UNIVERSITÉ Clermont Auvergne

Chimie
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Physique

Ecole Doctorale des Sciences Fondamentales

Title of the thesis:

Volatile (CO_2+H_2O)-assisted melting in the upper mantle

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Summary :

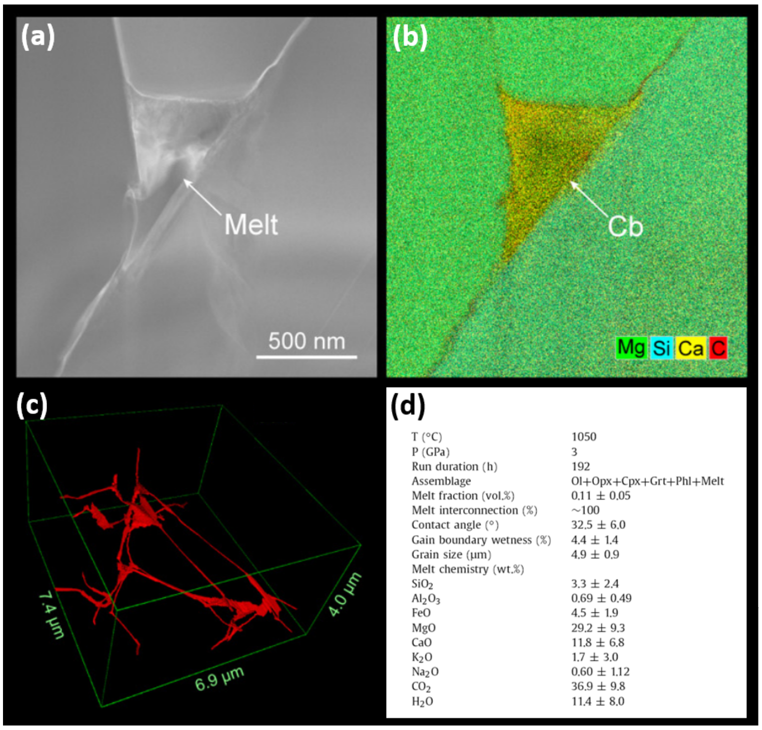
Numerous geophysical surveys report sharp drops in shear wave velocity (Vs) in the shallow, oceanic upper mantle (Rychert et al. 2020). Those Vs drops are observed beneath all seafloor ages in a region referred to as the low velocity zone (LVZ), ranging from ~60-80 km depth at its top to ~180 km depth at its bottom. The LVZ is commonly interpreted as a partially molten region in the upper mantle. Understanding its nature is crucial for understanding Earth global dynamics as the mechanical weakening due to partial melts in this region could favour or even allow plate tectonics.

While melting beneath mid-ocean ridges results from the decompression of hot, >1300°C mantle upwelling toward the surface, melting in cold mantle beneath old seafloors would not be possible without the assistance of volatiles. Both CO_2 and H_2O are present in the mantle, and their combination lowers the melting point of mantle rocks by several hundreds of degrees (Wallace and Green 1988). This allows partial melting in a vast region in the oceanic mantle extending from young and hot to old and cold oceanic mantle. Indeed, the top of the LVZ reported by geophysical surveys corresponds very well to the depths where the onset of (CO_2+H_2O)-assisted melting is predicted in the oceanic mantle (Sifré et al. 2014; Gardés et al. 2020; Hammouda et al. 2021). There are thus strong evidences that the LVZ in the upper mantle is a melting zone resulting from the presence of both CO_2 and H_2O.

We recently investigated the melting of a peridotite with mantle relevant amounts of CO_2 and H_2O (~500 and ~630 wt. ppm, respectively) at a pressure of 3 GPa (~100 km depth) and temperatures ranging from 1050 to 1360°C (Gardés et al. 2020; Fig. 1). We did find that (i) small fractions of melt are produced down to ~0.1 vol.% at 1050°C, (ii) melt is highly enriched in volatile with up to ~50 wt.% CO_2+H_2O, and (iii) melt always forms fully interconnected networks in all samples. Melt interconnection is crucial as it is the first requirement for melt to have a significant effect on bulk mantle properties.

The aim of this thesis is to investigate volatile-assisted melting over the whole range of LVZ depths in the upper mantle. High-pressure experiments (multi-anvil press) and state-of-the-art electron microscopy characterizations (SEM-FIB-STEM) will be involved for determining

the conditions of melting (e.g. pressure, temperature), the degree of partial melting, the chemical composition of melts, and their spatial distribution. This work will contribute in identifying the origin of geophysical signals from the upper mantle and the role of volatile-assisted melting in Earth dynamics.



T (°C)	1050
P (GPa)	3
Run duration (h)	192
Assemblage	Ol+Opx+Cpx+Grt+Phl+Melt
Melt fraction (vol.%)	0.11 ± 0.05
Melt interconnection (%)	~100
Contact angle (°)	32.5 ± 6.0
Gain boundary wetness (%)	4.4 ± 1.4
Grain size (µm)	4.9 ± 0.9
Melt chemistry (wt.%)	
SiO_2	3.3 ± 2.4
Al_2O_3	0.69 ± 0.49
FeO	4.5 ± 1.9
MgO	29.2 ± 9.3
CaO	11.8 ± 6.8
K_2O	1.7 ± 3.0
Na_2O	0.60 ± 1.12
CO_2	36.9 ± 9.8
H_2O	11.4 ± 8.0

Fig. 1 Partial melting of a (CO_2+H_2O)-bearing mantle rock experimentally re-equilibrated at shallow mantle temperatures and pressure (1050°C / 3 GPa). **(a)** Intergranular melt in a triple junction (STEM imaging of a FIB foil). **(b)** Corresponding chemical map (STEM-EDS). At the end of the experiment, the volatile-rich melt solidified in the form of a carbonate (Cb). **(c)** High resolution 3D reconstruction of melt showing full interconnection (serial FIB sectioning-electron imaging technique). **(d)** Summary of SEM-FIB-STEM characterizations : phase assemblage, melt volume fraction, contact angle at liquid/solid interfaces, grain boundary wetness, grain size, melt chemistry. After Gardés et al. (2020).

References :

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