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Conductivity anisotropy of partial molten peridotite under shear deformation

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Recent ocean bottom magnetotelluric investigations have revealed a high-conductivity layer (HCL) with high anisotropy characterized by higher conductivity values in the direction parallel to the plate motion beneath the southern East Pacific Rise (Evans et al., 2005) and beneath the edge of the Cocos plate at the Middle America trench offshore of Nicaragua (Naif et al., 2013). These geophysical observations have been attributed to either hydration (water) of mantle minerals or the presence of partial melt. Currently, aligned partial melt has been regarded as the most preferable candidate for explaining the conductivity anisotropy because of the implausibility of proton conduction (Yoshino et al., 2006).

In this study, we report development of the conductivity anisotropy of partial molten peridotite in three directions parallel and normal to shear on the shear plane, and perpendicular to the shear plane as a function of time and shear strain. Starting samples were pre-synthesized partial molten peridotite (Fe-free and Fe-bearing systems), showing homogeneous melt distribution. The Fe-free and Fe-bearing partially molten peridotite samples were deformed in simple shear geometry at 1 GPa and 1523 and 1723 K, respectively, in a DIA-type apparatus with uniaxial deformation facility. Conductivity of the partially molten peridotite parallel to the shear direction was initially identical to that normal to shear. However, shear-parallel conductivity increased by more than one order of magnitude after the initiation of shear by piston advancement. Shear-parallel conductivity then stayed constant for the duration of the experimental run. On the other hand, conductivity normal to the shear direction on the shear plane remained constant, whereas conductivity perpendicular to the shear plane decreased gradually after initiation of shear and finally close to that of olivine. Conductivity difference between parallel and normal to shear direction reached one order, which is equivalent to that observed beneath asthenosphere. In contrast, such anisotropic behavior was not found in the melt-free samples, suggesting that development of the conductivity anisotropy was generated under shear stress.

Microstructure of the deformed partial molten peridotite shows partial melt tends to preferentially locate grain boundaries parallel to shear direction, and forms continuously thin melt layer sub-parallel to the shear direction, whereas apparently isolated distribution was observed on the section perpendicular to the shear direction. The resultant melt morphology can be approximated by tube like geometry parallel to the shear direction. This observation suggests that the development of conductivity anisotropy is caused by the realignment of partial melt (forming tube-like melt) parallel to shear direction in the silicate matrix.

In conclusion, the high anisotropy of conductivity in the direction of plate motion can be well explained by anisotropic interconnection of melt in partially molten rocks at the top of asthenosphere, but not hydration of nominally anhydrous minerals. Therefore, our results provide the direct experimental evidence for supporting these geophysically observed high-conductivity anisotropy at the LAB and verify the validity of partial melting hypothesis (Yoshino et al., 2006; Naif et al., 2013).

References

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