

Effect of mineral grain size on the electrical conductivity of a melt-mineral system and implications for the origin of the asthenosphere

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The presence of the asthenosphere is a key prerequisite for plate tectonics, yet its origin remains debated. Interpreting geophysically-observed properties of the asthenosphere is critical to understand the origin. The high electrical conductivity of the asthenosphere is often attributed to partial melt. The role of melt in influencing the electrical conductivity of a melt-mineral system is determined by the melt configuration, which may be affected by the grain size of the constitutive mineral(s) through its effect on the edges and corners of grain boundaries in the system that are important in controlling the connectivity and distribution of melt along the grain boundaries. This issue has rarely been explored.

We have experimentally examined this issue by measuring the electrical conductivity of a melt-olivine mixture at elevated pressure and temperature conditions, using a highly mobile and conductive carbonatite melt analog and olivine of contrasting grain sizes. We carefully prepared the samples for textural equilibrium. We demonstrate that, under otherwise similar conditions, the bulk electrical conductivity decreases with increasing olivine grain size. We quantitatively model the effect of mineral grain size on the electrical conductivity of the melt-mineral system. We show that the required amount of partial melt for generating the geophysically detected electrical conductivity in the asthenosphere is much greater than previous estimates. If the volume fraction of partial melt in the asthenosphere that is stable over geological scales is indeed minor (e.g., <1%) as widely considered in petrological and thermodynamical studies, then its effect on the bulk electrical conductivity is small. The high electrical conductivity of the asthenosphere originates more likely from sub-solidus solid materials in the upper mantle. The grain size effect on the electrical conductivity of a melt-mineral system should also be taken into account when scaling laboratory data to natural systems, for any other melt- or fluid-bearing systems in the crust and mantle.