21. PETROLOGIC CHARACTERISTICS OF THE ULTRAMAFIC ROCKS FROM THE OCEAN/CONTINENT TRANSITION IN THE IBERIA ABYSSAL PLAIN¹

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ABSTRACT

Ultramafic rocks were recovered at Sites 897 and 899, drilled during Ocean Drilling Program (ODP) Leg 149 to the ocean/ continent transition in the Iberia Abyssal Plain. Such recoveries, in particular that at Site 897, attest to the southward extension of a peridotite ridge previously studied along the Galician Margin.

The ultramafic rocks are coarse-grained websterites and depleted peridotites with some minor plagioclase-rich lherzolites. The variations in modal compositions and primary-phase chemistry show that many of the peridotites were subjected to significant partial melting. These rocks also underwent some impregnation by undersaturated alkali magmas that, in many samples, have given rise to local resorption of orthopyroxene, cryptic enrichment in Fe and Ti of most phases, and plagioclase crystallization. Such magmas have left discrete traces composed of clinopyroxene, kaersutite, phlogopite, ilmenite, and rutile. This impregnation occurred during the last stages of the high-temperature deformation event that produced the porphyroclastic foliation in the peridotites. It stopped under static conditions, at a temperature around 965°-880°C and at a pressure below 1 GPa.

Subsequently, the websterites underwent a subsolidus reequilibration event, well defined by textural features, which implies that some spinel and plagioclase formed after Al-pyroxenes and AI-spinel, and also defined by some local Ti enrichment of both spinels and pyroxenes. This reequilibration event occurred after the main high-temperature deformation, at a temperature of about 780°C and a pressure below 1 GPa, but before a mylonitic stage well displayed in a few rocks, which ceased at a temperature close to 735°C.

The magmatic signature of the Leg 149 ultramafic rocks, their petrological and tectonometamorphic evolution, and their similarities with the peridotites recovered at the western edge of Galicia Bank support the hypothesis that they originated as a piece of asthenospheric mantle that has been accreted to the lithosphere in a rift system during stretching of the continental lithosphere.

INTRODUCTION

Studies in the west Iberian continental margin have popularized the idea that mantle rocks can be emplaced on the seafloor subsequent to continental rifting. Such a concept developed through studies performed along the Galicia Margin to the north. Indeed, peridotites were first dredged (Boillot et al., 1980), were subsequently drilled during ODP Leg 103 (Boillot, Winterer, Meyer, et al., 1987; Boillot et al., 1988b), and, finally, were sampled using the submersible Nautile during the "Galinaute" cruise in 1986 (Boillot et al., 1988b). The peridotites crop out at the ocean/continent boundary over a north-south distance of more than 100 km. Geophysical investigations performed to the south suggested that this peridotite ridge may extend beyond the Iberia Abyssal Plain (Hoffman and Reston, 1992; Beslier et al., 1993; Whitmarsh et al., 1990, 1993). The ultramafic rocks recovered from Sites 897 and 899, drilled during Leg 149 (Shipboard Scientific Party, 1994a, b), provide the first evidence that agrees with this assumption (Fig. 1).

Petrological, structural, and geochronological studies performed on the Galicia peridotites have shown that these mantle rocks rose to the ocean floor at the end of continental rifting (Evans and Girardeau, 1988; Girardeau et al., 1988; Kornprobst and Tabit, 1988; Féraud et al., 1988; Boillot et al., 1990; Beslier et al., 1990; Schärer et al., 1995), probably as the result of tectonic denudation along lithospheric normal shear zones (Boillot et al., 1988); Beslier and Brun, 1991).

¹Whitmarsh, R.B., Sawyer, D.S., Klaus, A., and Masson, D.G. (Eds.), 1996. *Proc. ODP, Sci. Results*, 149: College Station, TX (Ocean Drilling Program).

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³Laboratoire de Géodynamique sous-marine, Université Paris 6, BP48, 06230 Villefranche sur Mer, France. These peridotites, mostly plagioclase-bearing harzburgites, lherzolites, and minor dunites, underwent minor partial melting prior to their emplacement and have both oceanic and continental affinities (Evans and Girardeau, 1988; Kornprobst and Tabit, 1988). These rocks display evidence of a complex deformational history: they first underwent high-temperature deformation and subsequently mylonitization under lithospheric conditions (Girardeau et al., 1988; Beslier et al., 1990).

Shipboard studies showed that the ultramafic rocks recovered during Leg 149 were also plagioclase-rich, and included harzburgites, lherzolites, minor dunites, and abundant websterites (Shipboard Scientific Party, 1994a, b). The aim of the present paper is to examine their mineral chemistry and petrology to determine their origin and metamorphic evolution during uplift.

SITE CHARACTERISTICS

Ultramafic rock was recovered at two of the five sites drilled during Leg 149, from Holes 897C, 897D, and 899B. Holes 897C and 897D were drilled 100 m apart, both in 5315 m water depth. Hole 899B was drilled at about 20 km east-southeast of Site 897, in 5291 m water depth (Fig. 1).

In Hole 897C, the basement was reached under 648.7 m of sedimentary rocks and cored down to 744.9 meters below seafloor (mbsf) with a recovery of 28.33 m. At Hole 897D, 82.7 m of basement was recovered from depths between 684.3 and 837.2 mbsf. In both holes, the basement, described as Unit IV, is overlain by three sedimentary units, only recovered extensively in Hole 897C, and deposited between mid-Eocene and Pliocene-Pleistocene time. Shipboard studies have shown, however, that the top of Unit IV included upper Hauterivian to Aptian sediments between cobbles of basement to depth of 678 mbsf in Hole 897C and to 690 mbsf in Hole 897D. In both holes, the entire ultramafic section is extensively serpentinized. The upper part of Hole 897D has suffered an additional pervasive alteration and displays a distinct yellow-to-brown color. Downcore, spinel-peridotite rocks are pale-green or black, and the plagioclase-bearing peridotite is usually gray or black, depending on the abundance of plagioclase and the extent of alteration.

Similar lithological successions were found in Holes 897C and 897D. Carbonate-rich serpentinites (almost absent in Hole 897C) occur beneath friable serpentinite breccias, followed by brecciated serpentinites and serpentinized peridotites, including primarily harzburgite with minor lherzolite. These peridotites locally display plagioclase- and clinopyroxene-enriched zones, which correspond to pods or patches of plagioclase- and olivine-bearing websterites (labeled plagioclase-lherzolites in shipboard studies). Downward, banding becomes more apparent, with alternating layers of dunites and harzburgites with minor lherzolitic and websteritic horizons.

Besides fractures and local brecciation, indicative of late lowtemperature deformation, peridotite textures are still recognizable in most of the rocks, all of which appear coarse-grained. The most serpentinized facies displays poor evidence of intense deformation and generally does not bear clear traces of foliation. This is not the case in fresher samples that usually show porphyroclastic textures, particularly the pyroxenite or plagioclase-bearing lherzolitic rocks (Beslier et al., this volume).

Hole 899B was drilled on a basement high that was detected during the shipboard seismic survey. At that site, the acoustic basement was reached at 369.9 mbsf and cored over 180 m. It was overlain by a Pliocene to upper Eocene sedimentary column divided into three units. The recovered basement composes Unit IV, and was subdivided into Subunits IVA and IVB according to the differences in lithology and recovery (83% in Subunit IVA and 14% in Subunit IVB). Subunit IVA is 95 m thick and is composed of ultramafic breccias. Subunit IVB comprises a 19-m-thick transitional zone made of composite serpentinite breccias, basaltic lavas, and sediments underlain by about 78 m of unbrecciated boulders of peridotites, with intercalations of siltstone, basaltic lavas, undeformed microgabbros, and mafic metamorphic rocks. Sedimentary layers of early Aptian age were found in a normal stratigraphic succession as intercalations throughout the Unit IV, down to 540 mbsf.

The ultramafic breccias are poorly sorted. They are composed of ultramafic and metabasite clasts set in a serpentinite matrix. Metabasites are minor chlorite- and prehnite-rich components. Ultramafic clasts and boulders vary in size, composition, and range of serpentinization. The whole is considered to be a mass-flow deposit, including a cataclastic breccia (Comas et al., this volume). Ultramafic clasts and boulders have a large range of composition, from plagioclasebearing peridotites to pyroxene- and olivine-rich peridotites. The plagioclase-bearing rocks usually contain spinel rimmed by plagioclase. Some clasts are composed of spinel and abundant contorted fibrous tremolites deriving from pyroxene crystals. No plagioclase-rich websterite, nor dunite, similar to those of Site 897, have been identified. Most peridotite boulders from Subunit IVB are weakly altered and consist of almost fresh plagioclase lherzolites that grade downcore into harzburgites, locally deeply serpentinized; some secondary chlorite and fibrous tremolite occur locally. All minerals of fresh rock are finely and regularly cut by a cleavage-like framework, which makes difficult their identification in thin sections. Similar features have already been described in peridotites from Leg 125 (Ishii et al., 1992). Here again, these peridotites show coarse-grained equant to porphyroclastic textures.

LITHOLOGIC AND PETROGRAPHIC DATA

The rocks from Site 897 are spinel-dunites and harzburgites, and spinel-plagioclase-bearing peridotites, including harzburgites, lherzolites, and websterites. Those from Site 899 are plagioclase-bearing



Figure 1. Bathymetric map of Iberia Abyssal Plain and Galicia Bank showing the location of holes drilled during Leg 149 and the holes from which peridotites were recovered (solid circles). Small open circles = Leg 103 sites, Galinaute cruise. Bold lines = inferred peridotite ridge. VDGS = Vasco de Gama Seamount, VS = Vigo Seamount, PS = Porto Seamount.

lherzolites, harzburgites, and accessory pyroxenites. The origin of an almost completely serpentinized facies will tentatively be constrained using the composition of the preserved spinel. The spinel peridotites are dunites and harzburgites. Both types of rocks are intensively serpentinized (typically at least 90%) at Site 897.

Dunites generally contain less than 3% of their primary mineralogy: essentially spinel and more rarely olivine. In this case, the spinel is brown and generally anhedral. It occurs locally in bands parallel to the foliation. Olivine occurs as small (0.1 mm) relics within the serpentine mesh structure. Secondary magnetite and iowaite (chlorinebearing Mg-, Fe-hydroxide) are common in these rocks.

