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Electrical Conductivity Measurements on Hydrous Carbonate Melts at Mantle Pressure

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Electromagnetic methods image mantle regions in the asthenosphere with elevated conductivity (0.1 to 1 $S.m^{-1}$), which constrasts with the conductivity of dry olivine (10^{-2} to 10^{-3} $S.m^{-1}$). A correct interpretation of the petrological nature of the conductive mantle is critical for our understanding of mantle geodynamics because such conductive regions indicate mantle rocks with physical and chemical properties that importantly deviates from the canonical peridotites. For decades, such anomalously high mantle conductivities have been attributed to mineralogical defects associated to few tens of ppm water incorporated in olivine. Most recent experimental surveys, however, refute this hydrous olivine model. Conductive mantle regions could then reflect partial melting. The presence of melts in the Earth's mantle has long been proved by geochemical observations and experimental petrology on peridotite rocks. The requirement for melting in the asthenospheric mantle is the presence of volatile species (water, carbon dioxide, halogens). Small melt fractions are then produced by small volatile contents and they are the first liquids produced by melting magma. This study reports electrical conductivity measurements on such melts at mantle pressure and temperature. We investigated on melt chemical compositions produced by melting of peridotite that would interact with CO_2-H_2O and Cl. Such melts are carbonatite melts, carbonated silicate melts, hydrous carbonate melts, hydrous basalts.

A new system allowing in situ electrical conductivity measurements in piston cylinder has been deployed. This design has been specifically adapted to perfom measurements on liquid samples with elevated electrical conductivities. The chemical compositions investigated are pure liquid $CaCO_3$ and $CaMg(CO_3)_2$, to which, cloride (as salts), silicate (as basalts) and water (as brucite) have been added. Experiments have been realized at 1.5 and 2.7 GPa pressure and temperature of 1000-1700°C. Impedance spectrometry measurements are realized using a Solartron gainphase analyser.

In the liquid state, which was identified at T varying from 1000-1700°C depending on chemical compositions, all investigated samples are extremely conductive, i.e. >100 $S.m^{-1}$. It is 10,000 times more conductive than mantle olivine at similar P and T. The conductivities of samples increase with temperature and Arrhenius relationships can be adjusted. Activation energies depend on chemical compositions and vary from 40 to 80 $kJ.mol^{-1}$. Conductivity of melts increases in the following sequence: $\mathbf{CaCO_3} < \mathbf{MgCa(CO_3)_2} < \mathbf{(MgCa(CO_3)_2)_{0.9}\ (NaCl)_{0.1}} < \mathbf{(CaCO_3)_{0.45}\ (NaCl)_{0.1}\ (MgH_2O_2)_{0.45}}$. The latter melt composition is a simplified synthetic analogue of fluid inclusions entrapped in diamonds. Its electrical conductivity increases to >200 $S.m^{-1}$ at 1410°C and 2.7 GPa.

An electromagnetic survey (Tarits et al, this session) identifies a conductive mantle underneath mid-ocean ridge from 100 to nearly 500 km of depth. The determined conductivity, 0.1 $S.m^{-1}$, is obtained considering 0.07 volume % of hydrous carbonated melts in peridotite rocks. This is equivalent to a peridotite with 175 ppm CO_2 and 67 ppm water stored as small melt fraction wetting grain boundaries. Geochemical and geodynamic implications are discussed by Gaillard (this session).