

Evolution of the European mantle lithosphere a Sr-Nd-Pb isotope perspective

M. Wilson
J.M. Rosenbaum
H. Downes,

*Department of Earth Sciences, Leeds University, Leeds LS2
9JT, UK*

*Research School of Geological & Geophysical Sciences, Birkbeck
College & University College London, Gower Street, London
WC1E 6BT, UK.*

Introduction

One of fundamental challenges in petrology is to understand the chemical evolution of the lithospheric mantle, both oceanic and continental. Perhaps one of the most contentious issues in the past five years has been the potential of this part of the mantle to act as a magma source in zones of intra-plate extension (e.g. Wilson and Downes, 1991; Gallagher and Hawkesworth, 1992; Wilson, 1993). To resolve this issue, we clearly need to understand the processes by which this inherently refractory layer of the Earth may become re-fertilised enough to act as a magma source.

To a first order approximation, we can think of the lithosphere as consisting of two distinct layers (Wilson, 1993). The upper layer, the Mechanical Boundary Layer (MBL), is that part of the system which deforms in a brittle manner and is capable of sustaining geochemical heterogeneities over long periods of geological time (up to several Gyr). In contrast, the lower layer, the Thermal Boundary Layer (TBL), deforming in a more plastic manner, is unlikely to preserve long-term heterogeneities. While the TBL may behave as if it were part of the MBL over short time periods (perhaps up to several hundred Myr), over longer time periods it probably delaminates from the MBL and is recycled back into the underlying convecting asthenosphere.

Studies of the ocean basins have clearly demonstrated that the oceanic lithosphere increases in thickness (up to a maximum of ~ 100 km) with increasing age. There are also documented increases in continental lithospheric thicknesses between Phanerozoic and Archaean-Proterozoic tectonic domains which may be age-related. How the mantle part of the oceanic or continental lithosphere actually thickens, however, remains a source of some debate (e.g. McDonough, 1990; Hawkesworth *et al.*, 1990). Does this growth occur through underplating diapirs of depleted harzburgite (the residues from partial melting events - e.g. MORB genesis) or

does the lithosphere thicken as a consequence of conductive cooling by downward capture of the convecting asthenospheric mantle? In the latter case we would expect that the lithospheric mantle would be chemically stratified, becoming more fertile with respect to its major element composition with increasing depth, eventually approaching the composition of the convecting asthenosphere (MORB-source mantle).

Regardless of the mechanism by which the lithosphere thickens, it must become chemically heterogeneous with time as a consequence of infiltration by partial melts and H₂O-CO₂ fluids from the convecting asthenosphere. To understand the long-term geochemical evolution of the lithosphere we need to investigate the 'record' within the continental lithospheric mantle of such metasomatic events. It is clear that the upper parts of the MBL should retain an imprint, in the form of magmatic veins and channels, of all previous magmatic events which have influenced its evolution. In addition, the MBL may become enriched as a result of fluid metasomatism by, for example, H₂O-rich fluids ascending from subduction zones or by CO₂-rich fluids associated with kimberlite-carbonatite magmatic events. In contrast, the TBL, and perhaps also the base of the MBL, is likely to have a shorter 'memory' of older magmatic and metasomatic events, as these parts of the system become delaminated and are periodically replenished with 'fresh' mantle material. Nevertheless, over short time scales (perhaps up to 200-300 Myr), the TBL will become enriched by the same infiltration metasomatic processes affecting the MBL.

The nature of the European mantle lithosphere

The nature of the upper mantle (< 80 km depth) beneath central Europe is well constrained by the occurrence of abundant spinel peridotite mantle xenoliths (herzolites, harzburgites, dunites and wehrlites) entrained within Pliocene-Quaternary alkali basalts, basanites and nephelinites (Downes

et al., 1992; Menzies and Bodinier, 1993). These xenoliths provide a unique probe of the MBL-TBL transition zone from west to east across Europe.