The spinel-bearing harzburgites are generally coarse-grained rocks (Nicolas and Poirier, 1976; Mercier, 1985) that contain about 2% spinel and 20% orthopyroxene; no primary clinopyroxene was detected (Fig. 2). In these rocks, spinel is generally brown and forms holly-leaf large crystals (1 mm). It is rarely associated with the orthopyroxene and forms isolated crystals within the olivine matrix. The latter is usually totally transformed into secondary bastite and other serpentine minerals. Although the orthopyroxenes generally occur as ghosts, they still can be recognized because of their initial shape, size (up to 1 cm), and internal deformational structures such as kink bands and undulose extinctions. Some of them occur as clusters with irregular rims possibly resulting from resorption. At Site 899, the harzburgites contain more orthopyroxenes (up to 30% modal), which are undeformed and not resorbed.

The plagioclase-bearing harzburgites are rather scarce and generally occur near the plagioclase-websterite zones; they probably represent a transitional facies. In these harzburgites, plagioclase usually



Figure 2. Close-up photograph of a spinel-bearing harzburgite, entirely serpentinized and apparently weakly deformed. (Sample 149-897D-23R-3, 9.5-17.5 cm).

rims spinels but also occurs as lobate isolated crystals or in veinletlike ribbons. This plagioclase is strongly altered and transformed into a brownish clayey material. Spinel is light-brown and occurs either as large (1 mm) holly-leaf crystals or more rarely as small (0.1 mm) euhedral black crystals within plagioclase. Orthopyroxene occurs as rather large crystals (1 cm) with kink bands and exsolution lamellae. A few clinopyroxenes are present locally.

Plagioclase-bearing lherzolites are rare and have been clearly identified only at Site 899 where they are rather fresh. In these peridotites, clinopyroxene is abundant and may attain 15% modal. It occurs as large equant crystals with almost no traces of plastic deformation. Spinel is brown and forms lobate elongated crystals which well emphasize the foliation. Plagioclase is relatively fresh and attains 3% in modal composition. This phase is randomly distributed within the rock and spinels are not systematically rimmed by plagioclase. Olivine generally forms large porphyroclasts with locally narrow kink bands and some neoblasts at their margins.

Websterites have been found only at Site 897. They are very fresh and always contain abundant spinel, plagioclase, and olivine (Fig. 3). The clinopyroxene forms large crystals with very irregular shapes caused by recrystallization and resorption. The orthopyroxene occurs usually as smaller crystals with very irregular shapes and traces of resorption that clearly postdate the kink-band formation. These orthopyroxenes are commonly rimmed by secondary olivine and by plagioclase (Fig. 4). Both pyroxenes display large bent exsolution lamellae that locally extend outside the crystal, allowing development of small secondary pyroxene crystals. Different types of spinel are present in these websterites. The holly-leaf-shaped ones are about a millimeter in diameter and light-brown or green. Others that are subhedral, very small (0.0 1mm), and black are included in plagioclase. This latter phase is generally abundant (15%) and fresh. It occurs either as large crystals with locally bent twins or as millimetric crystals that may be neoblasts. Some of these small plagioclase crystals seem to interfinger with secondary olivine between former pyroxene crystals. In many samples, plagioclase associated with secondary orthopyroxene occurs as exsolution lamellae in clinopyroxene (Fig. 5). The websterites locally display traces of intense ductile deformation which has induced some dynamic recrystallization of all phases and local development of thin mylonitic shear zones. They also often show traces of late low-temperature deformation structures marked by the presence of local tight-spaced substructures and undulose extinctions in olivine and pyroxenes crystals.

Some remnants of ultramafic material with unusual mineralogy have been observed in a single thin section from the calcitized upper part of Hole 897D. Scarce, dismembered, veinlet-like ribbons with sheared texture are set in entirely calcitized serpentinite. They consist of clinopyroxene, Mg-ilmenite, rutile, kaersutite, Ti-phlogopite, and probably former orthopyroxene, transformed in bastite. Such a mineralogy is known to occur in veins within xenoliths or peridotites with subcontinental mantle affinities (Bergman et al. 1981; Dautria et al., 1987; Lorand et al, 1990). It differs from the so-called MARID xenoliths in kimberlite by the presence of kaersutite, which implies less severe conditions of formation (Dawson and Smith, 1977). According to these authors, the occurrence of such veins points to local metasomatism of peridotites by alkaline melts. At Site 897, these products occur as dynamically recrystallized neoblasts, which indicate that these melts have infiltrated the peridotite before or during a shearing event.

PRIMARY MINERALOGY

Phase compositions were determined on a CAMEBAX (SX50) microprobe (Microsonde Quest, Brest), using silicate and vanadate standards (albite, wollastonite, orthoclase, vanadinite) for calibration of Na, Si, Ca, K, Cl, and oxide standards for calibration of Fe, Mn, Ti, Cr, Al, and Ni. The accelerating voltage was 15 kV, the beam current was 15 nA, and the counting time was 25 s for Ni and Cl and 6 s for other analyzed elements. All phases have been analyzed at several places on their cores and margins. Selected data are listed in Tables 1-5. Secondary phases are described in Agrinier et al. (this volume).

Olivine

Olivines display a great range of composition. Their forsterite (Fo) contents range from 85.7% to 91.3% (Fig. 6). Ni varies from 2.5 to 7 millications per formula unit (mc/FU), with a few samples close to 10 mc/FU (Table 1).

The Fe-rich olivines with Mg# $[Mg# = 100 \times Mg/(Mg + Fe)]$ between 85.7% and 88% only occur in the plagioclase-bearing websterites from Site 897. In these rocks, Ni displays a slight positive correlation with Mg#. Mn correlates well with Mg#, reaching 0.44% (oxide weight) in the olivines richer in iron. Ca and Ti contents are low (between 0% and 0.08% oxide weight).

In the peridotites, the Mg# of olivine varies from 89.1% to 91.4%. In the plagioclase-bearing types, the olivines are Fe-rich (Mg# = 89.1% to 90.2%) compared to those from samples without plagioclase. In both, however, the Ni content remains constant around 6 (mc/FU), except for two harzburgites in which it attains 10 mc/FU (Fig. 6).

Our data show that olivine in websterites has a wide range of Mg# and Ni compositions, and these correlate positively. These variations may result from magmatic differentiation during their formation. The spinel lherzolites, the harzburgites, and the dunites all have similar



Figure 3. Close-up photograph of a websterite section (Sample 149-897C-65R-1, 107-116 cm). Notice the coarse grain size and the high content of spinels (black) rimmed by fresh plagioclase (white).

relatively low Mg# (between 90.2% and 91.4%), and Ni contents between 5 and 8 mc/FU. They display a slight positive correlation that points to a residual origin for these peridotites. However, considering the quasi-constant Mg# content of these different types of rock, it can be suggested that depletion is the result of incongruent melting of pyroxenes without melt-residue reequilibration. But, it can also point to some "late" Fe-Mg reequilibration of olivine, after the main melting event. The low Fo content of the olivine in plagioclase peridotites probably reflects such "late" exchanges with a melt responsible for the crystallization of the plagioclase (which locally constitutes 30% modal of the rocks).

These results are valid for the ultramafic rocks for both Sites 897 and 899, which differ only in the relative abundance of plagioclase-bearing rocks.



Figure 4. Photomicrograph of kinked orthopyroxene (Opx) rimmed by plagioclase (Pl) and secondary olivine (ol) in a websterite (Sample 149-897C-67R-3, 30-33 cm). **A.** Plane-polarized light. **B.** Crossed polars. Scale bar is 0.2 mm.

Spinel

Spinel is always present in the ultramafic rocks. It often is the only remnant of the primary phases and hence, when present, has been analyzed in all types of rock (Table 2).

Figure 7 shows that spinels from the whole ultramafic suites display a wide range of composition with Cr# [Cr# = $100 \times Cr/(Cr + Al)$] between 1% and 72%. Cr# varies between 1% and 34% in websterites, between 6% and 47% in the plagioclase-lherzolites, and between 27% and 72% in the spinel-lherzolites, harzburgites, and dunites. Spinels with Cr# between 1% and 12% are dominantly green (Fig. 8), whereas Cr#-enriched spinels are light to dark brown. The green spinels locally contain light-brown euhedral hexagonal platelets oriented parallel to the main symmetry axes of the spinel crystal. Platelets are up to 50 µm in diameter and up to 1 µm thick which makes analysis difficult. A mixing diagram shows that these platelets fit the composition of ilmenite, well consistent with their habit (Fig. 9).

Cr# spinel varies from 1% to 72% in peridotites at Site 897 and from 27% to 50% in peridotites from Site 899. Spinels from spinel-bearing lherzolites and harzburgites, and plagioclase-bearing types

from Holes 897C and 897D, show similar Cr# ratios around 40%-50%. Those from Site 899 show a wider range of Cr#, between 20% and 50%. In dunites from Site 897, spinel is present as subhedral crystals, and displays Cr# between 47% and 49% for Mg# between 58% and 63%. Some dunites with additional and secondary iowaite (see Agrinier et al., this volume) contain elongated and opaque spinels, which display a great increase in Cr# (between 62% and 72%) and a decrease in Mg# (between 27% and 47%). This evolution is probably the result of late modifications under oxidizing conditions at low temperature. Of course, the thermometers based on the Fe/Mg exchange between olivine and spinel (Fabriès, 1979; Sack, 1982) indicate a wide range of reequilibration temperatures: between 970° and 570°C (Table 3). Spinels from websterites are similar from both Holes 897C and 897D and have the highest content of Al among those within the peridotites recovered during Leg 149. Their Cr compositional range is wide, with Cr# between 1% and 35%. This interval overlaps the Cr# field of oceanic peridotites (Dick and Bullen, 1984; Fig. 7).

Except for the few spinel-harzburgites from Site 899, which have very low Ti contents, as expected for rocks resulting from partial



Figure 5. Photomicrograph showing clinopyroxene (Cpx) from a websterite (crossed polars; Sample 149-897C-67R-3, 30-33 cm). Note the exsolution lamellae where plagioclase and orthopyroxene coexist. Scale bar is 0.5 mm.

melting, all other spinels have relatively high Ti contents with clearly positive Ti/Cr# correlations (Fig. 10). In the websterites (Site 897), Ti displays a large range of values from O to nearly 14 mc/FU and is positively correlated with Cr#. Ti varies from 4 to 13 mc/FU in the plagioclase-bearing peridotites (Site 899) and only between 5 and 10 mc/FU in the spinel-dunites and harzburgites (Site 897). This Ti enrichment fits well the subsolidus reequilibration trend defined for rocks that reequilibrate in the plagioclase peridotite facies (Kornprobst and Tabit, 1988; Li, 1991). However, it may also point to some impregnation reequilibration.

