Viscosity and melt structure of CO_2-bearing melts in the Earth's upper mantle: implications for the mobilization, ascent rate and emplacement of carbonatite rocks over time

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Near-solidus carbonatitic melts produced by partial melting of either carbonated peridotite or eclogite are characterized by 35-45wt% CO_2 and ∼1-5wt% SiO_2 and evolve towards SiO_2-rich (10-30wt%) composition as function of pressure, temperature and mantle redox state (Stagno and Frost, 2010; Moussallam et al., 2015). Although previous studies constrained the P-T-fo2 conditions for the origin of carbonate and carbonate-silicate (transitional) magmas, their viscosity and structure remain poorly investigated.

We determined experimentally the viscosity and melt structure of molten materials, using both synthetic glasses and natural rock powders (vesicite and polzenite) as starting materials, with variable CO_2 content from 23wt% to 38wt% and SiO_2 ranging between 5wt% and 38wt%. Experiments were performed at pressures of 1-6 GPa and temperature between 1050 and 1750°C using the Paris-Edinburgh press combined with in situ synchrotron X-ray diffraction at beamline 16 BM-B (HPCAT) of the Advanced Photon Source (Argonne, USA). Viscosity measurements were conducted using the "falling sphere" technique. The use of a high resolution fast camera allowed the collection of 500-1000 frames per second of radiographic images, necessary to monitor the fall of a platinum sphere as function of time and, in turn, convert it to viscosity using the Stokes' equation. Structural measurements of liquids were performed by multi-angle energy dispersive X-ray diffraction technique at high temperature and pressure over 3-4 hours.

Preliminary results of the viscosity appear in agreement with Kono et al. (2014) with values between 0.0075 and 0.022 Pa·s for compositions of melts with 5wt% SiO_2, CaO and MgO of 30wt% and 21wt% respectively; while viscosity values for liquid with ∼18wt% SiO_2 are up to two orders of magnitude higher. Our results would imply that the viscosity of carbonatitic-to-kimberlitic melts changes during upwelling, hence changing their ascent rates from 30-50 m/years for compositions with 5wt% SiO_2 to ∼2 m/years for melts with ∼18wt% SiO_2, at conditions where they form. Only when they cross lithospheric pathways their velocity is expected to reach 3-17 m/s as previously proposed (Sparks et al. 2006).
The melt structure of the carbonatitic liquids with ∼5wt% SiO_2 shows M-O (M = Ca, Mg, Fe) and M-M distances being ∼2.5Å and ∼4Å, respectively, similarly to what noticed by Kono et al. (2014) for pure calcite (Ca-O = 2.3Å; Ca-Ca = 4.2Å) and for dolomite melts (M-O = 2.1Å; M-M = 3.9Å).

Our results are used to develop a geodynamic model of the ascent rate and emplacement time of carbonate-rich magmas with implications for the speciation of carbon from the mantle up to the surface.

Moussallam et al., 2015. Chemical Geology, 418, 198-205

Kono et al., 2014. Nature Communications, 5, 5091.

Sparks et al., 2006. Journal of Volcanology and Geothermal Research, 155, 18-48

Stagno and Frost, 2010. Earth and Planetary Science Letters, 300, 72-84