On the basis of studies of mantle xenoliths worldwide (e.g. McDonough, 1990), the European lithospheric mantle should be composed of four-phase spinel lherzolites (olivine-orthopyroxene-clinopyroxene-spinel) and more refractory residues from previous partial melting events (harzburgites, dunites). Within the Massif Central of France and the Pannonian Basin of Hungary, these lithologies do indeed dominate the xenolith population. Associated with these are small amounts of pyroxenite (Downes, 1987; Downes *et al.*, 1992) which are the products of silicate melt infiltration into the mantle. In both areas hydrous minerals such as amphibole or biotite are relatively rare, suggesting that any infiltrating melts/fluids were relatively dry. Locally, however, hydrous phases may form a significant component of the xenolith mineralogy.

Mantle xenoliths from the Rhenish Massif of Germany, in contrast, are predominantly clinopyroxene poor peridotites and harzburgites in which amphibole and phlogopite are common (Witt and Seck, 1989; Hartman and Wedepohl, 1990; Lloyd *et al.*, 1991). The presence of abundant hydrous minerals in these xenoliths has been attributed by some authors to fluid metasomatism above a Hercynian subduction zone, although this could also be explained by hydrous silicate or carbonatite melt infiltration related to the Tertiary-Quaternary magmatic activity (e.g. Thibault *et al.*, 1992). Further south within Germany, in the Urach and Hegau volcanic fields, the presence of unusual wehrlite-dominated lithologies has been attributed to metasomatism of the mantle lithosphere by CO₂-rich fluids (Glahn *et al.*, 1992).

Sr-Nd-Pb isotopic data

Detailed trace element and Sr-Nd-Pb isotopic studies of peridotite xenoliths from the Massif Central of France, the Rhenish Massif of Germany and the Pannonian Basin of Hungary suggest that at least two distinct processes have modified the European lithospheric mantle (Rosenbaum *et al.*, 1993; Downes *et al.*, 1992; Downes, 1987). The data provide compelling evidence for widespread infiltration of silicate melts derived from an enriched mantle source region, chemically similar to the source of HIMU ocean-island basalts, into a major-element fertile but incompatible element-depleted mantle protolith. We consider these silicate melts to be derived from a mantle plume source which also provided

the major asthenospheric source component for the widespread Tertiary-Quaternary volcanism within Europe.

Within the mantle lithosphere beneath the Pannonian Basin there is also clear evidence for lithospheric enrichment by aqueous fluid infiltration into a rapidly extending back-arc basin tectonic regime, related to Tertiary subduction along the Carpathian arc. Here, the geochemical signature of fluid metasomatism has been partially overprinted by infiltration of silicate melts with similar geochemical characteristics to those responsible for enrichment of the mantle beneath the Massif Central. This enables us to constrain the timing of silicate melt infiltration, in this part of Europe at least, to less than ~ 20 Ma. Lead isotopes appear to be the most sensitive indicator of the subduction-related flux, which has a distinctly enriched ²⁰⁷Pb signature, with ²⁰⁷Pb/²⁰⁴Pb ratios greater than 15.70 for ²⁰⁶Pb/²⁰⁴Pb ratios less than 18.5. While affecting the Pb isotopic composition of the lithosphere, the subduction fluid did not significantly alter the REE content of the mantle. The plume-component, however, affected both the radiogenic isotopic composition and the REE signature of the fluxed lithospheric mantle. With progressive silicate melt infiltration, Sr, Nd and ²⁰⁶Pb/²⁰⁴Pb isotopic compositions change from those typical of depleted MORB source mantle to those resembling HIMU OIB. The record of metasomatic enrichment in the Rhenish Massif xenolith suite appears to be more complex, possibly as a consequence of multiple enrichment events.

Geodynamic implications

On the basis of our studies of European mantle xenoliths we suggest that the lower portion of the lithosphere, as sampled by the Tertiary-Quaternary volcanism, is composed of major-element fertile but incompatible element depleted mantle similar to the source of MORB. This has been accreted by a process of downward capture from the convecting asthenosphere at some stage subsequent to the Hercynian orogeny (<300 Myr), which was probably the last time large-scale delamination of the TBL occurred within Europe. Over the past 20–30 Myr this part of the mantle has been infiltrated by silicate melts derived from a HIMU-mantle plume source and locally by aqueous subduction zone fluids (Pannonian Basin). Whilst we cannot constrain the age of accretion of the depleted mantle protolith, it is clear that the development of the observed isotopic heterogeneities is a geologically recent phenomenon.