Orthopyroxene

Although orthopyroxene was widespread in the recovered peridotites, it could only be analyzed in the plagioclase-rich websterites of Site 897 and the fresh peridotites of Site 899 (Table 4). Elsewhere, it occurs as ghosts without any relics. The orthopyroxene composition has a great range: Mg# varies from 86% to 96%, Cr# [Cr# = 200 \times Cr/(Cr + Al- Na)] from 18% to 32%, and Al₂O₃ from 2.5 to 6 wt%.

Orthopyroxene in the plagioclase-rich websterites from Hole 897 also has a high Al_2O_3 content and a Mg# between 86% and 92%. Two populations have been distinguished: one consists of porphyroclasts and the other of small neoblasts and of exsolution lamellae within clinopyroxene. The porphyroclasts have a Cr# ranging from 13% to 28% and have high contents of Ti (up to 11 mc/FU; Fig. 11) and Na (up to 4 mc/FU). The neoblasts have a Cr# between 5% and 11% and low Ti (< 4 mc/FU) and Na contents.

Orthopyroxenes from spinel-peridotites (both lherzolites and harzburgites) and plagioclase-bearing types from Hole 899B display Mg# between 90% and 96%, which is higher than those from Hole 897. Their Cr# ranges between 18% and 22%, except for one point corresponding to a very Cr-poor spinel within a websterite. Ti is low compared to that in the websterites (Fig. 11). In lherzolites, it ranges between 3 and 6 mc/FU, and in harzburgites, below 1 mc/FU. Na orthopyroxene varies between 0 and 3.5 mc/FU in both holes, as in websterites.

Figure 12 shows that there is a good correlation between orthopyroxenes in websterites and peridotites, indicating some equilibrium conditions for both phases in these different types of rock. Orthopyroxenes from the websterites and plagioclase lherzolites are rich in Fe and Ti, with significantly different Cr# contents. Those from the harzburgites are clearly residual, according to their Ti and Na signatures.

Clinopyroxene

Clinopyroxenes are abundant in websterites and lherzolites. In harzburgites, small rare crystals occur locally. They are all diopsides with, however, large variations in their compositions (Table 5).

In the websterites, the Cr# [Cr# = $200 \times Cr/(Cr + Al - Na)$] of clinopyroxene varies between nearly 0% and 30%, Ti between 5 and 22 mc/FU (Fig. 13), and Na between 15 and 40 mc/FU (Figs. 14, 15). Their Na content however, is very low: 4 times less than that measured in the undepleted mantle (Glü cklich-Herbas, 1992). Like the Orthopyroxenes, clinopyroxenes constitute two populations according to their sizes and compositions. The largest crystals (porphyroclasts) have low Cr# and are poor in Na and Ti compared to the smaller ones (neoblasts), including the exsolution lamellae. Chemical differences between large and small crystals, however, are not as clear as those evident in orthopyroxenes.

Clinopyroxenes from peridotites (Site 899) have a more constant Cr#, between 25% and 44%, with Ti and Na contents similar to those in clinopyroxenes from the websterites (Figs. 13-15). Most of clinopyroxenes from peridotites display residual signatures according to their Cr, Ti, and Na contents. A few of them are, however, Na-rich and Ti-poor, close to those from subcontinental peridotites. These peculiar clinopyroxenes either occur in dikelets cutting through the peridotites or form isolated crystals which may represent impregnation crystals. Clinopyroxenes from websterites and clinopyroxenes.

Plagioclase

Plagioclase from the harzburgites was too altered to be analyzed. In websterites, it has a composition range of An_{96-90} , with neoblasts frequently a little more calcic than in the core of porphyroclasts. A few lherzolites from Site 899 contain relics of plagioclase with a relatively low anorthite content (An_{77}). This probably does not represent the original composition, owing to their obvious altered condition (Table 6).

DISCUSSION

Petrologic Evolution

Our main petrologic results can be summarized as follows:



Figure 6. Olivine from peridotites of Leg 149 in a Ni (in millications) vs. Mg# = $100 \times Mg/(Mg + Fe + Mn)$ diagram. The shaded area represents the Galicia Margin peridotite from Leg 103 (Boillot, Winterer, Meyer, et al., 1987) and the mean primitive Iherzolite is after Glücklich-Herbas (1992).

- 1. There is evidence of partial melting in peridotites from Sites 897 and 899. This is shown by the variations of the compositions of their phases, particularly by the high Ni content of olivine and by the wide Cr# compositional range of spinels that overlaps the oceanic peridotite field, like in typical residual peridotites. This is also true of the pyroxenes when considering their Mg, Cr, Ti and Na contents. But melting was heterogeneous, as illustrated by the presence of strongly residual dunites, (45 < Cr# < 70) together with Iherzolites and websterites in the ultramafic pile. The apparent scarcity of harzburgites and dunites relative to the Iherzolites from Site 899, the abundance of websterites at Site 897 and the modal composition of the peridotites rather point to a low degree of depletion and partial melting (likely less than 10%) of the whole ultramafic unit.
- Some of the peridotites contains nearly 30% plagioclase that occurs either as patches or veinlets that locally invade the rocks pervasively (Fig. 16). This is mainly seen in peridotites sampled near the websterites and points to an impregnation origin for some plagioclase. In many samples, the plagioclase framework shows preferential orientations which parallel the main porphyroclastic foliation and lineation visible on the adiacent websterite. This suggests that some plagioclase melt was still present at the end of the rock's main deformation phase, which occurred at a high temperature according to olivine glide systems (Beslier et al., this volume). This also means that this plastic deformation phase occurred in the plagioclase-peridotite field, that is, at pressures below 1 GPa. In some samples, however, plagioclase forms isolated, but abundant, interstitial patches or veins oblique to this main hightemperature foliation. This indicates that the impregnation of the ultramafic series by plagioclase probably ended under the static conditions that followed the main high-temperature de-

formation phase. This impregnation phase by mafic magmas would be responsible for the Fe, Ti and Na local enrichments of some phases, particularly in olivine and pyroxenes.

- 3. The origin of the websterites is not constrained. Their phase chemistry, however, points to a magmatic origin which suggests that they may represent early melt products crystallized under mantle conditions, as has been proposed for many websterites in peridotite massifs (see discussion in Girardeau et al., 1989). The websterite horizons of Leg 149 underwent ductile deformation, as shown by their internal textures, in particular by the presence of kink structures in the largest pyroxene crystals and by some dynamic recrystallization structures at their periphery. Such deformation features, which are usual in boudinaged coarse-grained pyroxenite layers, were probably formed at the same time as the high-temperature plastic deformation that has produced the main foliation in their surrounding peridotites. The relatively low equilibrium temperatures (965°-880°C, Table 3), calculated for the websterites using the two-pyroxene thermometry method (Bertrand and Mercier, 1985), may reflect the physical conditions prevailing at the end of this deformation. It probably also corresponds to temperatures at the end of the plagioclase impregnation.
- 4. The websterites clearly underwent a subsolidus reequilibration event. This is shown by textural relations between orthopyroxene, clinopyroxene, olivine, spinel, and plagioclase. Indeed, plagioclase, in association with secondary olivine, locally interfingers the rims of orthopyroxene and clinopyroxene crystals. The websterite and secondary orthopyroxene also constitute exsolution lamellae in clinopyroxene. These relationships indicate that some plagioclase plus secondary olivine, which locally rims the orthopyroxenes, plus the very small subhedral to euhedral black spinels, which locally occur as inclusions in plagioclase, may have formed according to the following reaction: Al-spinel + orthopyroxene + clinopyroxene = olivine + plagioclase + Fe-Cr spinel. Such a reaction has been described previously in websterites from alpine-type massifs to explain similar secondary phase associations (Kornprobst, 1969; Boudier, 1978) and points to subsolidus reequilibration of the rocks under lithospheric conditions. Hence, plagioclase has a dual origin: a melt origin, which locally has pervasively impregnated the peridotite, and a metamorphic origin.
- 5. The compositional variations observed in spinels of the ultramafic rocks from Sites 897 and 899 support this reequilibration event. Indeed, they display clear enrichment in Ti, strongly correlated with their Cr#. Such a correlation trend has a steep slope similar to that defined experimentally by Li (1991) for spinel peridotites reequilibrated under plagioclase facies conditions. Such a trend is also similar to that defined for other plagioclase peridotite occurrences, such as Ronda, Zabargad, Lanzo, and the Galicia Margin (Kornprobst and Tabit, 1989; Li 1991).
- 6. In the websterites, the resorption of orthopyroxene during the subsolidus reequilibration phase took place after the high-temperature deformation that kinked them. This reequilibration probably occurred at temperatures around 770°C, as calculated from secondary pyroxenes present in recrystallized websterites, and at pressures below 1 GPa, according to the plagioclase formation.
- 7. The thin mylonitic shear bands described by Beslier et al. (this volume) crosscut the high-temperature deformation structures and the secondary plagioclase produced during the subsolidus reequilibration, which also allowed crystallization of secondary olivine after orthopyroxene. This indicates that the mylonitic deformation event clearly postdates the reequilibration phase. The 735°C temperature calculated from dynamically recrystallized pyroxene neoblasts from the shear bands may reflect the conditions at the end of the mylonitization, in good

