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Fine scale heterogeneity in the Earth's upper mantle - observation and interpretation

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High resolution seismic data has over the last decade provided significant evidence for pronounced fine scale heterogeneity in the Earth's mantle at an unprecedented detail. Seismic tomography developed tremendously during the last 20-30 years. The results show overall structure in the mantle which can be correlated to main plate tectonic features, such as oceanic spreading centres, continental rift zones and subducting slabs. Much seismological mantle research is now concentrated on imaging fine scale heterogeneity, which may be detected and imaged with high-resolution seismic data with dense station spacing and at high frequency, e.g. from the Russian Peaceful Nuclear Explosion (PNE) data set and array recordings of waves from natural seismic sources.

Mantle body waves indicate pronounced heterogeneity at three depth levels whereas other depth intervals appear transparent, at least in the frequency band of 0.5-15 Hz:

(1) The Mantle Low-Velocity Zone (LVZ) is a global feature which has been detected in more than 50 long-range seismic profiles (Thybo and Perchuc, Science, 1997). Since then numerous studies based on receiver functions, surface waves, and controlled source seismology have confirmed the presence of this zone. The data demonstrates that the top of the LVZ everywhere is at a depth of 100±20 km. A pronounced coda shows that the zone is highly heterogeneous at characteristic scale lengths of 5-15 by 2-6 km. We interpret that the rocks in the LVZ have a temperature close to the solidus or even may contain small fractions of partial melt. The solidus of mantle rocks is very low below a depth of ca. 90 km if volatiles are present due to a characteristic kink in the solidus which is much lower than for dry mantle rocks. We suggest that the rocks are in a totally solid state below the LVZ and that the depth to the interface to fully solid rocks is an indicator of the thermal state of the upper mantle.

(2) Significant scattering from around the top of the Mantle Transition Zone indicates the presence of highly heterogeneous depth intervals above and below the 410 km discontinuity at a characteristic scale length of 8-20 by 3-8 km. These observations may be explained by either (i) A high percentage of Fe in this part of the mantle (up to Fe# 17%) which affects the phase transformations of the olivine component; (ii) Possible phase changes from pyroxenes to the garnet phase majorite; or (iii) Heterogeneity arising from subducted slabs that have equilibrated around the Transition Zone.

We model characteristic scale lengths and velocity contrasts of the mantle heterogeneity by application of 2D Finite Difference simulation of seismic wave propagation. Unfortunately the seismic data does not allow direct detection of the structure, but the heterogeneous structure of the mantle is now well demonstrated, probably caused by different processes.