In the foreword of the volume *Mantle Metasomatism* by Menzies & Hawkesworth (1987), Boettcher stated that the concept of mantle metasomatism has been of immense heuristic value for Earth scientists. At that time, metasomatism was still strongly related to allochemical metamorphism, where chemical composition of the rock is changed by the additional or removal of material. However, the concept of modal or patent (where a new phase is petrographically evident) and cryptic (where chemical enrichment is not accompanied by the presence of a newly formed phase) metasomatism had already been introduced by the pioneering works of Harte (1983), Menzies (1983) and Dawson (1984).

Outstanding progress has characterized the past two decades, and the processes and agents of metasomatism are now much better understood, in part as a result of the significant advancements of *in situ* microanalytical techniques such as second-ablation-inductively coupled plasma-mass spectrometry (SIMS) and laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS). The *in situ* analyses substantially deepened knowledge of intermineral and solid–liquid partitioning coefficients as well as identifying the geochemical features of metasomatizing agents recorded by secondary paragenesis, (namely, clinopyroxenes, amphiboles and glasses), which are the main acceptors of trace elements within the mantle.

Glasses were initially interpreted as the product of host basalt infiltration and their petrological importance was disregarded. During the 1990s, the importance of identifying the geochemical features of the metasomatizing agents was properly highlighted and the study of glasses represented an important improvement in the understanding of metasomatic processes. Irrespective of their origin as products of (1) reaction (Coltorti et al. 2000), (2) *in situ* melting (Chazot et al. 1996; Yaxley et al. 1997), (3) decompressional melting (Francis, 1976; Gamble & Kyle, 1987) or (4) partial melting (Draper & Green, 1997), the glasses’ geochemical features can be a valuable clue to the nature of the metasomatizing agent. However, glasses are usually small and more difficult to analyse with the less time-consuming but larger-spot LA-ICP-MS. For this reason, at the beginning of this century, attention has been drawn back to minerals, such as clinopyroxene, amphibole and/or phlogopite (e.g. Grégoire et al. 2000; Moine et al. 2001; Coltorti et al. 2007a). Another revolution is on the horizon because of the introduction of LA-ICP-MS-MC (LA-ICP-MS with multicolonlector) and a new generation of femtolasers associated with ICP-MS which, with their increased sensitivity and enhanced performances, will allow the development of both *in situ* isotopic analyses and trace element analyses in orthopyroxene and olivine. LA-ICP-MS-MC will permit pinpointing of single ages and geochemical signatures instead of an average obtained by mineral separates, whereas femtolasers-ICP-MS will allow the study of more refractory rocks, such as harzburgites and dunites (which very rarely contain clinopyroxene and/or amphibole and/or glass) and other orthopyroxene-rich metasomatic parageneses, which are rather abundant in mantle wedges (e.g. Smith et al. 1999; Grégoire et al. 2001; McInnes et al. 2001; Ishimaru et al. 2007).

Most of the 14 papers in the present volume mainly rely on *in situ* major and trace element analyses of clinopyroxene and amphiboles, with the aim of identifying the nature of the metasomatizing agents affecting different portions of the lithospheric mantle. Some very basic concepts are at the core of these papers. Metasomatism is a process that enriches the lithosphere. Thus the lithosphere had previously been depleted by one or more partial melting episodes. As a consequence, metasomatism is the last event to be recorded by minerals, and it would be hidden or even completely erased by any melting process. Assuming that these logical connections are true at low melt–rock interaction, which can be practically considered synonymous with metasomatism, they are not valid for high melt–rock interaction, where percolation and impregnation can be responsible for both depletion


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**Metasomatism in oceanic and continental lithospheric mantle: introduction**

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and enrichment processes (see the work of Piccardo on several ophiolitic bodies of the Alpine–Apennine system). The increase of fluid/rock ratios also implies a drift in the metasomatizing agent’s composition from highly SiO$_2$-undersaturated, volatile- and alkali-rich silicate magmas (including CO$_2$-rich or even carbonatite melts) towards SiO$_2$-saturated and even SiO$_2$-oversaturated magmas. In parallel, the tectonic framework will change from intraplate, where SiO$_2$-undersaturated magmas are more abundant, to suprasubduction and mid-ocean ridge settings, where SiO$_2$-saturated and -oversaturated magmas predominate. The effects of these different interactions are presented in this volume, and they were studied on both continental and oceanic lithosphere, including the transition between the two that occurs when an ocean starts to open.