Hole

Core, section: Interval (cm):			66R-4 57–61		66R- 67-7	4 0	67F 43-	R-3 -50	70R-1 6–9	70R- 63–6	-3
		С	М	Ν	С	Ν	С	Ν	С	С	М
Major o SiO ₂ TiO ₂ Al ₂ O ₃ Cr ₂ O FeO MnO NiO MgO CaO Total Fo	xides	$\begin{array}{c} 40.94\\ 0.00\\ 0.00\\ 12.43\\ 0.16\\ 0.13\\ 46.78\\ 0.00\\ 100.44\\ 86.88\end{array}$	40.89 0.00 0.01 0.00 12.46 0.30 0.24 45.85 0.03 99.77 86.42	40.60 0.03 0.04 0.00 12.52 0.21 0.34 46.52 0.02 100.29 86.65	41.09 0.00 0.02 0.00 11.43 0.23 0.34 47.74 0.00 100.85 87.95	41.04 0.00 0.03 13.08 0.27 0.16 45.33 0.04 99.98 85.72	40.31 0.00 0.00 12.51 0.15 0.29 47.28 0.01 100.54 86.92	40.68 0.02 0.04 0.03 12.20 0.14 0.29 47.61 0.03 101.04 87.22	41.08 0.01 0.00 9.11 0.13 0.34 49.52 0.01 100.20 90.49	40.76 0.00 0.09 8.77 0.17 0.26 49.80 0.01 99.84 90.84	41.27 0.00 0.00 8.70 0.02 0.32 50.46 0.06 100.84 91.01
Hole:	897C	89	7D	899B	89	99B	899B		899B	8	99B
Core, section: Interval (cm):	71R-3 50–55	23H 82-	R-6 -88	20R-4 96–100	21	R-2 ⊢55	21R-4 82-89	4 9	23R-2 49-54	25	R-2 -46
	С	С	N	С	С	М	С	С	М	С	М
Major oxides SiO ₂ TiO ₂ Al ₂ O ₃ Cr ₂ O ₃ FeO MnO NiO NiO CaO Total	40.86 0.00 0.00 9.32 0.00 0.32 49.99 0.07 100.55	41.07 0.00 0.03 0.00 9.74 0.18 0.28 49.49 0.00 100.79	40.98 0.03 0.00 9.81 0.23 0.33 49.34 0.02 100.74	41.06 0.01 0.00 0.00 10.14 0.18 0.33 48.30 0.01 100.04	41.80 0.00 0.01 0.00 8.97 0.10 0.38 49.82 0.00 101.07	41.73 0.00 0.07 9.14 0.10 0.24 50.28 0.02 101.56	41.5 0.0 0.0 9.0 0.0 0.3 49.2 0.0 100.3	5 41. 11 0. 00 0. 3 0. 3 9. 99 0. 1 0. 7 49. 5 0. 3 100.	04 41.57 00 0.00 03 0.01 01 0.00 13 0.13 50 0.27 46 49.67 03 0.00 35 100.17	41.00 0.01 0.00 8.52 0.14 0.33 49.93 0.02 100.01	41.15 0.02 0.02 0.00 8.34 0.17 0.33 50.28 0.00 100.31
Fo	90.36	89.89	89.71	89.26	90.74	90.61	90.4	8 90.	38 91.10	91.07	91.33

Table 1. Selected analyses of olivines. 807C

807C

807C

807C

8070

Notes: Formula unit calculated on the basis of 4 oxygens. C = crystal core, M = crystal margin, N = neoblast, Fo = molecular proportion of forsterite.

agreement with the low-temperature olivine glide system determined with neoblasts (Beslier et al., this volume).

8. Crystallization of Na-Ti-rich phases such as kaersutite, phlogopite, rutile, and ilmenite, which provide evidence of metasomatism by alkaline melts before the main mylonitization events, has been found in one peridotite. This feature, together with locally pervasive plagioclase impregnation in many peridotites, shows that the ultramafic unit was locally and intensely percolated by magmas or fluids during its ascent. These magmas have produced the local resorption of orthopyroxene and cryptic variations in the peridotite primary phases chemistry, well marked by Fe and Ti behaviors. Accordingly, these melts probably were poor in Si and rich in Fe, Ti, Na, and Ca, as are undersaturated alkaline melts formed by low-degree fractional melting of peridotite at high pressure.

Comparison with the Galicia Margin Peridotites

Peridotites have been recovered all along Iberia from the Leg 149 drilling sites in the south to the Galicia Margin in the north. In Galicia, they were first dredged at Hill 5100 (Boillot et al., 1980), then drilled at the same place (Hole 637A) during Leg 103 (Boillot, Winterer, Meyer, et al., 1987; Boillot et al., 1988a), and later sampled by diving, about 100 km further north, during the Galinaute cruise using the submersible Nautile (Boillot et al, 1988b). At Site 637, 35.9 m of peridotite was recovered from a 73.6-m section (Girardeau et al., 1988; Evans and Girardeau, 1989). During the Galinaute cruise, 19 samples of peridotite were taken along four nearly 400-m-high escarpments (Dives 4, 6, 9, 10, and 14; Beslier et al., 1990).

Peridotites cored at Site 637 are serpentinized spinel-clinopyroxene-rich harzburgites and lherzolites, including rare dunites, as well as spinel-plagioclase-bearing peridotites. These peridotites are all strongly foliated, but still display a discrete banding with relatively pyroxene-rich and -poor zones and rare thin (millimeter-thick) websteritic bands parallel to the main foliation. In thin section, they display either porphyroclastic textures or mylonitic ones. These peridotites contain olivine, orthopyroxene, clinopyroxene, spinel, or spinelplagioclase as primary phases. A few samples also contain brown amphiboles as isolated crystals or in thin late veinlets. Secondary phases comprise serpentines (chrysotile and lizardite), chlorite, opaque minerals, including magnetite, and late calcite (Agrinier et al., 1988; Evans and Girardeau, 1988; Girardeau et al., 1988).

Peridotites recovered during the Galinaute cruise are mostly plagioclase-bearing harzburgites and lherzolites, with minor dunites (Beslier et al., 1990). These peridotites display evidence of strong deformation that has produced the development of porphyroclastic textures, generally overprinted by mylonitic ones. Like the Site 637 peridotites, they contain olivine, orthopyroxene, clinopyroxene, spinel, or spinel-plagioclase as primary phases, and serpentines (chrysotile and lizardite), chlorite, opaque minerals, including magnetite, and calcite as secondary phases. These peridotites are also locally crosscut by rare plagioclase-rich or brown-amphibole-rich veinlets a few millimeters thick and, more rarely, by dioritic intrusives, 1 decimeter thick. These intrusives were emplaced before the emplacement-related mylonitization event around 122 Ma (Féraud et al., 1988; Boillot et al., 1989). At one site, located about 50 km northeast of the peridotite ridge (Dive 14), a few pyroxenites interpreted as cumulates were sampled together with microgabbros and dolerites (Beslier et al., 1990). These later rocks were interpreted as formed through crystallization of transitional to tholeiitic magmas produced during the rift-drift transition (Kornprobst et al., 1988).

When we compare the Leg 149 peridotites to peridotites from the Galicia Margin (Figs. 6, 7, 10, 13), we can show that they have similar petrologic characteristics. The Leg 149 peridotites, however, appear to be much more residual than the Galicia ones. This is best illustrated by the Cr# content of all spinels, orthopyroxenes, and clinopyroxenes that overlap the Galicia field with significantly higher values for many samples, like residual rocks from many ophiolitic

Table 2. Selected analyses of spinels.

