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Rheological effects of very small melt fractions (0.01 to 0.07) in crustal rocks

C. Rosenberg (1), S. Medvedev (2), M.R. Handy (1)

1. Institute of Geology, Free University Berlin, Germany (cla@zedat.fu-berlin.de)
2. Physics of Geological Processes, University of Oslo, NORWAY

A review and reinterpretation of previous experimental data on the deformation of melt-bearing crustal rocks (Rosenberg and Handy, 2005) revealed that the relationship of aggregate strength to melt fraction is non-linear, even if plotted on a linear ordinate and abscissa. At melt fractions $\phi < 0.07$, the dependence of aggregate strength on ϕ is significantly greater than at $\phi > 0.07$. This melt fraction ($\phi = 0.07$) marks the transition from a significant increase in the proportion of melt-bearing grain boundaries up to this point to a minor increase thereafter. Therefore, we suggest that the increase of melt-interconnectivity causes the dramatic strength drop between the solidus and a melt fraction of 0.07. A second strength drop occurs at higher melt fractions and corresponds to the breakdown of the solid (crystal) framework, corresponding to the well-known "rheologically critical melt percentage" (RCMP; Arzi, 1978). Although the strength drop at the RCMP is about 4 orders of magnitude, the absolute value of this drop is small compared to the absolute strength of the unmelted aggregate, rendering the RCMP invisible in a linear aggregate strength vs. melt fraction diagram.

Predicting the rheological properties and thresholds of melt-bearing crust on the basis of the results and interpretations above is very difficult, because the rheological data base was obtained from experiments performed at undrained conditions in the brittle field. These conditions are unlikely to represent the flow of partially melted crust. The measured strength of most of the experimentally deformed, partially-melted samples corresponds to their maximum differential stress, before the onset of brittle failure, not to their viscous strength during "ductile" (viscous) flow. To overcome these problems, we extrapolated a theoretically-derived flow law for partially melted granite deforming by diffusion-accommodated grain-boundary sliding (Paterson, 2001) and an

experimentally-derived flow law for quartz deforming in the dislocation creep regime in the presence of 1-2 % of melt (Gleason and Tullis, 1995). In addition, we compared these data with deformation experiments on olivine plus basalt melt, also conducted in the ductile (viscous) field (Hirth and Kohlstedt, 2003). All these data show a dramatic decrease in viscosity for melt fractions < 0.06. Therefore, they are consistent with the aforementioned results of experimentally deformed granite in the brittle field. Extrapolation of these results to natural conditions suggests that localisation of deformation should effectively coincide with the onset of melting, or with very small melt fractions (0.06-0.07), which may not always be detected in the field.

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