

Solidus of carbonated peridotite and basalt to 33 GPa with implication to origin of kimberlite- and carbonatite-like melts in the deep mantle

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Introduction

Carbon and hydrogen species are the most important volatile constituents in deep Earth and they can produce drastic changes in the melting phase relations and partial melt compositions of mantle peridotite and eclogite/basalt (e.g. Fallon and Green, 1989; Kawamoto and Holloway, 1997; Litasov and Ohtani, 2002; Dasgupta and Hirschmann, 2006). Study of carbonated systems is closely related to petrogenesis of kimberlite and diamond. Ultradeep mineral inclusions in diamond (i.e. majorite garnet, Ca- and Mg-perovskite) suggest that kimberlites may transport to the surface the specimens from the transition zone and lower mantle (e.g. Hayman et al., 2005). Accordingly, it is important to study carbon-bearing systems at ultrahigh pressure and temperature.

Phase relations in carbonated peridotite and eclogite were studied in different model systems up to 12 GPa and revealed steep slope of the solidi (Canil and Scarfe, 1990; Dasgupta et al., 2004; Dasgupta and Hirschmann, 2006). In this work we report the results on solidus temperature and melt compositions of a CMASN-peridotite/basalt + 5 wt.% CO₂ system determined at 10-32 GPa and temperature range from 1300 to 1900°C combined with results for multicomponent peridotite + 5 wt.% CO₂ at 10-20 GPa and 1200-2000°C (Ghosh et al., in prep.).

Experimental

We used multianvil apparatus with ultrahard WC second stage anvils to generate pressure up to 33 GPa. The starting compositions were as follows (wt.%): SiO₂=44.76, Al₂O₃=4.73, MgO=41.77, CaO=3.44, Na₂O=0.30 (peridotite); and SiO₂=50.02, Al₂O₃=16.59, MgO=14.82, CaO=11.49, Na₂O=2.08 (eclogite/basalt). 5 wt.% CO₂ was added as carbonates. We used ZrO₂ and (Mg,Co)O pressure media and LaCrO₃ heaters. The samples were sealed into Pt capsules. Temperature was monitored by W/Re-thermocouples. Pressure was calibrated using results of *in situ* synchrotron experimental data with the same cell assemblies and

Au pressure scale by Fei et al. (2007). To determine solidus temperature we used also data for temperature gradient across experimental charge obtained at 4-5 GPa using two-pyroxene equilibria. The chemical composition of minerals and melts were determined by an electron microprobe at Geophysical Laboratory.

Results and discussion

We observed transition from magnesite- to carbonatite melt-bearing assemblages at 10, 16, 20, 27 and 32 GPa (Fig.1 and 2). No other carbonate phases than magnesite were observed under subsolidus conditions. Magnesite melts congruently in studied pressure range. Pressure induced phase transitions in carbonated peridotite and basalt were in general agreement with those in CO₂-free systems. Subsolidus phases in peridotite changes with increasing pressure from olivine-garnet-clinoenstatite-diopside-magnesite at 10 GPa, via wadsleyite-bearing assemblages at 16-20 GPa to Mg-perovskite-Ca-perovskite-periclase-magnesite at 27-32 GPa. Subsolidus phases in basalt are garnet-omphacite-stishovite-kyanite-magnesite at 10 GPa; garnet-stishovite-corundum-magnesite at 16 GPa; and Ca-perovskite-CF-phase (Na-Al phase with Ca-ferrite structure)-Mg-perovskite-stishovite-magnesite at 27-32 GPa (Fig.2).

Solidi of carbonated peridotite and basalt at 10-32 GPa have much gentler slopes than those at pressures below 10 GPa (Fig.2). The melting temperature of alkali carbonates at high pressures is very low (ca. 1000°C at 20 GPa, our unpubl. data) therefore presence of alkalis may drastically affect the solidi of carbonated peridotite and basalt. Accordingly, the solidus temperature of carbonated basalt and multicomponent peridotite (doped with Na₂O and K₂O) was lower than that of carbonated peridotite at 15-32 GPa. However at 10 GPa melting temperature of carbonated basalt was lower than that of peridotite. At 10 GPa melting temperature of peridotite is 100°C lower than that in CMAS-system and multicomponent peridotite (with nearly similar amounts of CO₂), whereas melting temperature of carbonated basalt is broadly consistent

with previous studies (Fig.2). We did not observe solidus temperature drop reported preliminary by Keshav et al. (2007) at 16 GPa for CMS-CO₂ peridotite (Fig.2).

