The Forsterite Layer and Density of Olivine under Lithospheric and Asthenospheric P-T-Conditions

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It was shown by Pilchin and Eppelbaum (2009) that formation of the lithosphere first began with the formation of a forsterite layer at a depth of about 100 km within the magma ocean as its layers were being stratified by density and iron content. This coincides with the fact that in most Archean cratons garnet peridotite xenoliths were brought up from depths usually greater than ~70 km and that the quantity of these xenoliths significantly increases with depth, with most originating from 100 km or deeper. Analysis of the *P-T* conditions of peridotite xenoliths also shows that the minimum depths of their equilibration is about 70-100 km. This is also in accordance with seismic data showing the regional seismic boundary in the uppermost mantle to be at a depth of about 100 km with a P wave velocity of 8.4-8.5 km/s.

Continental asthenosphere does not necessarily contain partially molten rocks, because low velocity zones (LVZ) could be caused by special thermodynamic conditions (Pilchin and Eppelbaum 2009), as well as the known fact of a decrease of both V_P and V_S velocities with increased iron content. This is also proven by the fact that mantle plumes reach the surface in continental areas, since they would be unable to pass through partially molten asthenosphere. The iron content (FeO content) of continental plumes in Phanerozoic is higher than 12-13 %, while iron content of mid-ocean ridge basalts is only 8.3-9.1 %. This is also supported with the fact that the asthenosphere has been found to be absent below some cratons, especially cratons with a lithospheric thickness of about 350-400 km found in some regions of the Siberian platform and Ukrainian shield. Geophysical studies of Northern Eurasia have also been unable to reveal a well-defined and continuous asthenosphere and in many cases the asthenosphere cannot be traced from the seismic data. This also means that in some cases the formation of kimberlites is possible within the asthenosphere.

Researches on xenoliths show that the absolute majority of cratonic xenoliths, especially ones from kimberlites, are peridotitic. Analysis of volume thermal expansion and compressibility of olivine ($Fo_{89.9}$), the main component of peridotites, in a wide range of P-T-conditions shows that at 0.100 GPa its density drops by about 4.4-5.4 % at temperatures of 1573-1773 K . At the same time, at a temperature of 373 K, its density at pressures of 4.0-6.0 GPa increases by 3.1-4.7 %. This means that to analyse the density of olivine at great depths the effects of both pressure and temperature should be considered. For instance, conditions of P-T-equilibrium with a constant density for olivine at temperatures of 1473 K and 1573 K could only be met at depths with a lithostatic pressure of about 5.0 and 5.6 GPa, respectively. In cases of these temperatures appearing at greater depths the density of olivine and olivine-containing rocks would be greater. At depths corresponding to pressures of 5.0-6.0 GPa at temperatures of 1573 K, the density of olivine would be variable from declining by about 0.5% to increasing by about 0.3%; while at temperatures of 1673 K and 1773 K, the density would decline by 1.0-0.2 % and 1.5-0.7 %, respectively. This means that for the subduction process to start it would be required for temperatures within the uppermost asthenosphere to be in the range of 1673-1773 K or even greater, because that would establish densities in the asthenosphere slightly lower than those of the mantle part of the lithosphere. However, it should also be taken into account that at a constant temperature, density increses with depth and the effect of pressure on density would overcome the effect of thermal expansion at depths with pressure 6.3 GPa and greater for 1673 K and 7.0 GPa and greater for 1773 K. This renders the process of kimberlite formation incompatible with the process of subduction, since they require much lower temperatures. Temperatures in the range of 1673-1773 K and higher are also too high for upper mantle of cratons, meaning that P-T-conditions within cratons are not favourable for the subduction process. However, it is completely different for oceanic regions, in which the variable density of olivine could decrease by 2.4 % for T=1473 K and P=2000 MPa, and 3.1 % for T=1773 K and P=3000 MPa.

References

Pilchin, A., Eppelbaum, L., 2009. The early Earth and formation of the lithosphere. In: Anderson, J. E. and Coates, R. W. (Eds.) The Lithosphere: Geochemistry, Geology and Geophysics. Nova, New-York, 1-68.