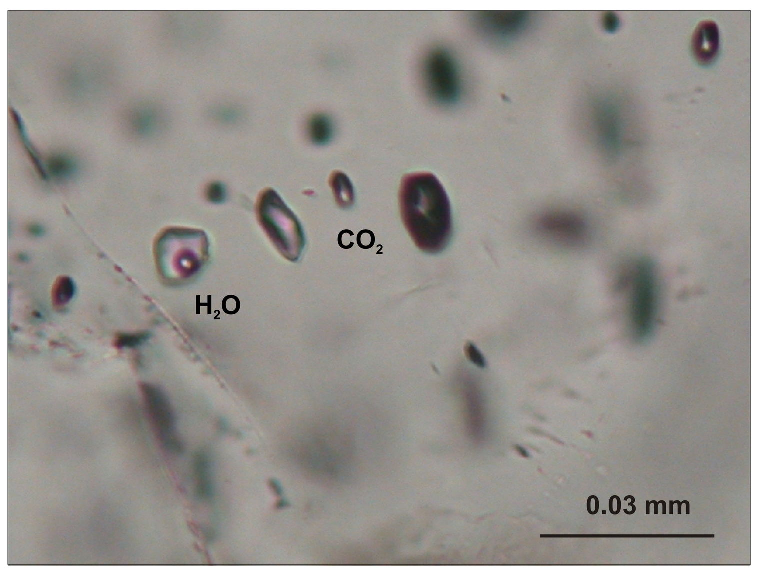


The high density of microcracks in quartz and feldspar exceeds that observed in the unaltered host rock by an order of magnitude. Photomicrograph of feldspar in light coloured quartz syenite.

Fluid inclusions

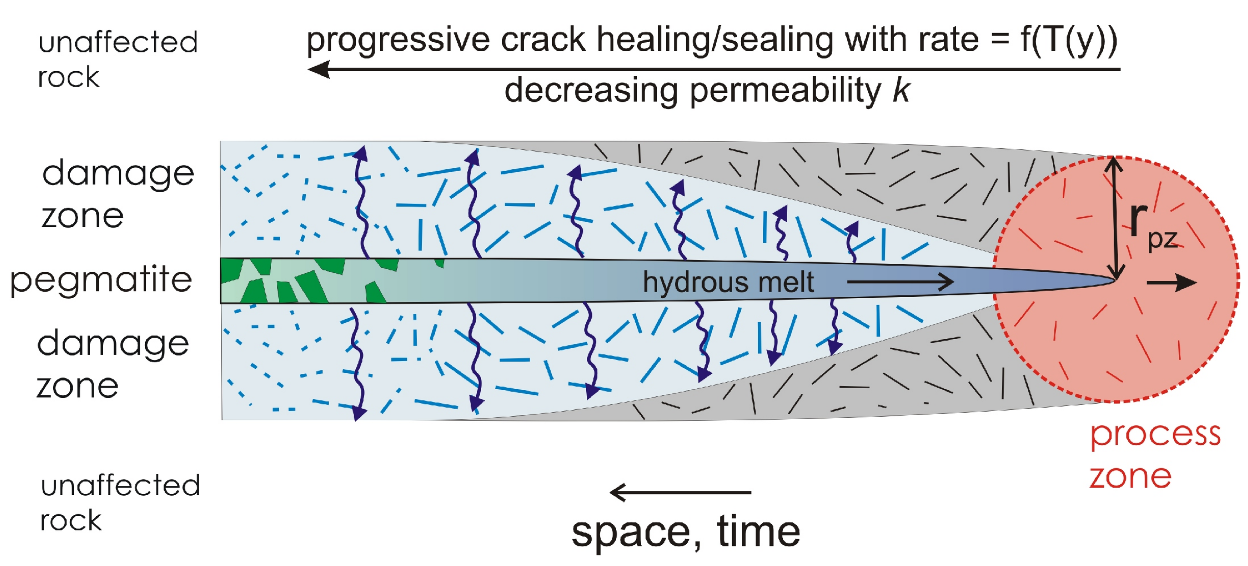


Trail of fluid inclusions filled by CO_2 showing a liquid phase and gas bubble.