The transition between continental and oceanic lithosphere

Piccardo presents a comprehensive review of petrological, field and age relationships of several peridotite and ophiolite bodies of the Alpine–Apennine system. The continental lithosphere here results from the accretion of several masses of the convective asthenospheric mantle, which occurred from Proterozoic to Permian times. Lithosphere extension caused adiabatic upwelling and decompression melting, resulting in large-volume production of mid-ocean ridge basalt (MORB)-like magmas, which percolated and impregnated the continental lithospheric mantle. The continental lithosphere was progressively heated and asthenospherized until complete failure of continental crust occurred and mantle was exhumed at the sea floor. From this study it appears that the separation between continental and oceanic mantle lithosphere is not straightforward. Continental lithosphere can be progressively transformed into oceanic through impregnation, and oceanic lithosphere can be accreted at the base of the continental lithosphere. These facts have some relevance when the provenance and the nature of both depleted and enriched components are described in mantle xenoliths from continental and oceanic settings, as well as the occurrence of pieces of continental lithosphere found as xenoliths in ocean island basalts (Bonadiman et al. 2005, 2006; O’Reilly et al. 2006). Moreover, the simple paradigm that depleted rocks record a partial melting event is questioned (see also Bodinier 2007), especially when the dimensions of the outcrop (as for xenoliths) do not permit a thorough investigation of the field relationships. The need for more sophisticated geochemical tools capable of distinguishing between harzburgites produced by reaction with a melt and those produced by a ‘simple’ partial melting episode is envisaged. Melt–rock impregnation casts doubts on the barometric significance of the aluminous phase; impregnated plagioclase peridotites that were previously reasonably interpreted as having formed at low pressure can in fact coexist with reactive spinel peridotite.

Metasomatism in subduction-related environments and post-collisional orogens

The study of mantle xenoliths is limited by their small dimensions compared with Alpine or ophiolitic peridotite, but they have the exclusive advantage of a very rapid (in geological terms) ascent (from a few hours to several days), which allows the preservation of the textural features formed at mantle depth. Therefore, geochemical studies can be applied to different generations of minerals, which in turn can be related to various metasomatic events. Most probably the concept of mantle metasomatism itself could not have been developed without xenoliths. Unfortunately, xenoliths are rarely brought to the surface by calc-alkaline sensu lato lavas, thus our knowledge of the mantle wedge above subduction zones is still limited. A vigorous debate is currently developing on the nature of the fluids migrating into this portion of the mantle, as well as on the different residential times of the subduction signature in mantle wedges.

Ishimaru & Arai studied one of the few occurrences of this type of xenoliths, from Avacha volcano (Kamchatka), contributing to knowledge of the petrological features of the fluids migrating into mantle wedges. The Avacha peridotites have experienced metasomatism to various extents, with the formation of metasomatic orthopyroxene replacing primary olivine, by the infiltration of slab-derived, sulphur-bearing, SiO$_2$-rich fluids. Secondary metasomatic minerals are also constituted by clinopyroxene, Cr-rich (in some cases Al-rich) spinels and tremolite to Mg-hornblende and edenite. This paper, which is complementary to that of Ishimaru et al. (2007), focuses particularly on the amphibole, which can be considered a key mineral for a better understanding of the geochemical signature of metasomatizing agents in subduction environments. In the Avacha peridotites, amphiboles appear particularly depleted in TiO$_2$ and Nb, supporting the idea that fluids from the slab are already depleted in these elements. The large mass of trace element data on amphibole provided by these two papers was also used by Coltorti et al. (2007a) to propose a geochemical separation, based on high field strength element (HFSE) contents, between amphiboles formed in
subduction settings and those formed in intraplate environments. This geochemical tool has already been used to identify relics of subduction events recorded in xenoliths entrapped in alkaline, intraplate settings (Beccaluva et al. 2004; Coltorti et al. 2007b).

