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Heterogeneous lithospheric mantle

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The lithosphere is a thermal boundary layer atop mantle convection and a chemical boundary layer formed by mantle differentiation and melt extraction. The two boundary layers may everywhere have different thicknesses. Worldwide, the thicknesses of thermal and chemical boundary layers vary significantly, reflecting thermal and compositional heterogeneity of the lithospheric mantle.

Physical parameters determined by remote geophysical sensing (e.g. seismic velocities, density, electrical conductivity) are sensitive to both thermal and compositional heterogeneity. Thermal anomalies are usually thought to have stronger effect than compositional anomalies, especially at near-solidus temperatures when partial melting and anelastic effects become important. Therefore, geophysical studies of mantle compositional heterogeneity require independent constraints on the lithosphere thermal regime. The latter can be assessed by various methods, and I will present examples for continental lithosphere globally and regionally. Of particular interest is the thermal heterogeneity of the lithosphere in Greenland, with implications for the fate of the ice sheet and possible signature of Iceland hotspot track.

Compositional heterogeneity of lithospheric mantle at small scale is known from Nature's sampling, such as by mantle-derived xenoliths brought to the surface of stable Precambrian cratons by kimberlite-type magmatism. This situation is paradoxical since “stable” regions are not expected to be subject to any tectono-magmatic events at all. Kimberlite magmatism should lead to a significant thermo-chemical modification of the cratonic lithosphere, which otherwise is expected to have a unique thickness (>200 km) and unique composition (dry and depleted in basaltic components). Nevertheless, geochemical studies of mantle xenoliths provide the basis for many geophysical interpretations at large scale.

Magmatism-related thermo-chemical processes are reflected in the thermal, density, and seismic velocity structure of the cratonic lithosphere. Based on joint interpretation of geophysical data, I demonstrate the presence of significant lateral and vertical heterogeneity in the cratonic lithospheric mantle worldwide. This heterogeneity reflects the extent of lithosphere reworking by both regional-scale kimberlite-type magmatism (e.g. Kaapvaal, Siberia, Baltic and Canadian Shields) and large-scale tectono-magmatic processes, e.g. associated with LIPs and subduction systems such as in the Siberian and North China cratons. The results indicate that lithosphere

chemical modification is caused primarily by mantle metasomatism where the upper extent may represent a mid-lithosphere discontinuity. An important conclusion is that the Nature's sampling by kimberlite-hosted xenoliths is biased and therefore is non-representative of pristine cratonic mantle.

I also present examples for lithosphere thermo-chemical heterogeneity in tectonically young regions, with highlights from Antarctica, Iceland, North Atlantics, and the Arctic shelf. Joint interpretation of various geophysical data indicates that West Antarctica is not continental, as conventionally accepted, but represents a system of back-arc basins. In Europe and Siberia, an extremely high-density lithospheric mantle beneath deep sedimentary basins suggests the presence of eclogites in the mantle, which provide a mechanism for basin subsidence. In the North Atlantic Ocean, thermo-chemical heterogeneity of the upper mantle is interpreted by the presence of continental fragments, and the results of gravity modeling allow us to conclude that any mantle thermal anomaly around the Iceland hotspot, if it exists, is too weak to be reliably resolved by seismic methods.

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