ASTENOSPHERE–LITHOSPHERE RELATIONSHIPS WITHIN OROGENIC MASSIFS.

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The existence of small volume melt fractions with MORB/OIB affinity in the asthenosphere has recently received much attention particularly with regard to continual interaction with the base of the overlying lithosphere (MacKenzie 1989). Whilst diamond inclusions, kimberlite-borne and basalt-borne xenoliths provide a vital record of the transformation of continental lower lithosphere of Archaean and Proterozoic age (Menzies and Hawkesworth 1987; Nixon 1987; Menzies 1990), orogenic massifs provide unparalleled "exposure" of upper mantle peridotites of Proterozoic to Phanerozoic age thus facilitating the study of more recent asthenosphere-lithosphere interaction (Bodinier et al 1991; Downes et al 1991; Mukasa et al 1991). Orogenic massifs provide vital information about the temporal and spatial relationships between the peridotite protolith and different generations of melts. Two extreme cases are apparent from recently acquired geochemical data on orogenic massifs from the Mediterranean. At one extreme Phanerozoic asthenosphere-Proterozoic lithosphere is exposed in the Lanzo massif Italy (Bodinier et al 1991) and Proterozoic-Phanerozoic lithosphere in the Lherz massif, France (Downes et al 1991; Mukasa et al 1991). These massifs provide a field laboratory for the study of the formation and segregation of MORB (Lanzo) and transformation of a Proterozoic peridotite protolith by the injection and percolation of small volume melts (some of which are MORB) throughout the Phanerozoic (Lherz).

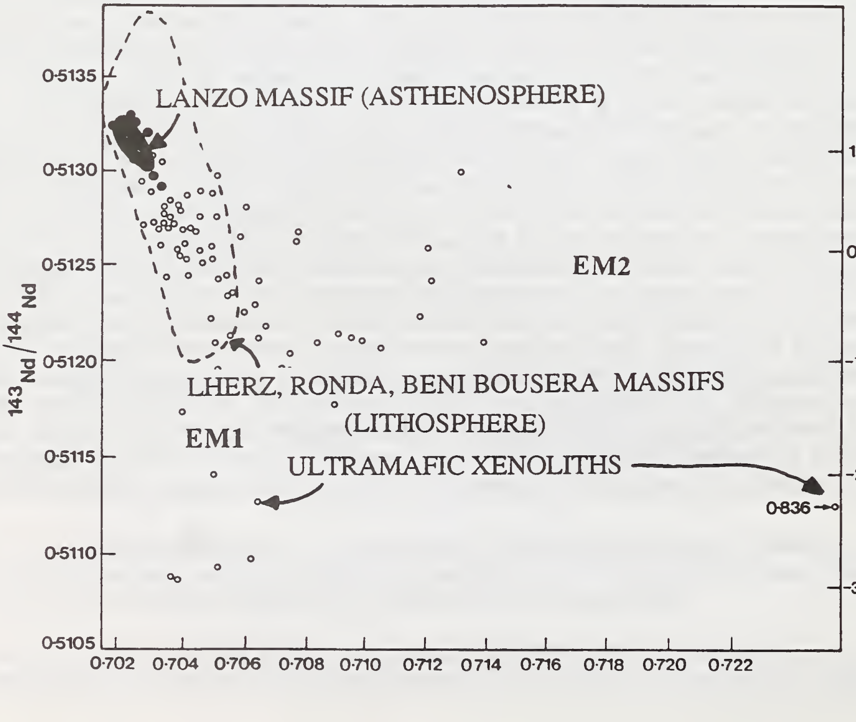
LITHOSPHERE-ASTHENOSPHERE TRANSITION.

Major, minor and trace element variations within the Lanzo massif, Italy can be used to define chemical provinciality within the massif on the scale of kilometres. While the northern part of the massif is characterised by protogranular textures and fertile lherzolite compositions the southern part of the massif is characterised by sheared textures and more refractory lherzolitic compositions. In terms of partial melting histories, these data indicate that more extensive melt extraction occured in the south than in the north. In contrast to the major and minor elements, variations in the LREE within the massif are believed to refelect primary mantle heterogeneity in that in the north the lherzolites are only moderately depleted in the LREE whereas in the south they are more markedly depleted in the LREE. When considered in conjunction with Sr, Nd and Pb isotopic geochemistry it is apparent that the northern part has very low 87Sr/86Sr ratios and very high 143Nd/144Nd ratios - the isotopic characteristics of aged depleted residua similar to (a) the Baldissero massif to the north, and (b) to mantle xenoliths entrained from beneath post-Archaean crust (e.g. Kilbourne Hole, San Carlos). The southern part of the massif is identical to Atlantic MORB asthenosphere with a tightly defined range of Sr and Nd isotopes. Elemental and isotopic data for the southern massif allow us to constrain the composition of the MORB source in particular the Sm/Nd ratio which is found to be similar (0.27) to that calculated from the Nd isotopic evolution of Phanerozoic MORB's from the northern hemisphere. The southern part of the massif is believed to represent deep well mixed convecting upper mantle which rose through the garnet stability field and experienced polybaric melt extraction thus accounting for its more depleted chemistry. The northern part of the massif is considered to be a fragment of sub-continental lithosphere isolated from the convecting upper mantle since the Proterozoic. Between these two extremes there exists a transition zone or hybrid containing components from the lithosphere modified by the ingress of asthenospheric melts. If we consider the north to be part of the **mechanical boundary layer** which underplated Proterozoic crust and the south to be **asthenosphere** then this hybrid zone has all the features of a **thermal boundary layer**. It is apparent from the study of Lanzo that formation of MORB melts began with extraction of < 5% melt in the garnet stability field and later upwelling into the spinel stability field triggered extraction of larger degrees of melt (5-12%). Moreover the Sm/Nd ratio of the least depleted lherzolite at Lanzo (i.e. analogue of the MORB source) differs from that of MORB melts indicating that during these processes the LREE are fractionated. Indeed consideration of a wider database reveals that throughout the Phanerozoic the MORB source has become more depleted with time.