The paper by Ntaflos et al. focuses on anhydrous spinel peridotite xenoliths enclosed in the Late Miocene olivine melanelephelinites of the Viliga River Volcanic Field (NE Russia), just a few hundred kilometres north of the previous occurrence. These strongly alkaline lavas overlie a hundred kilometres north of the previous occurrence. From Early to Late Cretaceous times. Ntaflos et al. propose that the mantle xenoliths derived from Pacific asthenospheric mantle and not from the Asian mantle wedge, which should have been affected by the subduction fluids. They also demonstrate that the xenoliths were not affected by metasomatic processes. The clinopyroxene REE modelling indicates that the fertile peridotites experienced 2 – 9% batch melting whereas the most depleted peridotites experienced 15% batch melting. Similar results were derived from the olivine and whole-rock FeO and MgO modelling. A magmatic refertilization of a depleted lithospheric mantle wedge is excluded as a possible reason for the fertility of the Viliga peridotites because neither whole-rock chemistry nor clinopyroxene trace elements provide evidence for metasomatism. In addition, the low $^{87}$Sr/$^{86}$Sr ratios and the high, partly higher than mid-ocean ridge basalt (MORB), $^{143}$Nd/$^{144}$Nd ratios point to an asthenospheric origin. The model that Ntaflos et al. propose to explain the origin of the Viliga peridotites is a ‘piecemeal’ breakup of the subducted palaeo-Pacific plate, which allowed the Pacific asthenospheric mantle to intrude the mantle wedge through a slab window. Subsequently, olivine melanelephelinites that were generated at deeper levels sampled this part of asthenospheric mantle on their way to the surface. The absence of any evidence for subduction-related metasomatism implies that the asthenospheric upwelling occurred when subduction was no longer active. This observation makes it also unlikely that subduction-metasomatized domains were preserved within the mantle at that time, thus giving some clues about the mode and time of material recycling above a subduction zone.

The paper by Seghedi et al. is the first report of a new occurrence of lamproite in a region where this rock type was previously unknown. These rocks are of great interest for understanding the genesis of ultrapotassic rocks in general, for defining the nature of the metasomatizing agents of the subcontinental lithospheric mantle, and for clarifying the geodynamic evolution of the central–eastern European basin and orogen. The area where the Gataia lamproite occurs is remarkable: the southernmost margin of the Pannonian Basin, where lithosphere thickness steeply increases southwards and eastwards, representing a transition between the Carpathian and the Serbo-Macedonian domains. The mantle source of this magma could have been influenced by several subduction events both beneath the Tisza–Dacia block and the Serbo-Macedonian Massif (Kovacs et al. 2007). Prelevic et al. (2007) inferred a two-stage metasomatism, the first being subduction-related whereas the second is linked to alkaline silicate metasomatism for similar lamproitic rocks in the Serbian domain, a few tens of kilometres to the south. Both stages of the metasomatism impinged upon a very refractory lithosphere, produced in a suprasubduction environment. The first slab-related metasomatism is not recognized for the Gataia lamproite. Based on trace element and isotopic data, Seghedi et al. exclude the presence of any subduction-related metasomatism and infer that only alkaline metasomatism can be recognized. The paper is a valuable contribution to a long-standing debate, and represents a stimulus for the discussion on the petrological evolution of the source of these very peculiar rocks (Conticelli et al. 2007; Prelevic et al. 2007).

Metasomatism in continental intraplate and rifting settings

The processes and nature of metasomatising agents in intraplate settings are much better understood than are those in subduction environments. A consensus exists on the way to distinguish between alkaline silicate (both Na- and K-rich) and carbonatite melts, considered to be by far the most important metasomatising agents in intraplate lithospheric mantle. On the other hand, a major debate is currently developing on the possibility of relating the various metasomatic signatures, which may be recorded in mantle xenoliths from the same locality, to a single metasomatic event through an infiltration–reaction process (Bodinier et al. 2004; Xu & Bodinier 2004). The increasing availability of dating on mantle material (Pearson et al. 2007) will hopefully permit, in the near future, linkages between geological processes recorded in the upper and lower crust and depletion and enrichment processes observed within the mantle. In this framework, the distinction between a single metasomatic event or multiple events will be crucial.