Hole: Core, section Interval (cr	on: m):	897 64R 77–	C 5 81	897C 66R-4 57–61	897 66R 67–1	C -4 70	89 67F 43-	7C R-3 -50	89 671 102-	7C R-3 -107	8 7	97C 0R-1 6–9		8970 70R- 63-6	C -3 56		897D 16R-1 33–38		8 1 6	897D 9R-5 6269	897 19R 80–	/D 2-5 86
		С	N	С	С	М	С	N	С	М	С	М		С	М	С	М	N		С	С	М
Major elemen SiO ₂ TiO ₂ Al ₂ O ₃ Fe ₂ O ₃ FeO MnO NiO MgO Total	nts4 1 1 1	0.00 0.26 4.12 0.39 4.83 3.97 0.12 0.23 6.16 0.08	$\begin{array}{c} 0.38\\ 0.38\\ 33.04\\ 24.40\\ 7.88\\ 19.94\\ 0.14\\ 0.19\\ 10.68\\ 97.02 \end{array}$	$\begin{array}{c} 0.00\\ 0.28\\ 48.48\\ 13.41\\ 6.58\\ 13.52\\ 0.36\\ 0.15\\ 16.61\\ 99.39 \end{array}$	$\begin{array}{c} 0.00\\ 0.04\\ 61.11\\ 3.26\\ 4.42\\ 10.64\\ 0.19\\ 0.23\\ 19.88\\ 99.77 \end{array}$	$\begin{array}{c} 0.01\\ 0.00\\ 62.61\\ 0.95\\ 4.55\\ 12.05\\ 0.19\\ 0.17\\ 19.10\\ 99.63 \end{array}$	$\begin{array}{c} 0.01\\ 0.51\\ 36.30\\ 21.47\\ 9.69\\ 17.34\\ 0.05\\ 0.16\\ 12.79\\ 98.33 \end{array}$	$\begin{array}{c} 0.00\\ 0.28\\ 32.50\\ 25.04\\ 10.95\\ 18.71\\ 0.29\\ 0.17\\ 11.30\\ 99.24 \end{array}$	0.03 0.14 56.06 8.63 4.52 9.88 0.20 20.03 99.48	$\begin{array}{c} 0.00\\ 0.09\\ 58.15\\ 6.05\\ 5.45\\ 9.82\\ 0.03\\ 20.35\\ 99.95 \end{array}$	$\begin{array}{c} 0.02\\ 0.31\\ 16.95\\ 46.55\\ 5.17\\ 23.50\\ 0.55\\ 0.00\\ 6.89\\ 99.95\end{array}$	0.0 0.3 12.2 48.2 8.4 25.2 0.3 0.0 5.2 100.2	$\begin{array}{cccccccccccccccccccccccccccccccccccc$	0.05 0.33 5.95 8.75 4.82 5.27 0.10 0.14 3.67 0.07	$\begin{array}{c} 0.01\\ 0.31\\ 28.29\\ 36.43\\ 5.30\\ 14.72\\ 0.03\\ 0.13\\ 13.99\\ 99.21 \end{array}$	0.00 0.12 49.61 18.07 1.91 11.66 0.13 0.24 18.22 99.94	0.00 0.11 49.31 18.48 1.78 11.73 0.05 0.20 18.20 99.83	0.0 0.0 51.6 15.7 1.3 12.5 0.1 0.1 17.7 99.3	00 17 12 13 14 15 15 15 15 15 15 15 15 15 15	0.03 0.05 11.30 5.30 1.79 0.88 0.03 0.30 8.56 8.23	0.00 0.23 44.82 21.75 3.58 12.19 0.07 0.21 17.53 00.38	$\begin{array}{c} 0.00\\ 0.29\\ 34.81\\ 31.09\\ 4.43\\ 13.59\\ 0.25\\ 0.12\\ 15.45\\ 100.01 \end{array}$
Si Ti Al Cr Fe ³⁺ Fe ²⁺ Mn Ni Mg Total		0.000 0.005 1.444 0.448 0.097 0.328 0.003 0.005 0.669 3.000	$\begin{array}{c} 0.012\\ 0.009\\ 1.196\\ 0.592\\ 0.171\\ 0.523\\ 0.004\\ 0.005\\ 0.489\\ 3.000 \end{array}$	$\begin{array}{c} 0.000\\ 0.006\\ 1.567\\ 0.291\\ 0.131\\ 0.315\\ 0.008\\ 0.003\\ 0.679\\ 3.000\\ \end{array}$	$\begin{array}{c} 0.000\\ 0.001\\ 1.849\\ 0.066\\ 0.083\\ 0.231\\ 0.004\\ 0.005\\ 0.761\\ 3.000 \end{array}$	$\begin{array}{c} 0.000\\ 0.000\\ 1.895\\ 0.019\\ 0.085\\ 0.261\\ 0.004\\ 0.003\\ 0.731\\ 3.000 \end{array}$	$\begin{array}{c} 0.000\\ 0.011\\ 1.268\\ 0.503\\ 0.205\\ 0.441\\ 0.001\\ 0.004\\ 0.565\\ 2.998 \end{array}$	$\begin{array}{c} 0.000\\ 0.006\\ 1.156\\ 0.597\\ 0.234\\ 0.486\\ 0.008\\ 0.004\\ 0.508\\ 2.999 \end{array}$	0.001 0.003 1.728 0.178 0.087 0.218 0.005 0.781 3.000	0.000 0.002 1.770 0.124 0.103 0.215 0.001 0.783 2.998	0.001 0.008 0.656 1.209 0.118 0.655 0.015 0.000 0.338 3.000	$\begin{array}{c} 0.00\\ 0.00\\ 0.44\\ 0.12\\ 0.11\\ 0.7\\ 0.00\\ 0.00\\ 0.00\\ 0.2\\ 0.30\\ 0.01\\ 0.00\\ 0$	00 00 1 00 91 00 92 00 97 00 34 00 11 00 00 00 20 00 00 00 00 00 00 00 00	0.001 0.007 0.956 0.922 0.104 0.39 0.002 0.003 0.613 2.998	0.000 0.007 1.004 0.867 0.115 0.376 0.001 0.003 0.628 3.001	$\begin{array}{c} 0.000\\ 0.002\\ 1.573\\ 0.384\\ 0.037\\ 0.264\\ 0.003\\ 0.005\\ 0.731\\ 3.000 \end{array}$	$\begin{array}{c} 0.000\\ 0.002\\ 1.567\\ 0.394\\ 0.035\\ 0.266\\ 0.001\\ 0.004\\ 0.731\\ 3.000\end{array}$	0 0.0 0 0.0 1.6 0.3 5 0.0 5 0.0 6 0.2 0 0.0 4 0.0 5 0.0 6 0.2 0 0.0 1 0.7 0 3.0	000 101 136 135 127 184 103 104 111 100	0.001 0.001 1.634 0.327 0.035 0.247 0.001 0.007 0.748 3.000	$\begin{array}{c} 0.000\\ 0.005\\ 1.448\\ 0.471\\ 0.071\\ 0.282\\ 0.002\\ 0.005\\ 0.716\\ 3.000 \end{array}$	$\begin{array}{c} 0.000\\ 0.006\\ 1.185\\ 0.710\\ 0.092\\ 0.332\\ 0.006\\ 0.003\\ 0.665\\ 3.000 \end{array}$
Mg# Cr#	6	7.10 3.68	48.32 33.11	68.31 15.66	76.71 3.45	73.69 0.99	56.16 28.40	51.11 34.06	78.18 9.34	78.46 6.55	33.53 64.83	26.4. 72.4	5 6 6 49	1.12 9.09	62.55 46.34	73.47 19.62	73.32 20.09	71.4 17.0	6 7 0 1	5.10 6.68	71.74 24.54	66.70 37.47
Hole: Core, section: Interval (cm):	89 ⁷ 20H 8-	7D R-3 13	897D 21R-1 10-15	5 8	397D 3R-6 2–88	897D 24R-1 0-5	899 20R 90	B -4 96	899B 20R-4 96-100		899B 21R-2 50–55		89 21 29-	9B R-3 -52		899B 21R-4 82–89		899 23F 49-	9B R-2 -54	2 4	399B 5R-2 1–46	899B 30R-1 83-86
	С	М	C	С	М	С	C		C N		С	М	С	М	C	М	[С	М	С	М	М
Major elements SiO ₂ TiO ₂ Al ₂ O ₃ Cr ₂ O ₃ FeO MnO NiO MgO Total Si	0.04 0.22 49.03 16.16 3.52 12.77 0.21 0.20 17.35 99.50 0.001	0.00 0.07 59.25 6.48 3.03 9.29 0.17 0.32 20.44 99.06 0.000	0.00 0.09 26.54 39.88 5.19 14.83 0.36 0.04 13.74 100.66 0 0.00	0.00 0.41 41.18 23.23 4.80 12.17 0.21 0.20 16.88 99.06 0 0.000	0.04 0.23 43.50 22.77 4.13 12.30 0.23 0.24 17.29 100.72	0.00 0.11 49.44 18.36 1.90 11.30 0.07 0.24 18.44 99.87 0.000	0.1 0.5 28.5 34.0 5.9 18.3 0.2 0.1 11.7 99.8	6 0 6 0 0 30 12 33 19 3 17 15 18 0 4 0 19 13 13 98 105 0	.36 1.5 .51 0.2 .49 37.3 .86 23.3 .37 4.7 .33 0.3 .05 0.0 .71 14.4 .42 98.9 .011 0.0	60 (0 20 (0 44 32 56 36 3 1 0 14 50 (0 22 (0 12 14 56 99 143 (0 14 32 14 32 14 14 32 14 14 14 14 14 14 14 14 14 14	0.00 0 0.00 0 2.10 27 5.15 36 1.98 2 4.17 18 0.36 0 0.00 0 4.56 11 0.31 98 0.000 0	.41 .41 .67 .66 .53 .31 .00 .63 .39	$\begin{array}{c} 1.55\\ 0.01\\ 49.46\\ 19.91\\ 0.00\\ 11.67\\ 0.21\\ 0.19\\ 16.23\\ 99.23\\ 0.042\end{array}$	0.06 0.03 30.98 36.00 2.22 13.94 0.22 0.27 14.31 98.02 0.00	0.0 0.0 37.9 29.0 2.2 13.1 0.3 0.0 15.7 98.4 2 0.0	08 0.0 03 0.0 01 47.7 00 21.1 20 1.1 2 11.5 66 0.0 03 0.1 3 18.2 66 100.0 002 0.0	02 79 80 85 55 10 00 27 10 27 10 10 00 100	0.20 0.39 32.42 34.77 2.55 16.61 0.16 0.08 13.79 00.97 0.006	$\begin{array}{c} 0.05\\ 0.00\\ 42.06\\ 25.10\\ 1.69\\ 12.49\\ 0.21\\ 0.30\\ 16.44\\ 98.35\\ 0.001 \end{array}$	0.00 0.32 46.90 22.05 1.43 10.38 0.13 0.14 19.07 100.42 0.000	0.18 0.55 26.45 38.95 0.47 22.96 0.40 0.01 8.56 98.52	8 0.02 5 0.31 5 49.18 5 19.82 7 1.07 5 0.035 0 0.035 0 0.17 5 19.37 2 100.32 06 0.001
Ti Al Cr Fe ³⁺ Fe ²⁺ Mn Ni Mg Total Mg#	0.005 1.572 0.347 0.069 0.293 0.005 0.004 0.703 2.999 70.58	0.00 1.80 0.13 0.05 0.20 0.00 0.00 0.78 3.00 79.52	1 0.00 7 0.93 3 0.94 8 0.11 3 0.37 4 0.00 7 0.00 8 0.61 1 2.99 61.96	2 0.000 8 1.36 6 0.51 2 0.093 7 0.290 9 0.000 1 0.000 4 0.700 9 3.000 70.97	9 0.005 7 1.411 7 0.495 8 0.083 0 0.286 5 0.005 4 0.005 9 0.709 0 3.000 71.26	0.002 1.568 0.391 0.037 0.256 0.002 0.005 0.74 3.001 74.30	0.0 0.1 0.1 0.1 0.1 0.1 0.4 0.1 0.4 0.1 0.4 0.1 0.4 0.5 0.0 52.9	113 0 119 1 119 1 116 0 29 0 174 0 1003 0 133 0 1000 3 133 0 100 3 133 0 133 0 133 0 133 0 133 0 133 0 133 0 133 0 140 3 15 60	.012 0.0 .079 1.2 .804 0.5 .073 0.0 .399 0.4 .008 0.0 .001 0.0 .614 0.6 .000 3.0	$\begin{array}{cccccccccccccccccccccccccccccccccccc$	0.000 0 1.115 1 0.843 0 0.042 0 0.042 0 0.009 0 0.000 0 0.000 0 0.640 0 3.000 3 4.58 52	.009 .004 .892 .060 .481 .008 .000 .534 .000	0.000 1.571 0.424 0.000 0.263 0.005 0.004 0.652 2.961 71.26	0.00 1.09 0.85 0.04 0.35 0.00 0.00 0.63 3.00 64.48	1 0.0 4 1.2 3 0.6 8 0.0 2 0.3 5 0.0 6 0.0 9 0.6 0 3.0 6 68.0	$\begin{array}{cccccccccccccccccccccccccccccccccccc$	000 524 451 023 262 000 002 737 000	0.009 1.115 0.803 0.053 0.408 0.004 0.002 0.600 3.000 59.52	0.000 1.402 0.561 0.035 0.297 0.005 0.007 0.693 3.000 70.00	0.000 1.48° 0.47° 0.023 0.000 0.000 0.76° 3.000 76.52	5 0.01 9 0.98 0 0.97 8 0.01 5 0.60 3 0.01 3 0.00 5 0.40 0 3.00 39.88	3 0.006 32 1.547 70 0.418 10 0.021 10 0.232 11 0.001 10 0.004 12 0.771 10 3.000 3 76.87
Cr#	18.08	6.86	50.21	27.44	25.97	19.96	44.4	7 42	.70 29.5	5 43	3.05 47	.05	21.25	43.81	33.9	3 22.8	34 4	41.87	28.58	23.99	49.69	21.27

Notes: Formula unit calculated on the basis of 4 oxygens. $Mg\# = 100 \times Mg/(Mg + Fe_2)$, $Cr\# = 100 \times Cr/(Cr + Al)$; C = crystal core, M = crystal margin, N = neoblast.