Trail of fluid inclusions with both H_2O-rich and CO_2-rich inclusions

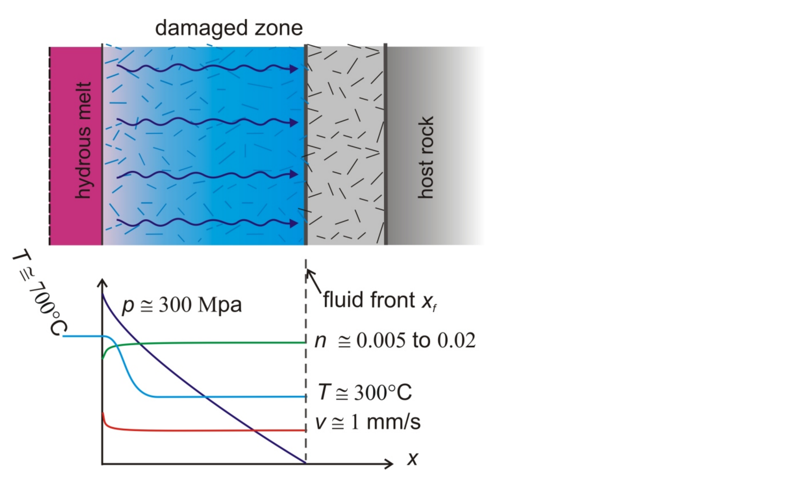
Qualitative model



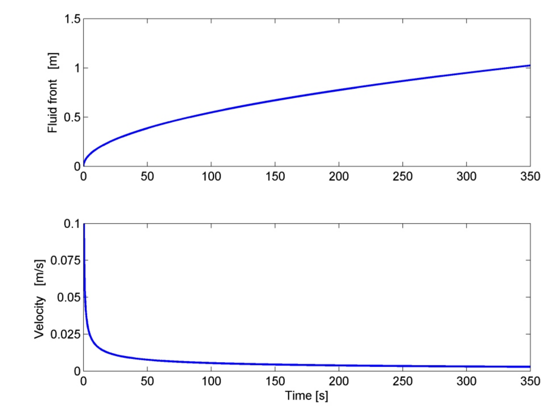
The field relations indicate that the veins originated as melt driven hydraulic fractures, sealed by pegmatite and aplite crystallising from volatile-rich melts, with the alteration halo being the wake of the process zone formed at the tip of the propagating fractures. It is proposed that the damage zone is characterised by a transient state of high permeability which was short-lived due to rapid healing and sealing of microcracks.

Quantitative modeling

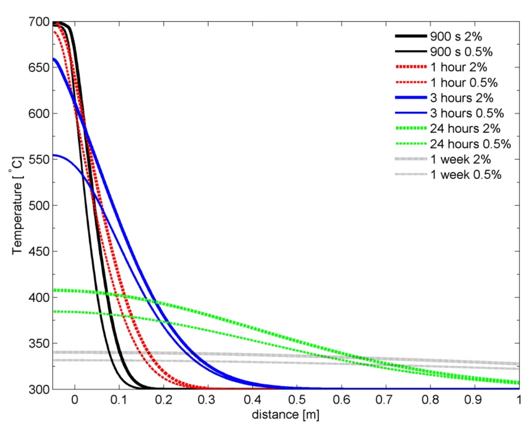
Fluid infiltration and healing time scales are investigated using a numerical model taking into account the combined effects of fluid flow, heat transfer and temperature dependent crack healing rates.



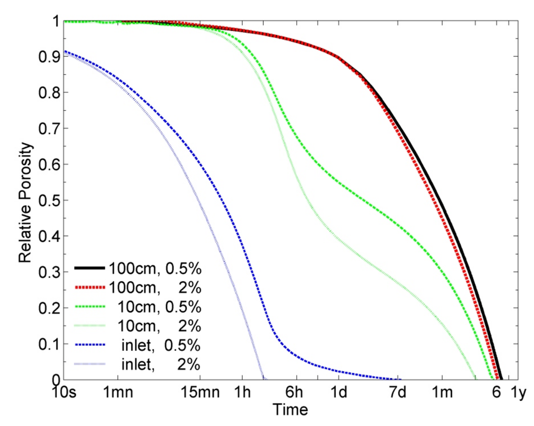
Key features of the infiltration process: Initial magma temperature of 700°C, far field temperature in the host rock of 300°C, an initial porosity in the damage zone of 0.5% and 2%, permeability of 10^{-16} m^2, and a pressure difference of 300 MPa.



Simple one-dimensional illustration of fluid flow in porous media (porosity of n=2%; fluid viscosity η=10^{-3} Pas).



Temperature distribution as a function of distance relative to the interface between the melt and the damage zone. (Example for central vein of 10 cm thickness and damage zone of 1 m width.)



Relative porosity as a function of time at various positions in the damaged zone. (Example for central vein of 10 cm thickness and damage zone of 1 m width.)

Fluid infiltration into the damage zone proceeds within seconds to minutes and the fluid flow contributes significantly to the heat transfer into the host rock. Assuming an initial microcrack aperture of 1 μm, the model predicts that the crack healing time scale is significantly longer than that of fluid infiltration in the case of thin veins with narrow damage zones (see Engvik et al. 2009). In this case crack healing does not hinder fluid infiltration. Only for thick veins with high heat content and prolonged crystallization history, permeability may become reduced by crack healing during progressive fluid infiltration. The results indicate that the formation of the alteration halos flanking pegmatitic veins is a quasi-instantaneous process on geological time scales.

For more information, please see:

Engvik A.K., Bertram A., Kalthoff J., Stöckhert B., Austrheim H. & Elvevold S. (2005). Magma-driven hydraulic fracturing and infiltration of fluids into the damaged host rock, an example from Dronning Maud Land, Antarctica. *Journal of Structural Geology*, 27, 839-854

Engvik, A.K. & Elvevold, S. (2006). Late Pan-African fluid infiltration in the Mühlig-Hofmann and Filchnerfjella of central Dronning Maud Land, Antarctica. In: Fütterer D.K., Damaske D., Kleinschmidt G., Miller H., Tessensohn F. (eds), Antarctica: Contributions to global earth sciences. Springer-Verlag, Berlin Heidelberg New York, pp. 55-62.

Engvik A.K. & Stöckhert B (2007). The inclusion record of fluid evolution, crack healing and trapping from a heterogenous system during rapid cooling of pegmatitic veins (Dronning Maud Land; Antartctica). *Geofluids,* 7, 171-185.

Engvik L., Stöckhert B. and Engvik A.K. (2009). Fluid infiltration, heat transport and healing of microcracks in the damage zone of magmatic veins numerical modelling. *Journal of Geophysical Research Solid Earth*, 114, B05203, doi:10.1029/2008JB005880.