Most of the papers presented in this section of the book deal with this aspect, although the question is clearly far from being solved.
The first question posed by Orejana & Vilaseca about alkaline metasomatism is its relationship with the host lavas; another important point to address when dealing with this topic. They present a complete dataset (major and trace element, and Nd–Sr isotopic compositions) of highly altered anhydrous and hydrated (amphibole- and phlogopite-bearing) pyroxenites hosted in Permian lamprophyric dykes. The occurrence of amphibole and phlogopite with major element composition similar to those found in peridotites affected by mantle metasomatism and also very different, particularly regarding Mg-number, Cr and Ti contents, from those found in cumulitic pyroxenites, leads Orejana & Vilaseca to think that these phases resulted from a reaction with an infiltrating melt after the pyroxenites were formed. The metasomatic processes seem to be heterogeneous, as the xenoliths show three different trace element signatures in minerals: (1) light rare earth element (LREE)-enriched clinopyroxenites with HFSE negative anomalies in primitive mantle-normalized spidergrams; (2) clinopyroxenites and amphiboles with high incompatible trace element contents (large ion lithophile elements (LILE); HFSE and REE); (3) relatively REE- and HFSE-poor clinopyroxenites and amphiboles. These metasomatic characteristics support three different metasomatic agents: carbonatites, silicate magmas and hydrous fluids or melts. Orejana & Vilaseca propose that these fluids are all derived from the progressive differentiation of a single CO2–H2O-rich highly alkaline agent, genetically related to the Spanish Central System Permian alkaline lamprophyric dykes. In this respect there should be a genetic relationship between the metasomatizing agents and the host lavas, as inferred in many other occurrences of intraplate metasomatism (Wulff-Pedersen et al. 1999; Beccaluva et al. 2001; Coltorti et al. 2004), but the reactions, as supported by high Mg-number of the secondary phases and their growing time with respect to the velocity of ascent, have to have occurred at mantle depths some time before the xenoliths were entrapped (Beccaluva et al. 2001; Coltorti et al. 2004).

The second, and even more relevant, point is the interpretation of the different geochemical signatures recorded by the metasomatic phases (namely, clinopyroxene, amphibole and phlogopite). Could they be interpreted as the result of a single metasomatic event or could they be the result of several episodes of metasomatism? This is, at the moment, an open debate. Coltorti et al. (2007a, b), for example, interpreted the low HFSE abundances and the relative negative anomalies in the chondrite-normalized diagram for amphibole as a signature for subduction-related metasomatism and, using a well-studied example of vein and disseminated amphibole from Kerguelen, demonstrated that the infiltration and reaction from a large vein into the peridotite matrix is not able to vary significantly the Zr/Nb ratios (Coltorti et al. 2007b). On the other hand, based on the study of Bodinier et al. (2004) and Xu & Bodinier (2004), Orejana & Vilaseca inferred that this depletion could be related to the differentiation of a single magma, which will be enriched in H2O and CO2. In this way, the different geochemical signatures recorded by the secondary phases can be ascribed to a single geochemical process instead of to different geological processes.

Galan et al. deal with similar questions in their examination of the geochemical features of clinopyroxenes, amphiboles and phlogopites in mantle xenoliths from Neogene–Quaternary alkaline mafic lavas from Catalonia (NE Spain). Their study provides evidence to show that the subcontinental lithospheric mantle beneath this area is mostly made of protogranular anhydrous spinel lherzolites and harzburgites, with minor pyroxenites, and subordinate porphyroelastic and equigranular peridotites. A melt depletion event (up to 30% partial melting), related to mantle decompression and probably starting within the garnet lherzolite field, affected the peridotites. Evidence for subsequent metasomatism is widespread in harzburgites, but also occurs in some lherzolites. Two types of cryptic metasomatism, one related to carbonatite melts and the other to alkaline silicate melts, are distinguished. Evidence of modal metasomatism is rare and is restricted to the formation of amphibole or phlogopite. This modal metasomatism could be linked to either kind of cryptic metasomatism. The carbonatite metasomatism is more widespread than the silicate Fe–Ti-rich melt type. The latter could be compared with that observed in the nearby Pyrenean peridotite massifs, adjacent to the intrusions of Cretaceous alkaline magmas. Catalonia pyroxenite xenoliths are interpreted as cumulates from these alkali basalts. In this case the two or three different metasomatic agents are considered independent and not derived by a single fluid differentiating while infiltrating into the peridotite matrix. However, the question of Nb-depleted carbonatite still arises. Could this melt be a derivative of a unique alkaline silicate melt after differentiation through a reactive chromatographic process with early crystallization of amphibole and phlogopite ± Ti-oxides? However, the very limited modal amount of these phases, none of which is particularly enriched in this element, limits the applicability of the model and again gives rise to the question of whether this HFSE depletion, particularly regarding Nb, could be a sign of a previous, tectonically different and independent metasomatism (Coltorti et al. 2007a, b).