HYDROFRACTURING OF PROTEROZOIC LITHOSPHERE.

The possible scale of inhomogeneities in the continental lithosphere can be assessed by consideration of the Lherz massif. The peridotite protolith (mechanical boundary layer) is believed to be a protogranular spinel peridotite that has been deformed thus allowing melt ingress. Melt conduits developed by hydrofracture are now healed with the crystallisation of amphibole-pyroxene veins. A chronology of fluid ingress is apparent at Lherz as (a) LREE enrichment within the protogranular peridotite protolith, (b) hydrofracture systems in porphyroclastic peridotite that helped channel basaltic melt (now crystallised as amphibole pyroxenite); (c) metasomatic and enrichment aureoles in the wall rock adjacent to these veins, and (d) multiple episodes of carbon-dioxide bearing fluid inclusions.

The metasomatic fronts and enrichment fronts that occur adjacent to the melt conduits are defined on the basis of the presence of hydrous minerals and elevated LREE/HREE ratios respectively. Extreme elemental and isotopic heterogeneity exists within the reaction aureole due to melt percolation and reaction with the wall rock (Bodinier et al 1990; Downes et al 1991). The range in Sr and Nd over a 60 cm. section is similar to that of MORB and OIB and greatly exceeds the range for Lanzo. Whilst the Lanzo massif is dominated by depleted mantle domains (MORB source and residue) several chemically discrete enriched mantle domains (i.e. DMM, EM2 and EM1) occur within the tiny massif at Lherz (>200x *smaller* than Lanzo). This illustrates the isotopic homogeneity of the asthenosphere and the isotopic heterogeneity of the lithosphere - isotopic heterogeneity that could, in some cases, be caused by a time-integrated reponse to elemental fractionation brought about by the reaction of MORB melt with depleted wall rock. For example a time-integrated response to the elemental fractionation observed within the reacted wall rock sections at Lherz would result in localised development of EM1 domains because of the very low Rb/Sr and Sm/Nd ratios generated in the reaction zone. Clearly concomitant metasomatic and enrichment processes involving MORB melts and depleted or enriched wall rock can be responsible for the development of enriched reservoirs (e.g. EM1) that may be consumed during genesis of small volume alkaline melts within the lithosphere. Where the main hydrous phase to crystallise in the wall rock is amphibole low Rb/Sr ratios and Sm/Nd ratios are observed due to the uptake of Sr and LREE by amphibole and the retention of Rb in the fugitive melt. A time-integrated response to this would produce localised EM1. In contrast where mica dominates in the reaction zone higher Rb/Sr ratios and Sm/Nd ratios are observed resulting in the time-integrated development of localised EM2 domains.



CONTRASTING CHARACTERISTICS

Asthenosphere	**Lithosphere**
(a) porphyroclastic plagioclase and spinel peridotites (=DMM)	(a) protogranular spinel [and garnet] peridotites(=DMM); development of porphyroclastic & mylonitised peridotites in association with shear zones and magma conduits.
(b) the existence of segregated melts that are compositionally identical to MORB. melts),	(b) healed hydrofracture networks (e.g polybaric derivatives of MORB/OIB)
(c) "hot" temperatures : oceanic to geotherm.	(c) "cold" temperatures : continental geotherm.
(d) redox state close to or above QFM,	(d) redox state well below QFM (protolith) or above QFM (metamorphic aureole around hydrofracture systems)
(e) clinopyroxenes extremely depleted in the LREE (= abyssal/oceanic peridotites),	(e) clinopyroxenes slightly depleted in the LREE (= basalt-borne xenoliths),
(f) no LREE enrichment in the melt-residue system	(f) multiple enrichments in the peridotite protolith due to fluid ingress
(g) isotopic homogeneity (=MORB) and elemental heterogeneity (Figure 1).	(g) isotopic and elemental heterogeneity (=MORB,OIB and crust) (Figure 1).
(h) isotopic equilibrium between melt and peridotite	(h) isotopic disequilibrium between hydrofractures and adjacent wall rock
<u>Examples</u> : **Orogenic (alpine) massifs.** Lanzo spinel-plagioclase peridotite Italy, Erro-Tobbio spinel-plagioclase peridotite Italy; Trinity spinel-plagioclase peridotite California; Othris spinel-plagioclase peridotite Greece.	<u>Examples</u> : **Orogenic (alpine) massifs.** Lherz spinel peridotite France; Tinaquillo peridotite Venezuela; Baldissero-Balmuccia Italy and many others.
Mantle xenoliths. No xenolith analogue.	**Mantle xenoliths.** Abundant xenolith analogues : Type IA (LREE depleted) - protolith Type IB (LREE enriched) - protolith+ "fluid" Type II - "fluid" derivative. GP (garnet peridotite) - protolith GPP (" + mica) - protolith + "fluid" PKP (" + K-richterite) - protolith "fluid" MARID (mica, amph., rutile, ilmenite, cpx.) - "fluid" derivative.
Oceanic peridotites. Segregated plagioclase peridotites; Zabargad Island, Red Sea.	**Oceanic peridotites.** Abyssal peridotites; St. Paul's rocks Atlantic.

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