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CO_2 analysis in high-pressure melts and implications for carbon recycling in subduction zones

J. Hermann and L. Martin
Research School of Earth Sciences, The Australian National University, Canberra, Australia (joerg.hermann@anu.edu.au)

Carbon recycling in subduction zones plays an important role in the evolution of climate through geological time and in the formation of diamonds in the deep mantle. Carbonates formed during seafloor alteration of the oceanic crust are buried into the deep Earth along subduction zones. We conducted experiments with a starting material made of a synthetic Potassium, CO_2 and H_2O-bearing basaltic composition at 3.0 and 3.5 GPa, 700 - 800°C and at 4.5 GPa, 800-900°C in a piston-cylinder apparatus, corresponding to typical conditions of the subducted slab at subarc conditions. The experimental results indicate that the solidus occurs between 700 and 750°C at both 3.0 and 3.5 GPa. In order to understand the CO_2 transfer in subduction zones it is thus important to quantify the molar $X(CO_2)=CO_2/(CO_2+H_2O)$ of such aqueous fluid or hydrous melt. However, so far this has not been possible because CO_2 exsolves from the fluid/melt in the experiments during quenching.

We have developed a new method where the experimental capsules are pierced under vacuum and the gas present after the experiment is mixed with He and directly analysed with a gas chromatograph equipped with a thermal conductivity detector (GC-TCD). Peak areas read in the chromatograms are proportional to the partial pressures of CO_2 and H_2O. Small quantities of these gasses can be determined with accuracy (±5%, on average) after the calibration of the GC-TCD using pure gas standards. For subsolidus runs at 700°C, GC-TCD analyses of the aqueous fluid show a decrease of the $X(CO_2)$ from 5.9±0.3% to 3.8±0.3% with increasing pressure from 3.0 to 3.5 GPa, respectively.

It is more difficult to assess the CO_2-H_2O compositions of the hydrous melts. GC-TCD analysis of runs at 775°C show that approximately 75% ($X(CO_2)=3.6\pm0.1\%$) and 50% ($X(CO_2)=5.7\pm0.3\%$) of the volatiles dissolved in the melt are exsolved during the quench in the 3.5 and 3.0 GPa experiments, respectively. Additionally, the glass pools have been analysed by FTIR spectroscopy using an ATR objective, which provides an excellent means of comparison between relative amounts of dissolved volatile species. The main carbon species in the melt pool is the carbonate ion. The relative heights of the total water and carbonate peaks indicate that the glass at 3.5 GPa has about four times higher $X(CO_2)$ than the one at 3.0 GPa and $X(CO_2)$ values are 2-3% and 8-12% at 3 and 3.5 GPa, respectively. The resulting $X(CO_2)$ of the melt that was present at experimental conditions is thus ~3% at 3.0 GPa and ~7% at 3.5 GPa, 775°C (Fig. 3), providing evidence for a significant enhancement of carbonate solubility with increasing pressure in hydrous melts.

Our results suggest that fluid fluxed partial melting of altered basalts provides an efficient mechanism by which significant amounts of subducted carbon can be brought back to the atmosphere via arc magmatism on relatively short time scales of less than 10 Ma.