The paper by Demény et al. reports mineral chemistry, D/H and oxygen isotope ratios for
amphibole, biotite, pyroxene and feldspar from gabbroic plutons and amphibole xenoliths or xenocrysts in younger basalts of La Palma, following an analogous study on Fuerteventura (Demény et al. 2004). Demény et al. use the data reported here to support their earlier interpretation that the H–O isotopic signature derived from a deep mantle source. This conclusion would be very important for our understanding of mantle stable isotope systematics, although some difficulties may arise in clearly discriminating between shallow differentiation processes and those occurring at mantle depth. This approach is contributing to the current debate regarding mantle plumes, whose existence is under heavy criticism (Foulger et al. 2005). The H and O isotopic compositions of amphibole, biotite, pyroxene and feldspar separates from the Basal Complex gabbros, as well as amphibole xenocrysts and amphibololite xenoliths in basalts seem to be devoid of any metasomatic influence (−90‰ and 5.1‰, respectively, relative to V-SMOW), and are very similar to those found for Fuerteventura. According to Demény et al., the most plausible explanation for the low δ18O value is the presence of subducted ocean crust in the mantle plume source, whereas the low δD values could be related to volatiles ascending from deep in the Earth. Thus stable isotope data could provide a potentially powerful tool to support not only the existence of mantle plumes but also the presence of recycled (via subduction and deep mantle circulation) oceanic crust in the source of ocean-island basalt (OIB) magmatism (see also Thirlwall et al. 2006, who found similarly low δ18O for some Icelandic basalts). Eventually this paper may also contribute to the estimation of the role and abundance of pyroxenites in the genesis of basaltic magmas (see also Sobolev et al. 2005).

Tounon et al. present major and trace element stable and radiogenic isotope analyses of minerals from two localities within the Devès Volcanic District (French Massif Central). Anhydrous spinel lherzolites characterize mantle xenoliths from Mt. Briançon, whereas at Marais de Limagne, amphibole-bearing (with sporadic presence of plagiopite) lherzolites and harzburgites are also present. The metasomatic agent can be modelled as a sub-alkaline TiO2, Th- and U-rich fluid or melt. Associated with negative anomalies in HFSE in chondrite-normalized spidergrams, such chemical characteristics are compatible with a carbonate-rich silicate melt or fluid as the metasomatic agent. Nevertheless, the occurrence of two geochemical signatures in amphibole, even within a single sample, may suggest a multistage metasomatism. Previous studies attributed the amphibole origin to an enriched mantle component, possibly related to the Variscan subduction in the Massif Central (Deloule et al. 1991; Lenoir et al. 2000). The isotopic compositions of Sr and Nd of clinopyroxene and amphibole indicate that the metasomatic fluid or melt derived from mixing between a depleted mantle (DM)-type, deeply recycled component and the European asthenospheric reservoir (Granet et al. 1995).