Observed solidus temperatures of carbonated peridotite and basalt are consistent with CO₂ contents of partial melts. At 10 GPa CO₂ content are higher in the melt from basalt, at 16 GPa they are nearly equal, and at 20 GPa CO₂ content of the melt from peridotite is higher at the same temperature (Fig.3). A small fraction of partial melt (<20%) has magnesio- to calciocarbonatite composition in studied pressure range with SiO₂ contents <20 wt.% and exists at least 200°C above the solidus, where it may change to kimberlitic silicate melt. We observed both carbonatite and silicate melt (with 6-10 wt.% CO₂) in carbonated basalt at 10 GPa (Fig.3), which may indicate their immiscibility similar to that reported by Dasgupta et al. (2006) for carbonated basalt at 3 GPa. However, at 16 GPa this separation is not clear since we observe scarce silicate melt only in the low-T run (Fig.3). At 16-20 GPa carbonatite melt contains more CaO and Na₂O than that at lower (10 GPa) and higher (32 GPa) pressures, whereas the melt from basaltic system is always more

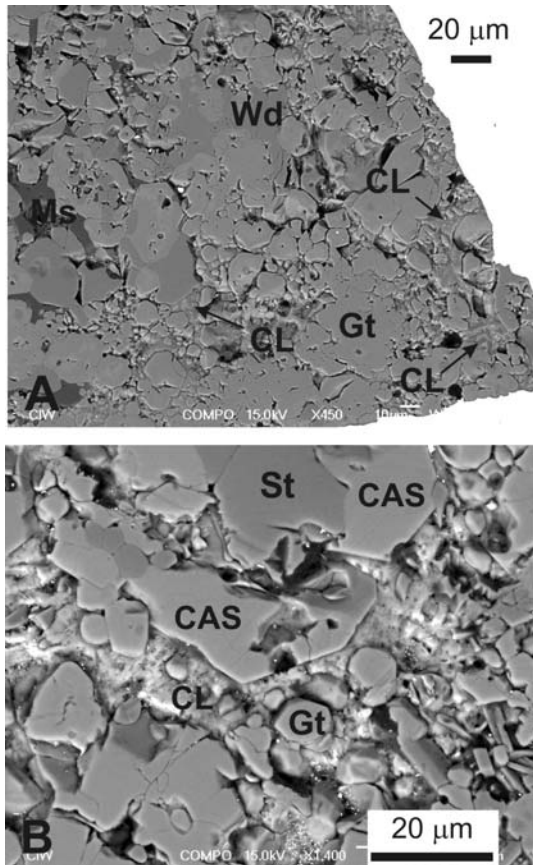


Figure 1. BEI image of carbonated peridotite (A) and basalt (B) at 20 GPa and 1700°C. Peridotite has smaller degree of partial melting. Note presence of magnesite (Ms) in peridotite. Phases: Wd – wadsleyite, Gt – garnet, St – stishovite, CAS – Ca-Al phase, CL – carbonatite liquid.

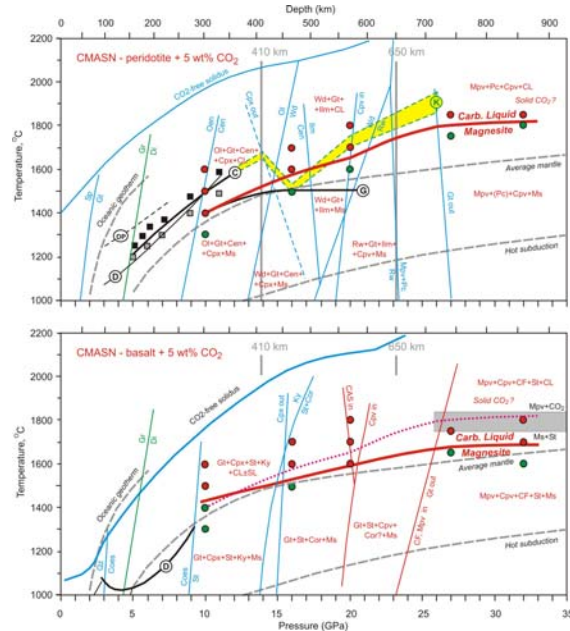


Figure 2. Phase relations in carbonated peridotite and basalt to 32 GPa. Green circles – all solid; red circles – melt is present. Solidi of peridotite from previous works: C – Canil and Scarfe (1990) for CMAS-CO₂, DP – Dalton and Presnall (1998) for CMAS-CO₂; D – Dasgupta and Hirschmann (2006) and G – Ghosh et al. (in prep.) for multicomponent peridotite; K – Keshav et al. (2007) for CMS-CO₂. Blue lines – phase relations for CO₂-free system. Solidus of carbonated basalt (D) is from Dasgupta et al. (2004). Grey field – approximate brackets for the reaction magnesite+stishovite=Mg-perovskite+CO₂-V (solid) after Seto et al. (2008). Dashed pink line shows solidus of carbonated peridotite from above figure for comparison. Phases: Sp – spinel, Gt – garnet, Gr – graphite, Di – diamond, Oen – orthoenstatite, Cen – clinoenstatite, Ol – olivine, Cpx – clinopyroxene, Ms – magnesite, Wd – wadsleyite, Rw – ringwoodite, Ilm – MgSiO₃-ilmenite, Mpv – Mg-perovskite, Cpv – Ca-perovskite, Pc – periclase, Qz – quartz, Coes – coesite, St – stishovite, Ky – kyanite, Cor – corundum, CAS – Ca-Al phase, CF – Na-Al phase with Ca-ferrite structure, CL – carbonatite liquid.

calci and contains more Na₂O relative to that from peridotite.