Figure 7. Correlation diagram for spinel in a $Cr\# = 100 \times Cr/(Cr + Al)$ vs. $Mg\# = 100 \times Mg/(Mg + Fe)$ diagram. The shaded area represents the Galicia Margin peridotite from Leg 103 (Boillot, Winterer, Meyer, et al., 1987) and the mean primitive lherzolite is after Glücklich-Herbas (1992).

and oceanic peridotites. The Ti content of spinel, orthopyroxene, and clinopyroxene in Leg 149 spinel peridotites is also very low, as expected for residual rocks. This is not the case in the plagioclase-bearing rocks in which Ti displays high values, higher than on the Galicia Margin. This Ti enrichment, like the Fe enrichment which is the best seen in olivine, most likely occurred during the peridotite impregnation process, which allowed the local crystallization of large amounts of plagioclase in some studied Leg 149 peridotites. Na clinopyroxenes are always low. In the Na vs. Cr diagram (Fig. 14), which tries to discriminate between clinopyroxenes from oceanic and continental environments (Kornprobst et al., 1981), the Leg 149 peridotites plot in the oceanic field, being less depleted in Na than most oceanic peridotites but significantly more depleted than the Galicia ones. When considering the Ti contents of clinopyroxenes (Fig. 15), they also clearly plot in the oceanic field defined by Seyler and Bonatti (1994).

Controversy existed as to whether the Leg 103 peridotites are oceanic (Evans and Girardeau, 1988) or subcontinental (Kornprobst and Tabit, 1988). The subcontinental interpretation was mostly based on the high Na content of the clinopyroxenes and in regard to compositional similarities between the Leg 103 peridotites and those from Ronda, Lanzo, and the Pyrénées. The Na criterion in clinopyroxenes cannot discriminate between these two types of environment in the case of Leg 149 peridotites, which have clinopyroxenes with low Na contents like oceanic peridotites. The Leg 149 peridotites, however, display clear subsolidus reequilibration reactions like subcontinental ones. Such reequilibrium features have indeed never been seen in oceanic peridotites but are common in orogenic ones (Kornprobst, 1969; Boudier, 1978; Obata, 1980; Kornprobst and Tabit, 1989), which makes a good argument for an evolution in a continental rift environment.

These subsolidus reequilibration features are best seen in the websterite levels that are abundant in the Leg 149 rocks. The existence of large amounts of websterite (about 30% of the ultramafic pile) in the Leg 149 ultramafic suite provides, in fact, the major difference between the two areas. The evidence of plagioclase formation by subsolidus reequilibration in the Leg 149 websterites, and not in the Galicia websterites, is another major difference.

Evidence for metasomatism by alkaline melts before the main mylonitization events was found in peridotites from the Galicia Margin (Féraud et al., 1988; Beslier et al., 1990) and in those recovered during Leg 149 (this work). This is in good agreement with what was observed in Leg 149 mafic rocks (Cornen et al., this volume) and with an origin and evolution of the Leg 149 peridotites in a continental rift system.

According to their structures, peridotites from the Leg 149 area and the Galicia Margin underwent a similar history, including a hightemperature ductile deformation followed by a mylonitization event (Girardeau et al, 1988; Beslier et al., 1990; Beslier et al., this volume). From our textural and thermometric data, we can consider that the Leg 149 peridotites first underwent some partial melting and melt impregnation, which occurred at the end of their high-temperature ductile deformation and probably ended under static conditions at temperatures around 965°-888°C and pressures below 1GPa. They next underwent a clear lithospheric history: first, a subsolidus reequilibration under static conditions at temperature around 770°C, and second, mylonitization, which probably ended at temperatures around 735°C. Both events occurred at decreasing pressures. This tectonometamorphic evolution at decreasing pressure-temperature conditions is guite similar to that defined for the Galicia peridotites (Girardeau et al., 1988; Beslier et al., 1990) and is in good agreement with that expected for mantle in a continental rift environment. Mylonitization seems, however, to have been much more localized in the Leg 149 peridotites than in the Galicia Margin rocks (Beslier et al., this volume).

CONCLUSION

All data presented and discussed in preceding sections show that the Leg 149 ultramafic unit is made of websterites and of depleted peridotites that underwent a heterogeneous partial melting and melt impregnation phase during, or at the end of, their high-temperature plastic deformation. Such an event occurred in the plagioclase field, i.e., at pressures below 1 GPa, and at temperatures around 965°-880°C. These ultramafic materials likely behave as asthenospheric mantle before their emplacement at shallow levels in a relatively cool thermal regime that did not allow a large pervasive partial melting of the ultramafic pile.

These peridotites then underwent a subsolidus static history, at decreasing temperature (770°C), followed by some mylonitization that ended around 735°C, (i.e., under lithospheric conditions). Such an evolution at decreasing temperatures probably reflects accretion of the asthenospheric mantle to the lithosphere, during stretching of a continental lithosphere (Table 7).

ACKNOWLEDGMENTS

We would like to thank M. Bohn, E. Boeuf, A. Cossard, and R. Derval for their skillful technical help. This work was supported by Geoscience Marine.

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Date of initial receipt: 2 January 1995 Date of acceptance: 17 July 1995 Ms 149SR-215



Figure 8. Green spinel (Sp) within clinopyroxene, rimmed by plagioclase and secondary olivine in websterite (Sample 149-897C-66R-4, 67-70 cm). Planepolarized light. Scale bar is 0.2 mm.



Figure 9. Platelets of ilmenite within spinel in websterite (Sample 149-897C-67R-3, 102-107 cm). Plane-polarized light. Scale bar is 0.2 mm.





Table 3. Geothermometric results.

Sample locations	Peridotite features	Geothermometer						
Core Section,		Ol/Sp	Ol/Sp	Opx/Cpx				
Interval (cm)		Fabriès (1979)	Sack (1982)	Bertrand & Mercier (1985)				
899B-21R-2, 50-55 899B-21R-4, 82-89 899B-23R-2, 49-54	Coarse-grained without plagioclase	702°	785°					
899B-20R-4, 96-100 899B-21R-4, 82-89				880°				
899B-20R-4, 90-96 897C-64R-5, 77-81 899B-20R-4, 90-96	Coarse-grained with plagioclase	715°	840°	965°				
897C-66R-4, 57-61 897C-66R-4, 67-70	Recrystallized with plagioclase	692°	827°					
897C-64R-5, 77-81 897C-66R-4, 57-61 897C-67R-3, 102-107	(using pyroxene neoblasts)			782°				
897C-67R-3, 43-50	Mylonitic with plagioclase	603°	789°	735°				
897C-70R-1, 6-9	Highly serpentinized dunite	804- 567°	971- 655°					

Note: Geothermometric results were determined using the olivine-spinel thermometers of Fabriès (1979) and Sack (1982) and the two-pyroxene thermometers of Bertrand and Mercier (1985).

Figure 10. Ti/Cr# correlation diagrams for spinel within peridotites from Leg 149. The shaded area represents the Galicia Margin peridotite from Leg 103 (Boillot, Winterer, Meyer, et al., 1987), and the mean primitive lherzolite is after Glücklich-Herbas (1992).

Hole:		893	7C		897C	89	7C	89	7C	89	7D	897D
Core, section:		64F	R-5		66R-4	671	R-3	671	R-3	231	R-6	23R-6
Interval (cm):		77-	-81		57-61	43-	-50	102-	-107	82-	-88	82-88
	С	М	Х	Ν	N	С	М	С	Х	С	М	С
Major elements												
\tilde{SiO}_2	54.76	54.84	52.92	53.13	56.14	54.51	56.01	56.02	53.56	55.32	57.22	52.88
TiO_2	0.14	0.18	0.09	0.10	0.15	0.30	0.25	0.24	0.08	0.21	0.11	0.08
Al_2O_3	2.99	2.64	6.30	5.90	1.95	3.09	3.38	3.48	5.91	3.24	1.66	7.54
Cr_2O_3	0.57	0.46	0.38	0.36	0.14	0.55	0.55	0.68	0.33	0.57	0.14	0.31
Fe_2O_3	1.56	1.30	0.99	1.70	0.00	0.73	0.00	0.35	1.63	0.10	0.21	0.00
FeO	6.64	6.19	7.04	6.77	8.65	7.21	7.69	8.09	6.80	6.17	6.37	7.08
MnO	0.06	0.22	0.15	0.19	0.21	0.07	0.24	0.24	0.16	0.19	0.17	0.10
NiO	0.03	0.03	0.04	0.06	0.03	0.09	0.04			0.05	0.03	0.02
MgO	32.14	32.67	31.14	31.34	32.05	31.80	32.41	32.38	31.73	32.95	34.30	30.86
CaO	1.14	0.72	0.44	0.56	0.41	0.88	0.45	0.87	0.42	0.91	0.54	0.53
Na_2O	0.03	0.03	0.00	0.00	0.00	0.05	0.00	0.00	0.01	0.01	0.03	0.02
K_2O	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Total	100.06	99.28	99.50	100.10	99.72	99.29	101.02	102.35	100.62	99.71	100.76	99.42
Si	1.908	1.918	1.850	1.850	1.961	1.913	1.926	1.910	1.852	1.919	1.960	1.843
Al ^{IV}	0.092	0.082	0.150	0.150	0.039	0.087	0.074	0.090	0.148	0.081	0.040	0.157
Al ^{VI}	0.031	0.027	0.110	0.092	0.041	0.041	0.063	0.050	0.093	0.052	0.027	0.152
Ti	0.004	0.005	0.002	0.003	0.004	0.008	0.007	0.006	0.002	0.005	0.003	0.002
Cr	0.016	0.013	0.011	0.010	0.004	0.015	0.015	0.018	0.009	0.016	0.004	0.009
Fe ³⁺	0.040	0.034	0.025	0.044	0.000	0.019	0.000	0.009	0.042	0.003	0.005	0.000
Fe ²⁺	0.194	0.182	0.206	0.198	0.253	0.212	0.221	0.231	0.197	0.179	0.183	0.206
Mn	0.002	0.007	0.004	0.006	0.006	0.002	0.007	0.007	0.005	0.005	0.005	0.003
Ni	0.001	0.001	0.001	0.002	0.001	0.003	0.001			0.001	0.001	0.001
Mg	1.669	1.704	1.623	1.626	1.669	1.664	1.661	1.646	1.636	1.704	1.751	1.603
Ca	0.042	0.027	0.017	0.021	0.016	0.033	0.016	0.032	0.016	0.034	0.020	0.020
Na	0.002	0.002	0.000	0.000	0.000	0.003	0.000	0.000	0.000	0.000	0.002	0.001
K	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Total	4.001	4.002	4.000	4.002	3.994	4.000	3.991	3.999	4.001	4.000	4.000	3.998
Mg#	89.49	90.02	88.54	88.85	86.57	88.60	87.93	87.37	89.01	90.25	90.30	88.47
Cr#	23.32	21.64	8.12	7.94	9.52	21.46	19.74	22.79	7.21	21.54	11.56	5.69
Wo	2.23	1.41	0.89	1.14	0.80	1.74	0.86	1.66	0.84	1.76	1.02	1.07
En	87.59	89.09	87.93	88.14	86.16	87.16	87.49	86.25	88.48	88.89	89.64	87.65
Fs	10.19	9.49	11.18	10.72	13.04	11.10	11.65	12.10	10.68	9.35	9.35	11.28

