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Asthenosphere-lithosphere interaction: Effects on the microstructure and seismic anisotropy of the lithospheric mantle

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Evidence of mantle flow observed in peridotite massifs as well as seismic anisotropy measurements in currently deforming and fossil orogenic belts suggest that the upper mantle is largely involved in orogenic processes. Strain-induced crystallographic fabric is formed in the upper mantle in response to large-scale tectonic processes, and results in the development of the observed anisotropy. When deformation stops, this fabric is fossilized in the lithospheric mantle and may be preserved over a long time, provided no subsequent event modify the mantle lithosphere fabric.

However, processes such as rifting or impingement of an upwelling mantle plume may trigger interactions between the stable lithosphere and abnormally hot asthenosphere. The base of the lithosphere might be eroded through reheating (upward migration of the isotherms by thermal conduction) and through the thermo-mechanical action of small-scale convection cells. Moreover, magmas resulting from decompression melting of upwelling asthenosphere may percolate through the lithosphere, advecting heat and modifying its microstructure. These processes alter the mineralogy, microstructure and geochemical signature of the lithospheric mantle; altogether they lead to progressive asthenospherization of the lithosphere. As a consequence of heating and refertilization, seismic velocities in the modified mantle lithosphere are significantly reduced and its apparent thickness diminished.

Does this evolution modify or even erase the seismic anisotropy of the initial lithospheric mantle? In other words, is the structural memory of the lithospheric mantle preserved in such geodynamic situations?

Insights on this process are provided by the measurement of the Crystallographic Preferred Orientation of rock-forming minerals and the computation of seismic properties of mantle rocks from the Ronda Peridotite Massif, and of xenoliths from Tanzania and Polynesia volcanoes. The Ronda massif displays clear microstructural and geochemical variations characterizing the limit between the lithospheric mantle and its asthenospherized counterpart that has undergone partial melting and magmas percolation. The CPO measured in peridotites from both domains is quite similar and so are seismic properties, suggesting that the tectonic fabric inherited from previous deformation and the resulting seismic anisotropy are only slightly modified by asthenospherization.

The Labait volcano in Tanzania sampled the Tanzania cratonic mantle at depths between 150 km and less than 70 km. Although significant annealing and exaggerated grain growth of olivine occur between 70 km and 120 km the olivine CPO does not vary significantly, suggesting that the initial anisotropy of the lithospheric mantle was preserved. Deeper in the mantle, nucleation recrystallization becomes widespread, the grain size is much finer and the microstructure is equilibrated. It is remarkable that despite the microstructural modifications, no weakening of the seismic anisotropy is observed with depth.

Xenoliths from several Polynesian volcanoes display composition and geochemistry that suggest percolation of variable amounts of melt in the lithospheric mantle even at relatively shallow depths. Most samples display a strong fabric and seismic anisotropy. Only dunites that have undergone extensive percolation, probably through channel flow, display a weak olivine CPO and thus a weak seismic anisotropy.

Altogether the results of these studies suggest that asthenospherization does not necessarily erase the inherited seismic anisotropy of the older, previously deformed, lithosphere. As far as no significant deformation occurs and if melting and melt-rock interaction remain moderate, the CPO of olivine, and thus the seismic anisotropy of the lithospheric mantle are largely preserved. However, when melt-rock interactions results in the crystallization of olivine, then the lithospheric seismic anisotropy signature of the mantle may be progressively obliterated.