The metasomatism of the upper mantle beneath the Hyblean Plateau (Sicily) is the purpose of the first paper by Perinelli et al. They propose a two-stage evolutionary history for Hyblean anhydrous spinel lherzolites and harzburgites: (1) a slight to moderate (6–13%) partial melting event, which, using Re–Os in situ isotopic determinations (Sapienza et al. 2006), was estimated to have occurred at a minimum Palaeoproterozoic–Archaean age; (2) a cryptic metasomatism event that introduced LREE, Sr, HFSE, V and Ti into the ‘barren’ peridotite, probably lasting from Carboniferous times to the present day, which is supported by the Sm–Nd isotopic study (Tonarini et al. 1996) and by the widespread presence of glassy veins. The latter metasomatizing episode was caused by a hawaiitic melt and, according to Perinelli et al., is related to the presence of the glassy veins, and is not considered relevant on a regional scale. The metasomatizing melt determined oxidation of the upper mantle, increasing its redox state to above the fayalite–magnetite–quartz buffer (FMQ). Melt–peridotite interaction episodes are generally related to metasomatic re-equilibration with a silicic melt similar to the Upper Miocene host basalt, again posing the question of the relationships between metasomatism and magmatism: the former probably representing a precursor to the latter. Some peculiar spoon-shaped clinopyroxene trace element patterns are explained as chromatographic effects of the melt flowing into a conduit and variably metasomatizing the surrounding country rocks. The Hyblean peridotites were equilibrated in the spinel peridotite stability field. P–T estimates are consistent with the data obtained previously on pyroxenite xenoliths, suggesting a highly perturbed palaeo-geotherm, probably, related to the numerous magmatic intrusions at the crust–mantle boundary and responsible for the metasomatic event(s) recorded by peridotites.

Ismail et al. present an original occurrence of spinel ± amphibole-bearing mantle xenoliths from the Neogene–Quaternary volcanic province of Jabel El Arab (southern Syria). This locality, together with many others in the region, is difficult to access and the study contributes to the knowledge of the lithosphere of the Dead Sea rift zone, at the boundary between the African and Arabian plates. The great majority of xenoliths are harzburgites, with a few lherzolites and wehrlites. Based on clinopyroxene trace element contents, three groups of
harzburgites are distinguished, showing a complex evolutionary history that involves polybaric partial melting (from garnet to spinel stability fields) at various degrees (<20%), followed by various metamorphic episodes. Some Group II harzburgite mineralogical and geochemical compositions indicate a near re-equilibration with a silicate melt at a relatively high melt/rock ratio, which increased the incompatible trace element abundances but did not significantly affect major element compositions. Some of the Group III harzburgites have mineralogical and geochemical compositions indicative of metasomatism by small silicate- or carbonate-rich melt fractions, resulting in selective major and trace element enrichments in the clinopyroxenes (high LREE/HREE ratio coupled with low HFSE). The carbonate-rich melt is not considered a mantle-derived carbonatite but the result of progressive reactions and crystallizations of an original volatile-bearing silicate melt with the residual peridotites. These metasomatic events were responsible for the presence of amphibole, as well as for the enrichment observed in the clinopyroxenes. The widespread presence of glassy patches filled with secondary cpx + ol + sp in both anhydrous and hydrous xenoliths provides evidence for the percolation of small silicate melt fractions shortly before eruption. These melts did not originate by in situ partial melting of amphibole but were derived from partial melting of amphibole in the nearby lithospheric mantle and subsequent fractional crystallization of clinopyroxene, olivine and spinel in reaction zones. Whether the different types of metasomatism could all be contemporaneous and derivatives of the same original silicate melt source or whether the lithospheric mantle was affected by different metasomatic media at different times, also considering that volcanism in southern Africa, suggesting a common sub-lithospheric metasomatic agent across the region.

