Radiative Heat Transfer in a Hydrous Mantle Transition Zone

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Abstract

We report the effects of pressure and temperature on the optical spectra of two major transition-zone minerals: hydrous ferromagnesian wadsleyite and ringwoodite. From these spectra we obtain unusually large radiative thermal conductivities. These results suggest that the mantle transition zone may contribute significantly to radiative heat transfer, with potentially significant effects for geodynamic models of heat transport in Earth's interior.

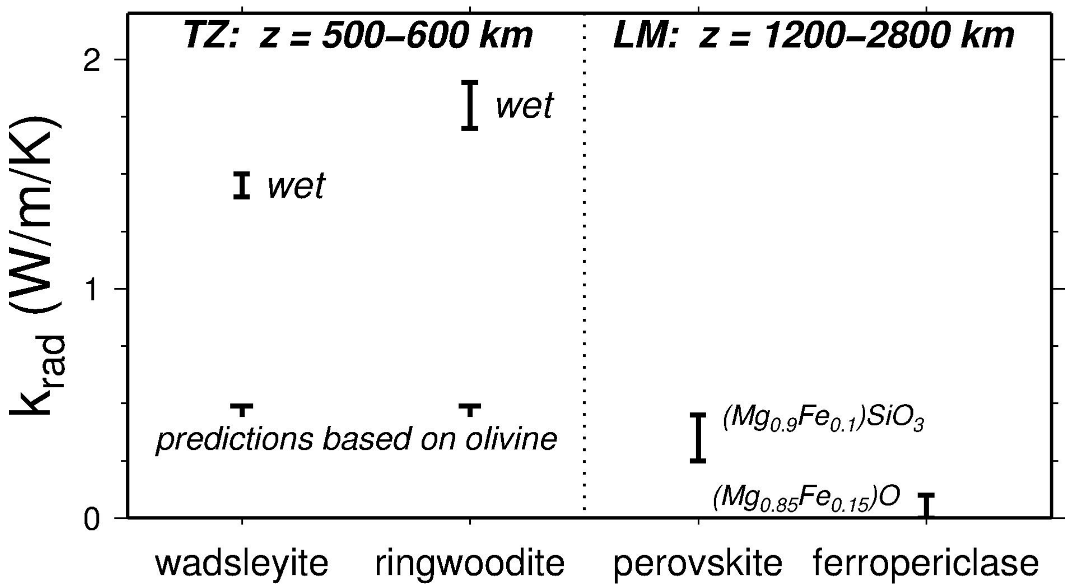
1 Motivation and methods

The structure and dynamics of Earth's interior depend crucially upon heat flow and thus upon the thermal conductivity of its constituents. Thermal conductivity in the mantle is commonly assumed to arise primarily from the lattice component (governed by phonon propagation). The radiative component (governed by absorption and emission of photons) has generally been assumed to be negligible, as most ferromagnesian minerals become opaque in the VIS-IR range at high pressures due to intensification and red-shift of electronic charge-transfer bands [1, 2]. However, more recent studies have suggested that mantle minerals may, in fact, remain relatively transparent at high pressures, thereby allowing for a potentially significant contribution to thermal conductivity from the radiative component [3, 4].

We examined two major transition zone phases, hydrous ferromagnesian wadsleyite and ringwoodite, whose thermal conductivities are poorly constrained due to sparse temperature- and pressure-dependent experimental data and evolving theoretical frameworks. Gem-quality single crystals were synthesized in a multi-anvil apparatus and analyzed by FTIR, SIMS, Mössbauer, and Raman spectroscopy (as well as by electron-probe microanalysis and X-ray diffraction). Temperature- and pressure-dependent optical absorption measurements in the IR-VIS-UV spectral range were performed in resistively heated diamond-anvil cells with argon pressure media. Following standard methods [5, 6, 7, 8], these spectra were numerically integrated to determine estimates of the radiative components of thermal conductivities.

2 Results and implications

Analysis of our absorption spectra reveals an energy transmission "window" in the IR-VIS spectral range, as for both mineral phases the crystal field and intervalence charge-transfer bands



continuously shift to higher (rather than lower) frequencies with increasing pressure. Thus, under transition-zone conditions, the effects of pressure and temperature on the absorption spectra of these major transition-zone minerals appear to enable (rather than block) energy transmission in the near-infrared region, resulting in large radiative thermal conductivities and the potential for the mantle transition zone in aggregate to support significant radiative heat transfer. A dependence upon hydration state may suggest subduction zones as loci of particular thermal complexity [9].

These results illustrate the importance of radiative heat transfer in controlling processes in Earth's mantle, with implications for geodynamic models of heat transport in Earth's interior. While such spatially varying thermal conductivities will affect the dynamics of the lower mantle [10, 11, 12, 13], their effects should also be significant within subduction zones [14, 15, 16, 17].

(Figure shows ranges of k_{rad} values in a wet transition zone from this work, predicted k_{rad} values for the transition zone from [18], and k_{rad} ranges in the lower mantle from [8].)

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