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Towards seismic data inversion for crustal thermo-chemical structure: what thermodynamics say

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Unraveling the temperature distribution and composition of Earth's Crust is key to understanding its origin, evolution and mechanical behavior. Models of compressional (VP) and shear (VS) velocity and the mapping of seismic discontinuities are derived from seismological studies and interpreted in terms of temperature and composition. Nonetheless seismic models require approximations and assumptions that can be geologically inconsistent or poorly justified. Moreover, the relationship between the seismic and material properties of rocks are often non-linear and non-unique. A better and more quantitative understanding of rock behavior with respect to temperature, pressure, composition and water content is necessary, to clarify the limits and feasibility of seismic methods in inferring geological features.

We use thermodynamic modeling to predict bulk seismic velocities and densities of proposed (both dry and hydrous) compositions for the upper, middle and lower crust in the Italian province, at varying temperature and pressure. A comparison is made with the VP and VS from the EPCrust model (Molinari & Morelli, 2011) and the ones from Molinari et al. (2015), based on ambient noise surface wave inversion.

We find that different dry compositions proposed for the Italian crust would be seismically indistinguishable.
The variation induced by a different composition is always lower than that caused by temperature and water content. Moreover, a mechanical mix of different chemical compositions produces bulk seismic properties which correspond, within errors, to what obtained by modeling their average composition. For these reasons, a global composition for the Crust (i.e Rudnick and Gao [2003]) can be used as a reasonable approximation.

The presence of water, although important to retrieve the correct crustal mineralogy, does not affect significantly seismic velocities in a large P-T range. Only felsic, upper crustal compositions with water content >0.25 wt%, show a drastic decrease in VS and an increase in VP/VS when reaching melting temperature.

The ratio VS/density of the bulk crustal rock shows a narrow variability across a wide range of temperatures (400-1000 K), dry compositions and water content. We suggest that this ratio can be used as a constraint in joint-inversions of gravity and seismic data or to derive the density distribution of the crust given a VS model.

Sharp impedance jumps in correspondence of main phase transitions cause relevant seismic signature (i.e. receiver functions. In particular, the transformation of -Quartz in -Quartz represents a non-negligible seismic discontinuity, marked by increases in VP and VP/VS that are larger than those generated by compositional change at the upper-middle, middle-lower crust boundaries. Since the depth of the - Quartz transition is mainly controlled by temperature, information about the local geothermal gradient is fundamental for discriminating between compositionally-induced increase in VP and VP/VS from those related to the Quartz transition.

Our findings can be used as a basis for an improved and geologically-consistent joint-inversion of surface wave and receiver functions for the Italian crust. Additional constraints from gravity data on density structure will be first tested with the purely seismically-based model and then included into the joint inversion.