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Formation and metasomatism of continental lithospheric mantle in intra-plate and subduction-related tectonic settings

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Our knowledge of the origin and evolution of the continental lithospheric mantle (CLM) remains fragmentary and partly controversial in spite of recent advances in petrologic, geochemical and geophysical studies of the deep Earth and experimental work. Debate continues on a number of essential topics, like relative contributions of partial melting, metasomatism and 're-fertilisation' as well as the timing, conditions and tectonic settings of those processes. These topics can be addressed by studies of ultramafic xenoliths in volcanic rocks which arguably provide the least altered samples of modern and ancient CLM.

The subcontinental lithosphere is thought to be a mantle region from which melts have been extracted, thus making the lithosphere more refractory. Melting degrees can be estimated from Al contents while the depth of melt extraction can be assessed from Al-Fe (Mg#) relations in unmetasomatized melting residues in comparison with experimental data, e.g. [1]. High silica and opx in the residues may indicate melting in water-rich conditions. High-precision Mg# and Mn for olivine may constrain degrees and conditions of partial melting and/or metasomatism, tectonic settings, modal compositions (e.g. presence of garnet) and equilibration conditions of mantle peridotites [2]. These estimates require both adequate sampling and high-quality major element and modal data; sampling and analytical uncertainties in published work may contribute substantially to chemical heterogeneities (and different origins) inferred for CLM domains [3].

Very fertile peridotite xenolith suites are rare worldwide [3]. They were initially viewed as representing mantle domains that experienced only very small degrees of melt extraction but are attributed by some workers to 'refertilization' of refractory mantle by percolating asthenospheric melts. Such alternative mechanisms might be valid for some rare hybrid and Fe-enriched peridotites but they fail to comprehensively explain modal, major and trace element and isotope compositions of fertile lherzolites and thus cannot provide viable alternatives to the concept of melt extraction from pristine mantle as the major mechanism of CLM formation.

Published data on xenoliths from andesitic volcanoes and on supra-subduction oceanic peridotites [4] show that the most common rocks in mantle wedge lithosphere are highly refractory harzburgites characterized by a combination of variable but generally high modal opx (18-30%) with very low modal cpx (1.5-3%). At a given olivine (or MgO) content, they have higher opx and silica, and lower cpx, Al and Ca contents than normal refractory peridotite xenoliths in continental basalts; the Mg-Si and Al-Si trends in those rocks resemble those in cratonic peridotites. These features may indicate either fluid fluxing during melting in the mantle wedge or selective post-melting metasomatic enrichments in silica to transform some olivine to opx. High oxygen fugacities and radiogenic Os-isotope compositions in those rocks may be related to enrichments by slab-derived fluids, but these features are not always coupled with trace element enrichments or patterns commonly attributed to "subduction zone metasomatism" deduced from studies of arc volcanic rocks and experiments.

The valuable insights provided by experimental work and xenolith case studies are difficult to apply to many natural peridotite series because late-stage processes commonly overlap the evidence for initial melting.

References: [1] Herzberg C., J. Petrol. 45: 2507 (2004). [2] Ionov D. & Sobolev A., GCA 72 (S1): A410 (2008). [3] Ionov D., Contrib. Miner. Petrol. (2007) [4] Ionov D., J. Petrol. doi: 10.1093/petrology/egp090 (2010)