The second paper by Perinelli et al. develops an experimental approach aimed at reproducing the effect of metasomatism induced by alkaline magma on upper mantle of Northern Victoria Land (Antarctica). This is one of the few attempts to experimentally model this process; it also had the aim of constraining the $P - T - X$ conditions suitable for the formation of amphibole. The model is developed using a natural nephelinite magma (variableally doped with $H_2O$ and $TiO_2$) sandwiched between natural anhydrous peridotite and pyroxenite matrixes in analogy to what has been observed in mantle xenoliths from Antarctica (Coltorti et al. 2004; Perinelli et al. 2006). These experiments are difficult to perform for many reasons, one of which is the differential temperature gradient that exists when basaltic magmas intrude a peridotite host. This condition cannot be simulated in a small capsule, and the nephelinite has to be pre-heated and pre-quenched. During the reaction, if the conditions to form amphibole are to be created, the temperature cannot be too high (amphibole is not stable above 1100 °C at 1.5–2 GPa, Niida & Green 1999), which means that the nephelinite is not completely melted and the composition of the infiltrating melts would be different from that of the starting material (i.e. the nephelinite). Perinelli et al. show that, in experiments on nephelinite–lherzolite and nephelinite–pyroxenite assemblages, considerable chemical modifications are observed in both lherzolitic and pyroxenitic portions of the charges, suggesting that metasomatic reactions developed during the experiments. Clinopyroxene composition changes from diopside to high-Mg–Cr–(Na) augite and omphacite in lherzolite and to low-Mg and high-Ti–Al–Fe–Na augite in pyroxenite. The observed Ti increase in natural clinopyroxenes is fairly well matched by crystals formed in pyroxenite, whereas even the use of Ti-doped nephelinite caused a negligible Ti increase in clinopyroxene of lherzolite. Spinels (in lherzolite) and
olivines (in pyroxenite) were compositionally modified by metasomatic melts: Cr-number increases and Mg-number decreases in spinel, and forsterite decreases in olivine. Synthetic glasses that fit better with natural melts are produced by runs at $T < 1250\,^\circ\mathrm{C}$ in nephelinite–wehrlite experiments and at $T = 1250\,^\circ\mathrm{C}$ and 1.5 GPa in the nephelinite–lherzolite experiment.

**Pre-Mesozoic metasomatism in continental intraplate settings**

The paper by Bonadiman et al., based on major and trace element and Nd–Sr–Hf isotopic (both on whole rock and separate clinopyroxenes) compositions, demonstrates that the Scottish lithospheric mantle beneath Rinibar and Streap has been affected by Palaeozoic kimberlite or carbonatite and subduction-related metasomatic events. Rinibar mantle xenoliths show two different metasomatic styles, one carbonatitic and one kimberlite-like, both derived from the same source. This is supported by the similarity of Sr and Nd isotopic ratios at $550 \pm 50\,\text{Ma}$. This age can be related to the opening of the Iapetus Ocean following the break-up of the Rodinia supercontinent. Late Proterozoic–Early Phanerozoic carbonatite magmatism is also recognized within Scotland. Moreover, the genesis of the coherent suite of megacrysts from the Scottish Permo-Carboniferous high-alkaline lavas involved carbonatitic melt fractions. The emplacement of very small fraction partial melts (and related mantle metasomatism) in relation to the rifting and drifting of the Iapetus Ocean could be compared with the opening of the Atlantic Ocean, where Early to Late Cretaceous kimberlite and alkaline–carbonatite complexes are found on both sides of the ocean in Brazil and Angola. At $500\,\text{Ma}$ the tectonic regime changed from divergent to convergent. It may have been during this convergent stage ($c. 400\,\text{Ma}$) that the metasomatism affecting the Streap lithospheric mantle occurred. The various terranes that now constitute Scotland in fact came into conjunction at the end of Caledonian Orogeny, and were certainly contiguous by $416\,\text{Ma}$. Clinopyroxenes from this locality show trace element contents that can be explained by slab-related metasomatic fluids, and based on Nd–Sr and Hf isotopes a substantial amount of sediments ($c. 10\%$) is necessary to explain the isotopic features of these samples. The Rinibar clinopyroxenes record no subduction-related imprint. This could imply that either the northeasternmost portion of the Highland Terrane lithospheric mantle was unaffected by the Caledonian subduction or, alternatively, that the subduction-related metasomatism recorded in the Streap mantle may have been older, and occurred when the two lithospheric blocks were far apart.

Finally, the study of Aschepkov et al., proposes to use monomineral thermobaroometry to reconstruct mantle sections beneath Yakutian kimberlite pipes (Siberia, Russia). They demonstrate that their methods offer the possibility to determine the general features of the lithological stratigraphy of mantle columns. They also propose that mantle sections containing large amounts of eclogites have, as a rule, peridotites with hybrid features, and sometimes metasomatites and anatexic pyroxenites. For them, a layered mantle structure is characteristic beneath most kimberlite pipes and is probably related to the periodicity of superplume activity in the Precambrian. Finally, they argue that the largest diamondiferous pipes exhibit the specific structural features of their underlying mantle columns; that is, the presence of dunite horizons, subadiabatic temperature gradients, and large amounts of pyroxenites.


**References**