We could not observe partial melts in the samples at 27 GPa. Besides, carbonatite melt at 32 GPa (<8% partial melting) has relatively low CO₂ contents (32-38 wt.%), which is inconsistent with bulk CO₂. Absence of magnesite and presence of some cavities and vugs in the recovered samples may indicate presence of solid CO₂ among the run products, forming by the reaction magnesite+stishovite=Mg-perovskite+CO₂-V (solid) (Fig.2).

Conclusions

Our data indicate that release of CO₂ (if present) and related melting in the deep mantle are controlled by the stability of magnesite in basaltic and peridotitic

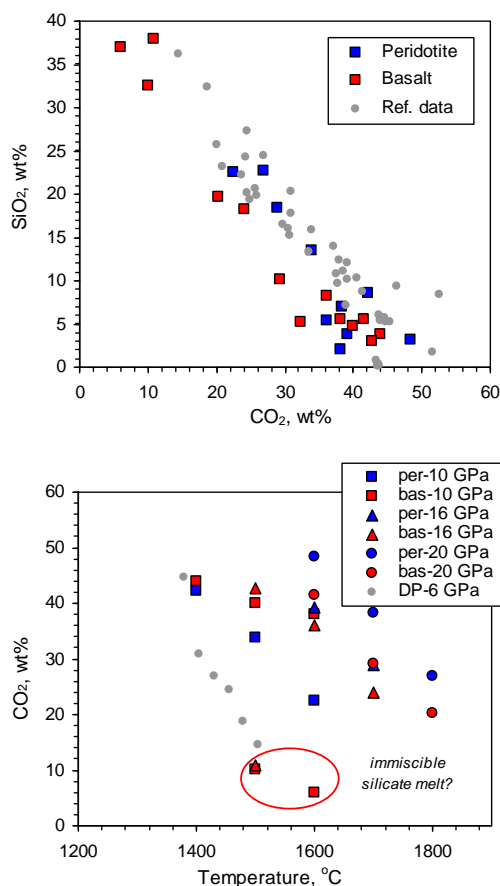


Figure 3. CO_2 - SiO_2 and CO_2 -temperature dependences in the partial melts.

compositions and the presence of alkalis. The slope of the solidus lines at 10-33 GPa is rather shallow relative to that at lower pressures of 3-10 GPa. Accordingly, even minor heating of the mantle may initiate melting of carbonated peridotite or basalt. Change of the solidus slope may cause partial melting at 8-9 GPa, producing highly mobile carbonatite and kimberlite (at higher degree of melting) melts.

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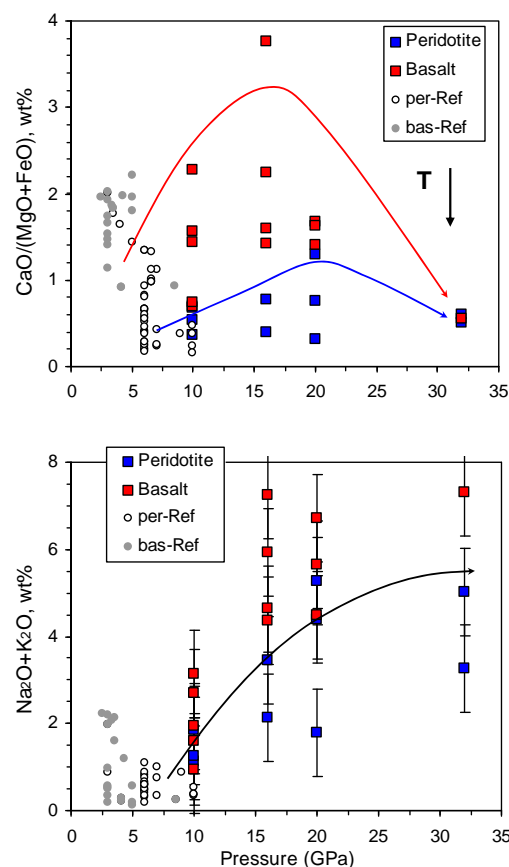


Figure 4. Pressure dependence of partial melt compositions.

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