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Composition of uppermost mantle beneath the Northern Fennoscandia – numerical modeling and petrological interpretation

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Studying of the uppermost mantle beneath the northern Fennoscandia is based on the data of the POLENET/LAPNET passive seismic array. Firstly, arrivals of P-waves of teleseismic events were inverted into P-wave velocity model using non-linear tomography (Silvennoinen et al., in preparation). The second stage was numerical petrological interpretation of referred above velocity model.

This study presents estimation of mineralogical composition of the uppermost mantle as a result of numerical modeling. There are many studies concerning calculation of seismic velocities for polymineral media under high pressure and temperature conditions (Afonso, Fernàndez, Ranalli, Griffin, & Connolly, 2008; Fullea et al., 2009; Hacker, 2004; Xu, Lithgow-Bertelloni, Stixrude, & Ritsema, 2008). The elastic properties under high pressure and temperature (PT) conditions were modelled using the expanded Hook's law – Duhamel-Neumann equation, which allows computation of thermoelastic strains. Furthermore, we used a matrix model with multi-component inclusions that has no any restrictions on shape, orientation or concentration of inclusions. Stochastic method of conditional moment with computation scheme of Mori-Tanaka (Prodaivoda, Khoroshun, Nazarenko, & Vyzhva, 2000) is applied instead of traditional Voigt-Reuss-Hill and Hashin-Shtrikman equations.

We developed software for both forward and inverse problem calculation. Inverse algorithm uses methods of global non-linear optimization. We prefer a "model-based" approach for ill-posed problem, which means that the problem is solved using geological and geophysical constraints for each parameter of a priori and final models. Additionally, we are checking at least several different hypothesis explaining how it is possible to get the solution with good fit to the observed data. If the a priori model is close to the real medium, the nearest solution would be found by the inversion. Otherwise, the global optimization is searching inside the restricted volume in the multi-dimensional parameter space. In order to constrain concentration of minerals we used equilibrium of mineral associations for selected P-T condition obtained by free Gibbs energy minimization (c.f. Stixrude & Lithgow-Bertelloni, 2005). We also considered the mineralogical composition of upper mantle xenoliths, although the representativeness of xenoliths in Precambrian rocks could be treated with care, if one tries to describe the modern mantle.

As a first step, we estimated 1D model of mineralogical composition in the depth range of 35-350 km using the IASP91 reference model (Kennett & Engdahl, 1991). Both the P- and S- wave velocities were used for inversion, in order to improve the reliability of the model. More comprehensive result could be obtained if density distribution is involved. In our study we used the 1D PEMC density model (Dziewonski, Hales & Lapwood, 1975) as it is the most adequate for the continental lithosphere.

The 1D modeling showed that the garnet lherzolite model (forsterite, fayalite, enstatite, ferrosilite, diopside, jadeite, pyrope) can be considered as a basic one. The end-members of olivine and orthopyroxene solutions were included with the aim of Fe/Mg ratio estimation. Testing with modified models including hedenbergite, harzburgite spinel, etc. showed that these minerals have no significant influence on bulk elastic properties. Selected set of minerals allows modelling the most species of peridote-pyroxenite associations known from xenoliths investigations (Kukkonen, Kuusisto, Lehtonen, & Peltonen, 2008; Lehtonen, O'Brien, Peltonen, Johanson, & Pakkanen, 2004). However, there exist also a number of evidences for mantle eclogite xenoliths from the region under study and its surrounding (Lehtonen et al., 2004; Peltonen, Kinnunen, & Huhma, 2002). That is why we also made modelling for garnet-clinopyroxene model of eclogite. The volumetric mineral compositions obtained were transformed into weight concentration of rock-forming oxides using stoichiometric formulas.

The results indicate significant variation of Fe and Mg oxides concentration in the uppermost mantle. The Mg/Fe ratio could be different from the results of previous studies (Griffin et al., 2003; Svetov & Smolkin, 2003), but it is in agreement with the geophysical models considered in our study. At the same time the SiO_2 concentration is close to the chemical composition of xenoliths from the Fennoscandia, including Kola Peninsula and Central

Finland (Beard, Downes, Mason, & Vetrin, 2007; Kukkonen et al., 2008; Lehtonen et al., 2004).
Brief conclusions from our study could be formulated as follows:
1) Modelling confirms potential significant lateral inhomogeneity of mineral composition of the uppermost mantle of northern Fennoscandian Shield.
2) Lherzolitic composition of the mantle lithosphere generally explains seismic velocities obtained by teleseismic tomography in northern Fennoscandian Shield. It could be used as a primary a priori model for interpretation. But potential presence of eclogites cannot be rejected, at least for some parts of studied area.
3) The future study needs to include more precise evaluation of temperature and density in the upper mantle using gravity and heat flow data.

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