**The Effect of Phase Transitions on the Elastic, Anelastic, and Plastic Properties of the Upper 800 km of the Earth**

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The velocity of seismic waves provides the highest precision probe of the chemistry and temperature of the deep Earth. While seismology continues to provide higher precision of the velocity and density as a function of depth, mineral physics defines the acoustic velocity of a broader range of mineral assemblages as a function of composition, phase, pressure and temperature. The mineralogical data are gathered from Brillouin spectroscopy and ultrasonics at MHz and GHz frequencies along with theory based on density functional theory. Here we focus on whether or not phase transitions can have an effect on mechanical properties of the Earth's mantle. In particular, phase transitions in the Earth are generally multi-variant in character. That is, both high and low pressure phases coexist in the region of transition from one phase to the next. A small pressure variation will cause a small amount of transformation with attendant volume strain.

The seismic velocity jumps at 410 and 660 km have been long understood to be due to phase transitions in the olivine component of the Earth's mantle. Knowledge of the acoustic velocities of the high- and low-pressure phases have provided quantitative input into the chemistry of the mantle. Less well understood or accounted for is the effect on the elastic properties at seismic frequencies that can result from the interaction of the acoustic wave and the phase transition in regions where high- and low-pressure phases coexist. Even the low stress field of the seismic wave can induce a small amount of phase transformation to occur, and the small amount of transformation, inducing a small strain due to the volume change, can cause a large softening of the elastic properties and slowing of the seismic wave. That the seismic wave can be at relatively low frequencies (Hz to mHz) with the transition time longer than the kinetic time may allow the transition to proceed, thereby producing changes that are not observed at laboratory frequencies (MHz).

Figure 1 shows the major phase boundaries expected in a pyrolite composition as a function of depth down to 1000 km. Vertical lines would indicate phase transformations that occur at a fixed depth; curved or slanted lines indicate a region in which both the high- and low- pressure phases coexist. We see that for all but about 10% of the upper 800 km there are coexisting high- and low-pressure phases. Thus, most of this part of the mantle is a candidate for transition – induced elastic softening. The key to whether or not softening occurs is the kinetics of the transformation. 'Fast' transformations allow some of the transformation to proceed during the time of the seismic period and will result in elastic softening. For slow transformations, this will not occur, and no effect will be observed on the elastic properties.

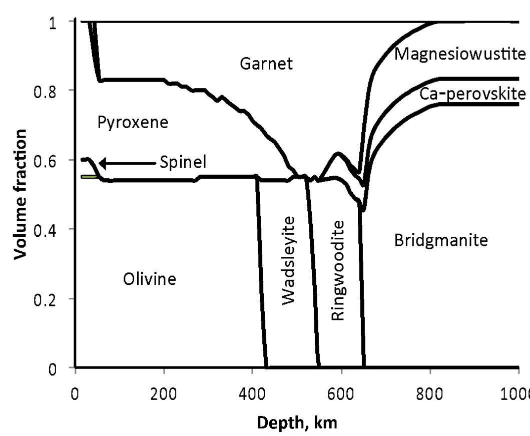


*Figure 1. Stable phases as a function of depth for a pyrolite composition.*

Initial studies (Li and Weidner, 2013; Weidner and Li, 2015, 2021) indicate that the bulk modulus of a mantle peridotite is affected by this phenomenon with a bulk modulus reduction of 65% at 5% melting. The solid – solid phase transitions are probably more sluggish, but the kinetics at relevant temperatures are mostly absent. In addition to softening of the elastic modulus, there should be a considerable attenuation signature of these phase transitions if this process is activated.

All of these transitions involve a change in volume and hence length of grains. Anisotropic length changes give rise to shear strains and hence contributions to flow. *Panasyuk and Hager* (1998) argue that phase transformations can provide a significant contribution to mantle flow.

Understanding the interaction of phase transitions and the various mechanical properties stands as an important challenge to better understand the Earth's mantle. Each of elastic, anelastic, and plastic properties can be affected by these transitions. We are at the point where ½% resolution of seismic velocity is possible. We need to match that with that level of precision of mineral properties if we are to take advantage of the high-quality seismic data to define the properties of the Earth's mantle.