Table 4. Selected analyses of orthopyroxenes.

Hole:		899B			899B		899B		899B		899	9B
Core, section:		20R-4			20R-4		21R-4		23R-2		25H	R-2
Interval (cm):		19-22			96-100		82-89		49-54		41-	-46
	С	С	М	С	M	М	С	С	С	M	С	С
Major elements												
SiO ₂	55.49	54.13	55.42	56.87	56.94	56.11	56.34	56.87	56.31	56.27	54.40	53.78
TiO2	0.21	0.19	0.18	0.20	0.23	0.23	0.04	0.04	0.00	0.04	0.13	0.21
$Al_2\tilde{O}_3$	3.06	2.73	2.63	2.73	2.18	2.55	4.09	2.86	3.20	3.46	3.20	3.39
Cr_2O_3	0.62	0.68	0.55	0.52	0.55	0.69	0.60	0.55	0.73	0.52	0.88	1.06
Fe ₂ O ₃	0.00	3.28	0.92	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.97	3.35
FeO	6.76	3.52	5.38	6.08	6.66	6.15	5.77	5.67	5.47	5.40	3.06	2.77
MnO	0.01	0.10	0.21	0.15	0.10	0.07	0.21	0.08	0.12	0.05	0.24	0.20
NiO	0.05	0.00	0.05	0.11	0.02	0.00	0.00	0.06	0.00	0.00	0.06	0.05
MgO	32.60	33.41	33.49	32.62	33.67	32.74	32.89	33.44	31.72	32.43	33.60	33.59
CaO	0.57	1.17	0.71	1.40	0.60	1.01	1.17	0.81	3.26	2.35	1.21	0.99
Na ₂ O	0.02	0.04	0.02	0.06	0.02	0.05	0.03	0.01	0.05	0.00	0.06	0.07
$K_2 \tilde{O}$	0.00	0.00	0.03	0.02	0.00	0.04	0.04	0.00	0.00	0.00	0.02	0.00
Total	99.39	99.25	99.57	100.74	100.96	99.62	101.17	100.38	100.85	100.51	99.83	99.45
Si	1.932	1.888	1.924	1.950	1.950	1.946	1.921	1.949	1.935	1.932	1.883	1.870
Al ^{IV}	0.068	0.112	0.076	0.050	0.050	0.054	0.079	0.051	0.065	0.068	0.117	0.130
Al ^{VI}	0.057	0.001	0.031	0.061	0.037	0.050	0.085	0.065	0.064	0.072	0.014	0.008
Ti	0.006	0.005	0.005	0.005	0.006	0.006	0.001	0.001	0.000	0.001	0.003	0.005
Cr	0.017	0.019	0.015	0.014	0.015	0.019	0.016	0.015	0.020	0.014	0.024	0.029
Fe ³⁺	0.000	0.085	0.024	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.077	0.087
Fe ²⁺	0.197	0.103	0.156	0.174	0.191	0.178	0.164	0.162	0.157	0.155	0.089	0.081
Mn	0.000	0.003	0.006	0.004	0.003	0.002	0.006	0.002	0.003	0.001	0.007	0.006
Ni	0.001	0.000	0.001	0.003	0.001	0.000	0.000	0.002	0.000	0.000	0.002	0.001
Mg	1.692	1.737	1.733	1.667	1.718	1.692	1.671	1.708	1.624	1.660	1.734	1.741
Ca	0.021	0.044	0.026	0.051	0.022	0.037	0.043	0.030	0.120	0.086	0.045	0.037
Na	0.001	0.003	0.002	0.004	0.002	0.003	0.002	0.000	0.003	0.000	0.004	0.005
K	0.000	0.000	0.001	0.001	0.000	0.002	0.002	0.000	0.000	0.000	0.001	0.000
Total	3.992	4.000	3.999	3.984	3.994	3.989	3.990	3.985	3.991	3.989	4.000	4.000
Mg#	89.57	94.25	91.45	90.35	89.85	90.38	90.77	91.24	91.03	94.75	95.24	95.24
Cr#	24.12	29.45	24.91	23.15	29.88	31.78	17.99	22.96	27.40	31.78	35.70	35.70
Wo	1.11	2.32	1.38	2.71	1.138	1.96	2.28	1.57	6.314	4.54	2.39	1.98
En	88.58	92.19	90.46	88.08	88.98	88.70	88.97	89.89	85.424	87.30	92.84	93.66
Fs	10.31	5.49	8.16	9.20	9.882	9.34	8.75	8.55	8.262	8.16	4.77	4.37

Notes: Formula unit calculated on the basis of 6 oxygens and 4 cations. Mg# = 100 × Mg/(Mg + Fe²⁺ + Mn), Cr# = 200 × Cr/(Cr + Al - Na) after Glücklich-Herbas (1992). C = crystal core, M = crystal margin, N = neoblast, X = exsolution. Wo, En, Fs = molecular proportion of wollastonite, ensatite, and ferrosilite.



Figure 11. Ti/Cr# correlation diagram for orthopyroxene within peridotites from Leg 149. The shaded area is for the Galicia Margin peridotite from Leg 103 (Boillot, Winterer, Meyer, et al., 1987). Cr# = $200 \times$ Cr/Cr + Al - Na) and the mean primitive lherzolite is after Glücklich-Herbas (1992).



Figure 12. Partition of Cr# between spinel and orthopyroxene. $Cr# = 100 \times Cr/(Cr + Al)$ for spinel and $Cr# = 200 \times Cr/(Cr + Al - Na)$ for orthopyroxene. Partition ratios and their corresponding line are indicated. The mean of primitive lherzolite is after Glücklich-Herbas (1992).

Table 5. Selected analyses of clinopyroxenes.

Hole:		897C			89	7C			89	7C		89	7C	89	7C		897D	
Core, section:		64R-5			661	R -4			661	R-4		671	R-3	67	R-3		14R-4	
Interval (cm):		77-81			57-	-61			67-	-70		43-	-50	102-	-107		95-100	
	С	С	Ν	С	С	М	N	С	С	М	N	С	М	С	М	С	С	N
Major elements	10.10	10.00	10.54	51.04	50.50	51.07	51.05	10.55	10.07	52.01	50 (7	10.00	50.04	50.45	51.61	51.07	50.00	52.00
S ₁ O ₂	49.48	49.82	49.56	51.24	52.73	51.97	51.95	49.65	49.87	53.91	52.67	49.02	50.04	50.45	51.61	51.97	52.28	53.08
T_1O_2	0.64	0.61	0.65	0.62	0.56	0.54	0.56	0.22	0.15	0.16	0.15	0.78	0.72	0.55	0.67	1.06	0.16	0.62
Al_2O_3	6.01	6.87	6.08	4.71	4.12	3.52	3.96	8.09	7.75	2.17	3.58	6.43	5.48	6.38	4.38	2.61	3.44	1.95
Cr_2O_3	0.77	0.44	0.75	0.57	0.39	0.66	0.57	0.07	0.00	0.01	0.23	0.69	0.80	0.74	0.47	1.05	1.47	0.75
FeO	3.63	3.97	3.68	3.66	4.38	3.52	4.27	4.13	4.51	2.81	3.73	4.10	3.54	4.19	3.53	2.16	2.39	2.18
MnO	0.29	0.15	0.11	0.12	0.10	0.14	0.02	0.10	0.02	0.09	0.24	0.06	0.11	0.15	0.15	0.09	0.03	0.00
NiO	0.02	0.05	0.01	0.00	0.06	0.00	0.00	0.20	0.04	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00
MgO	15.47	16.35	15.35	15.23	17.01	15.88	15.93	14.32	13.93	16.72	16.00	14.70	15.09	15.56	16.10	16.73	16.88	17.59
CaO	23.00	21.38	23.04	23.42	20.70	23.30	22.70	23.54	23.91	23.22	24.01	23.10	23.34	21.83	23.26	23.33	22.50	23.01
Na_2O	0.44	0.36	0.42	0.52	0.31	0.34	0.35	0.30	0.30	0.22	0.26	0.33	0.39	0.32	0.40	0.53	0.64	0.46
Total	99.74	100.00	99.65	100.13	100.39	99.89	100.38	100.68	100.49	99.33	100.89	99.21	99.52	100.22	100.57	99.52	99.78	99.66
Si	1.808	1.809	1.813	1.869	1.910	1.900	1.892	1.801	1.815	1.968	1.905	1.807	1.836	1.837	1.870	1.898	1.899	1.929
Al ^{IV}	0.192	0.191	0.187	0.131	0.090	0.100	0.108	0.199	0.185	0.032	0.095	0.193	0.164	0.163	0.130	0.102	0.101	0.071
Al^{VI}	0.066	0.103	0.075	0.071	0.085	0.052	0.062	0.147	0.148	0.061	0.057	0.086	0.073	0.111	0.056	0.011	0.046	0.013
Ti	0.018	0.017	0.018	0.017	0.015	0.015	0.015	0.006	0.004	0.004	0.004	0.022	0.020	0.015	0.018	0.029	0.004	0.017
Cr	0.022	0.013	0.022	0.016	0.011	0.019	0.017	0.002	0.000	0.000	0.007	0.020	0.023	0.021	0.013	0.030	0.042	0.022
Fe ³⁺	0.100	0.068	0.084	0.046	0.000	0.025	0.024	0.059	0.050	0.000	0.042	0.067	0.057	0.023	0.052	0.040	0.049	0.035
Fe ²⁺	0.011	0.053	0.028	0.065	0.133	0.083	0.105	0.066	0.087	0.086	0.071	0.059	0.052	0.104	0.054	0.026	0.023	0.031
Mn	0.009	0.005	0.003	0.004	0.003	0.004	0.001	0.003	0.001	0.003	0.007	0.002	0.003	0.005	0.005	0.003	0.001	0.000
Ni	0.001	0.002	0.000	0.000	0.002	0.000	0.000	0.006	0.001	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000
Mg	0.842	0.885	0.837	0.828	0.918	0.865	0.865	0.774	0.756	0.910	0.862	0.808	0.825	0.845	0.869	0.911	0.914	0.953
Ca	0.900	0.832	0.903	0.915	0.803	0.912	0.886	0.915	0.932	0.908	0.930	0.912	0.918	0.852	0.903	0.913	0.875	0.896
Na	0.031	0.025	0.029	0.037	0.022	0.024	0.024	0.021	0.021	0.016	0.018	0.024	0.028	0.023	0.028	0.038	0.045	0.033
Total	4.000	4.003	3.999	3.999	3.992	3.999	3.999	3.999	4.000	3.988	3.998	4.000	3.999	4.001	3.998	4.001	3.999	4.000
Mg#	97.68	93.85	96.43	92.31	87.10	90.86	89.08	91.81	89.57	91.09	91.70	92.98	93.75	88.57	93.64	96.91	97.44	96.85
Cr#	17.67	9.22	17.25	17.68	13.41	25.85	20.86	1.22	0.00	0.00	9.93	14.55	19.83	15.44	15.20	57.14	58.33	60.27
Wo	51.34	47.02	51.07	50.61	43.32	49.05	47.73	52.14	52.52	47.71	49.92	51.29	51.13	47.30	49.43	49.38	48.31	47.66
En	48.03	50.01	47.33	45.79	49.53	46.50	46.59	44.11	42.58	47.78	46.28	45.40	45.98	46.91	47.59	49.25	50.42	50.68
Fs	0.64	2.98	1.60	3.60	7.16	4.45	5.68	3.75	4.90	4.51	3.80	3.31	2.89	5.79	2.98	1.38	1.28	1.65

