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Constraining Upper Mantle Viscosity Using Temperature and Water Content Inferred from Seismic and Magnetotelluric Data

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Mantle viscosity controls a variety of geodynamic processes such as glacial isostatic adjustment (GIA), but it is poorly constrained because it cannot be measured directly from geophysical measurements. To improve viscosity estimates, we develop a method that computes viscosity using empirical viscosity flow laws and mantle parameters (temperature and water content) inferred from geophysical observations. We find that combining both seismic and magnetotelluric constraints allows us to place significantly tighter bounds on viscosity estimates compared to either geophysical observation by itself. In particular, electrical conductivity inferred from MT data can determine whether upper mantle minerals are hydrated, which is not seismically detectible but significantly reduces viscosity. Additionally, we show that rock composition should be considered when estimating viscosity from geophysical data because composition directly affects both seismic velocity and electrical conductivity. Therefore, temperature and water content is more uncertain for rocks of unknown composition, which makes viscosity also more uncertain. Furthermore, calculations that assume pure thermal control of seismic velocity may misinterpret compositional heterogeneity for temperature variations, producing erroneous predictions of mantle temperature and viscosity. Stress and grain size also affect the viscosity and its associated uncertainty, particularly via their controls on deformation regime. Overall, mantle viscosity can be estimated best when both seismic and MT data are available and the mantle composition, grain size and stress can be estimated. Collecting additional MT data probably offers the greatest opportunity to improve geodynamic or GIA models that rely on viscosity estimates.