

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 contrasts 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. 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. This study reports electrical conductivity measurements on volatile-rich melts at mantle pressure and temperature. We investigated on chemical compositions produced by melting of peridotite that would interact with $\text{CO}_2\text{-H}_2\text{O}$ and Cl. Such liquid compositions are carbonatite melts, carbonated silicate melts, hydrous carbonate melts, hydrous basalts, depending on P and T.

A new system allowing in situ electrical conductivity measurements in piston cylinder has been deployed. This design has been specifically adapted to perform measurements on liquid samples with elevated electrical conductivities. The chemical compositions investigated are pure liquid CaCO_3 and $\text{CaMg}(\text{CO}_3)_2$, to which, chloride (as salts), silicate (as basalts) and water (as brucite) have been added. Experiments have been realized at 3 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. $>100 \text{ S.m}^{-1}$. 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: $\text{CaCO}_3 < \text{MgCaCO}_3 < (\text{MgCaCO}_3)_{0.9}(\text{NaCl})_{0.1} < (\text{CaCO}_3)_{0.45}(\text{NaCl})_{0.1}(\text{MgH}_2\text{O}_2)_{0.45}$. The latter melt composition is a simplified synthetic analogue of fluid inclusions entrapped in diamonds. Its electrical conductivity increases to $>200 \text{ S.m}^{-1}$ at 1410°C and 3 GPa. Measurements performed on carbonated basalts (with 5-15 wt% SiO_2) indicate that they are almost as conductive as pure molten carbonate.

Based on these new data and published results on hydrated olivine, we propose a re-interpretation of electrical conductivity in the asthenospheric mantle involving small quantities of volatile-rich melts. The bulk rock CO_2 and H_2O required are less than 200 ppm and 150 ppm respectively.