Water partitioning between upper mantle minerals and melts

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Water in the Earth's upper mantle is predominantly stored in nominally anhydrous minerals (NAMs) such as olivine, orthopyroxene, clinopyroxene and garnet. Since incorporated water has a strong influence on mantle properties, namely melting temperature, rheology, electrical conductivity and seismic velocity, it is important to know the distribution of water among phases. Knowledge of how water partitions between upper mantle minerals and melts is essential for estimation of water content in incipient melts at different depths, water transport by these melts, and total amount of water in the upper mantle.

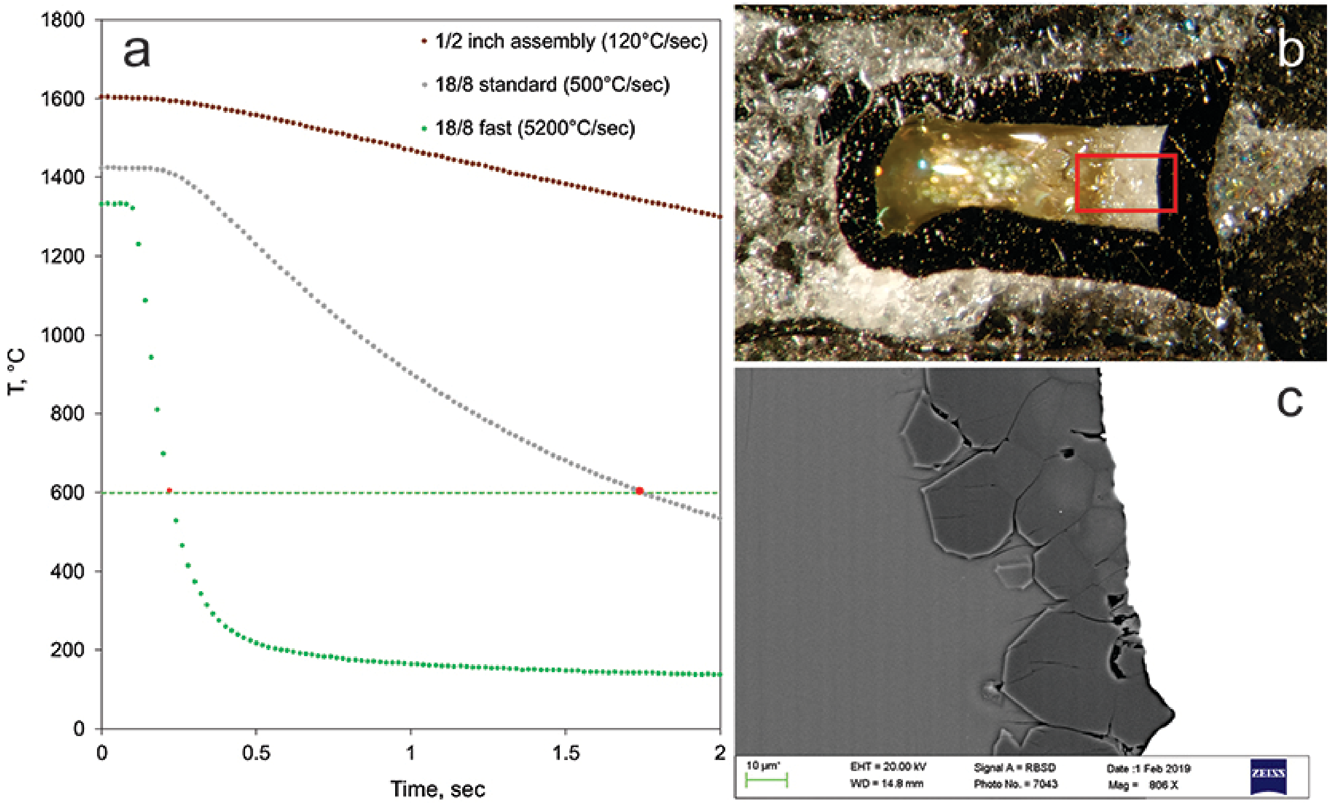
There are quite a few studies providing data on water partitioning between NAMs and melts. The most challenging part of these studies is to quench melt coexisting with mineral phases to form glass at elevated pressures (>2 GPa), which is necessary to measure water partitioning with high accuracy. It also becomes more difficult to quench melt with higher Mg/Si ratio into glass, which is necessary in order to crystallize olivine from the melt. Previous studies produced mantle minerals coexisting with quenched melt up to only 5 GPa, namely olivine up to 3 GPa, orthopyroxene up to 4 GPa, clinopyroxene and garnet up to 5 GPa. As a result, there is no systematic pressure, temperature and water content dependence of water partitioning from the data scattered over the narrow pressure range. Many authors also reported that glasses in some run products were not transparent, which implies micro-crystals may have crystallized in those studies.

The difficulty of quenching melt into glass lies in the insufficient cooling rate. The cooling rates of regular piston-cylinder and multi-anvil experiments used for these purposes are 120°/sec and 500°/sec, respectively. Quenching glass at elevated pressures and at various compositions is important not only for measuring water partitioning, but also for a number of other tasks, such as melt structure studies and partitioning of other components and elements.

The purposes of the present study are (1) to develop a multi-anvil technique allowing much faster cooling rate than conventional ones and (2) to measure water partitioning between upper mantle minerals and melts for a pressure range from 1 to 13 GPa, which covers the whole upper mantle. Our design for a fast-cooling multi-anvil technique has already been shown to produce a very high quenching rate (5200°/sec) in comparison with those of regular piston cylinder and multi-anvil apparatus (120°C/sec and 500°C/sec, respectively) (Fig. 1a). Using this technique, completely transparent glass coexisting with garnet was successfully quenched at 6 GPa (Fig.1b,c). We plan to improve the fast quenching technique to allow quenching melts under even wider conditions.

Fig 1. (a) Comparison of cooling rate among different assemblies. 1/2 and 18/8 are piston-cylinder and multi-anvil assemblies, respectively. Cooling rate was calculated for the temperature range between target temperature and 600°C; (b) Glass coexisting with garnet at 6 GPa; (c) BSE image of the area in the red box from picture b.

Keywords: Water partitioning, Water distribution, Upper mantle, Nominally anhydrous minerals , Quenched melts, Basaltic glass


a
1/2 inch assembly (120°C/sec)
18/8 standard (500°C/sec)
18/8 fast (5200°C/sec)
T, °C
1800
1600
1400
1200
1000
800
600
400
200
0
0
0.5
1
1.5
2
Time, sec
b
c
10 µm
EHT = 20.00 kV
WD = 14.8 mm
Signal A = RBSD
Photo No. = 7043
Date :1 Feb 2019
Mag = 806 X