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Creep Fractures in the Mantle and their role for Deep Fluid Transfer

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When hot and ductile rocks fail they do so with an astonishing variety. Observations from crustal deformation show that when the fluid content is low (less than a few per cent) they form the cores of anastomosing mylonitic shear zones, which feature strong gradients in grain size towards their metamorphic fluid rich centre (Fusseis et al., 2009). In circumstances where the fluid/melt content is high they form macroscopically visible ductile fractures (Weinberg and Regenauer-Lieb, 2010) which allow melt transfer into the shallower crust forming the feeder zone of granites. We show here that all of the above phenomena are new types of instabilities well known from high temperature deformation of ceramics, i.e. materials that otherwise show brittle cleavage at cold laboratory conditions. The new failure modes boil down to a series of microscopic processes, where upon increasing temperature and decreasing applied stress failure modes transition from brittle cleavage to transgranular and intergranular “creep fractures”, summarized by Ashby’s classical deformation mechanism maps (Ghandi and Ashby, 1979).

Although Material Scientists are well aware of these creep enhanced fracture modes we have been lacking concise evidence in the laboratory and field proving the existence of these failure transitions. As creep fracture processes are happening on relatively slow geodynamic time scales they have been argued to provide the critical mechanism linking plate tectonic processes and deep fluid transfer processes (Regenauer-Lieb, 1999). In these considerations fluids are viewed as creating their own pathways through facilitating shear localization by creep fractures, rather than being a passive constituent simply following brittle fractures that are generated inside a shear zone caused by other localization mechanisms.

Recently, the missing laboratory (Rybacki et al., 2008) and field evidence for creep fractures have been found (Fusseis et al., 2009). Ghost images of both creep fractures and brittle fractures can also be seen in OH diffusion profiles on grain boundaries (Sommer et al., 2008) and fully embedded intragranular cracks in mantle xenoliths (Sommer et al., 2012).

In order to illustrate the fundamental implications for deep fluid transfer we extend classical solutions of material sciences to geodynamic conditions and incorporate melting reactions into the numerical formulation. We will show the implications to a number of applied field studies.

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