

Redox-dependent electrical conductivity of olivine and the origin of the electrical asthenosphere: a new perspective

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Anomalously conductive layer in the oceanic shallow mantle has been well recognized. It broadly coincides in depth with the asthenosphere, the mantle portion of lowered viscosity that is key for plate tectonics, but the origin remains clouded. It has been proposed that water (structural OH groups) enrichments in olivine, the dominant mineral in the upper mantle, or partial melts greatly enhance conductivity and account for the electrical anomalies. These models, both assuming a very low conductivity for dry/water-poor olivine, have fundamentally different implications for mantle dynamics under sub-solidus or melt-bearing conditions.

The conductivity of silicate minerals is related to the transfer of electrical charges at thermally-activated state, and is sensitive to thermodynamic parameters and composition (e.g., water). The explanation of geophysically-determined electrical structure requires a robust understanding of the electrical behaviors of the main constituents and the factors that affect the charge transport. A solid constraint on the conductivity of dry and wet olivine at well-controlled conditions is a prerequisite for insights into the electrical asthenosphere. Particularly, the shallow mantle, including the asthenosphere that is the source of mid-ocean ridge basalts, is actually not reducing but oxidizing (close to the FMQ buffer), which differs from the redox state in many available studies on olivine conductivity. Here we show by experimental work that, at upper mantle conditions of pressure, temperature, oxygen fugacity and water inventory, the conductivity of olivine is actually insensitive to water, although the enhancement is great at relatively low temperature (e.g., below ~ 700 °C). Moreover, the conductivity is in fact quite high, about 0.01-0.1 S/m, at the oxidizing conditions of the asthenosphere, and is broadly similar to the high conductivity geophysically-observed for the electrical asthenosphere. The heterogenous distribution of redox state and/or temperature in the shallow mantle can cause heterogeneity (or anisotropy) of conductivity in the asthenosphere. We suggest that the electrical asthenosphere mostly originates from mantle olivine itself, by integrating experimental data with geochemical and geophysical approaches.