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The effect of sub-solidus water loss on the melt fertility of crustal source rocks: constraints from phase equilibria modelling

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During high temperature prograde metamorphism any free water (including pore water and water produced via the breakdown of hydrous minerals) is likely to be expelled from a source rock due to decreasing porosity and increasing confining pressure at temperatures and pressures up to just below the solidus. Therefore, it is necessary when considering prograde melting to adjust the water content of the bulk rock so that it is only just water saturated at the solidus. Using sub-solidus water loss as a constraint a series of melt fraction curves were produced to examine melting behavior at a variety of pressures and temperatures for several bulk compositions (representing tonalite, granodiorite, pelite and greywacke) in the model system Na_2O-CaO-K_2O-FeO-MgO-Al_2O_3-SiO_2-H_2O-TiO_2-O_2 (NCKFMASHTO). The results were compared to melt fertility curves derived from published melting experiments that used similar starting compositions.

Most of the model runs predicted a reduction in melt fraction, for a given pressure and temperature, of between 10% and 80% when compared with the experiments. The effect was most significant at low melt fractions just above the solidus. The locus of 7% melt fraction, corresponding to the rheologically significant melt connectivity threshold (MCT), is typically offset to higher temperature by 100 to 150 ˚C. Several of the models included peritectic K-feldspar that was only stable at low water contents (below those measured in the experiments). This resulted in the generation of less potassic and less aluminous melt compositions over the region of P-T-M_{H_2O} space for which K-feldspar was stable.

Most of the experimental runs were shown to have initial water contents indicating significant excess water at the P-T conditions of the solidus, even when the experimentalists noted that the starting materials had ‘no water added’. This observation may be explained by uncertainties in the measurement of water contents of the starting materials and/or water produced via the sub-solidus breakdown of hydrous minerals (e.g. micas) in starting materials that were effectively ‘dry’ at ambient conditions. An exception to this behavior was a natural tonalite starting composition that yielded similar melt fractions when compared to the corresponding phase equilibrium models. This result can be explained by the expulsion of water from the tonalitic melt as it crystallised, thereby minimising the water content of bulk rock at the solidus.

These results indicate that under typical conditions of crustal melting lower melt fractions may be attainable than previously thought and will have important implications for our understanding of the overall melt - fertility of the crust and the volumes of granitic melt that can be produced during anatexis. Furthermore, the increase in temperature of the MCT will have a significant impact on the strength of crustal rocks during the onset of melting.