Table 5 (continued).

Hole:		897D			897D		89	7D		897	'D			899B		899B	89	9B	89	9B
Core section:		16R-1			19R-5		201	2-3		236	-6			20R-4		21R-4	231	8-2	291	2-1
Interval (cm):		33-38			80-86		8-	13		82_	88			90-96		87_89	49-	-54	111-	-114
mervar (em).		55 50			00 00		0	15		02				70 70		02 07		54	111	114
Maior elements	C	M	N	C	М	N	C	С	С	С	M	X	C	С	M	C	С	M	C	C
SiO ₂	51.49	50.96	50.88	51.11	50.97	51.73	49.71	49.37	51.12	49.41	51.52	50.06	50.05	51.15	51.95	50.71	53.25	53.47	51.13	50.14
TiO ₂	0.25	0.26	0.29	0.53	0.55	0.59	0.42	0.54	0.48	0.35	0.58	0.54	0.55	0.59	0.48	0.11	0.02	0.00	0.46	0.20
Al_2O_3	5.75	5.15	5.78	5.42	4.63	3.30	6.40	6.20	5.53	8.15	3.93	5.93	5.82	4.24	3.33	5.10	3.68	2.98	5.33	4.51
Cr_2O_3	0.96	1.10	1.27	0.97	1.33	0.57	0.12	0.55	1.16	0.44	0.94	1.19	1.25	1.24	1.04	1.23	1.16	0.95	1.25	1.32
FeO	1.76	2.29	2.43	2.47	2.98	2.81	3.44	3.45	3.06	2.96	3.06	2.97	2.79	2.35	2.66	2.49	2.30	1.99	2.61	7.82
MnO	0.07	0.02	0.12	0.09	0.08	0.09	0.12	0.06	0.07	0.09	0.08	0.13	0.10	0.00	0.08	0.09	0.00	0.00	0.12	0.16
NIO	0.00	0.06	0.00	0.00	0.01	0.01	0.00	0.00	0.01	0.02	0.01	0.00	0.00	0.03	0.00	0.00	0.05	0.11	0.01	0.01
MgO	15.42	15.92	16.19	15.52	16.93	16.95	15.32	19.07	17.05	14.59	16.02	15.24	16.25	15.94	10.68	17.74	17.70	16.78	15.68	17.11
CaO	23.51	23.37	22.86	23.03	21.99	23.20	23.29	20.51	21.08	23.04	23.35	23.53	22.52	23.41	23.50	21.77	23.22	24.44	22.58	20.11
Na ₂ O	0.67	0.57	0.00	0.42	0.42	0.45	0.40	0.39	0.44	0.40	0.33	0.37	0.59	0.54	0.52	0.33	0.22	0.16	0.58	0.46
Total	99.88	99.69	100.48	100.17	99.90	99.75	99.23	100.13	100.01	99.46	99.83	99.95	99.93	99.48	100.24	99.57	101.60	100.86	99.76	101.83
Si	1.869	1.854	1.835	1.857	1.852	1.881	1.821	1.781	1.852	1.806	1.882	1.827	1.818	1.869	1.882	1.840	1.899	1.927	1.864	1.865
Al ^{IV}	0.131	0.146	0.165	0.143	0.148	0.119	0.179	0.219	0.148	0.194	0.118	0.173	0.182	0.131	0.118	0.160	0.101	0.073	0.136	0.135
Al^{VI}	0.114	0.075	0.081	0.089	0.050	0.023	0.097	0.045	0.088	0.157	0.051	0.082	0.067	0.051	0.024	0.058	0.054	0.054	0.093	0.063
Ti	0.007	0.007	0.008	0.014	0.015	0.016	0.012	0.015	0.013	0.010	0.016	0.015	0.015	0.016	0.013	0.003	0.001	0.000	0.013	0.006
Cr	0.027	0.032	0.036	0.028	0.038	0.016	0.004	0.016	0.033	0.013	0.027	0.034	0.036	0.036	0.030	0.035	0.033	0.027	0.036	0.039
Fe ³⁺	0.024	0.065	0.073	0.027	0.059	0.079	0.084	0.104	0.031	0.035	0.031	0.054	0.085	0.051	0.073	0.076	0.029	0.003	0.022	0.056
Fe ²⁺	0.029	0.005	0.000	0.048	0.032	0.007	0.021	0.000	0.062	0.055	0.062	0.037	0.000	0.021	0.007	0.000	0.040	0.057	0.057	0.046
Mn	0.002	0.000	0.004	0.003	0.003	0.003	0.004	0.002	0.002	0.003	0.002	0.004	0.003	0.000	0.003	0.003	0.000	0.000	0.004	0.005
Ni	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.001	0.000	0.000	0.001	0.003	0.000	0.000
Mg	0.834	0.863	0.870	0.841	0.917	0.919	0.836	1.025	0.921	0.795	0.872	0.829	0.880	0.868	0.901	0.960	0.941	0.901	0.852	0.949
Ca	0.914	0.911	0.883	0.920	0.856	0.906	0.914	0.793	0.818	0.902	0.914	0.920	0.876	0.916	0.913	0.846	0.887	0.944	0.882	0.801
Na	0.047	0.040	0.046	0.030	0.030	0.031	0.028	0.027	0.031	0.029	0.023	0.026	0.042	0.038	0.036	0.023	0.015	0.011	0.041	0.033
Total	3.998	4.000	4.001	4.000	4.000	4.000	4.000	4.027	3.999	4.000	3.998	4.001	4.004	3.998	4.000	4.004	4.001	4.000	4.000	3.998
Mg#	96.42	99.42	99.54	94.28	96.32	98.92	97.10	99.81	93.50	93.20	93.16	95.29	99.66	97.64	98.90	99.69	95.92	94.05	93.32	94.90
Cr#	24.00	30.05	30.51	24.35	36.89	25.20	3.17	12.65	27.73	7.76	31.21	25.86	58.22	52.31	81.56	56.09	34.32	5.04	20.95	50.68
Wo	51.43	51.20	50.37	50.86	47.44	49.48	51.59	43.60	45.45	51.49	49.44	51.51	49.91	50.77	50.12	46.86	47.50	49.62	49.23	44.61
En	46.91	48.52	49.63	46.48	50.81	50.14	47.20	56.40	51.14	45.37	47.19	46.42	50.10	48.08	49.48	53.14	50.37	47.39	47.56	52.81
Fs	1.66	0.28	0.00	2.66	1.75	0.37	1.21	0.00	3.42	3.14	3.37	2.07	0.00	1.15	0.40	0.00	2.13	2.99	3.21	2.58

Notes: Formula unit calculated on the basis of 6 oxygens and 4 cations. $Mg\# = 100 \times Mg/(Mg + Fe^{2+} + Mn)$, $Cr\# = 200 \times Cr/(Cr + Al - Na)$ after Glücklich-Herbas (1992). C = crystal core, M = crystal margin, N = neoblast.



Figure 13. Ti/Cr# correlation diagram for clinopyroxene. The shaded area corresponds to the Galicia Margin peridotite from Leg 103 (Boillot, Winterer, Meyer, et al., 1987). Cr# = $200 \times Cr/(Cr + Al - Na)$, and the mean of primitive lherzolite is after Glücklich-Herbas (1992).



Figure 14. Na/Cr correlation diagram for clinopyroxenes: suboceanic and subcontinental fields are from Kornprobst et al. (1981). The light shaded area corresponds to the Galicia Margin peridotite from Leg 103 (Boillot, Winterer, Meyer, et al., 1987). The mean primitive lherzolite is after Glücklich-Herbas (1992).



Figure 15. Ti/Na correlation diagram for clinopyroxenes: oceanic field after Seyler and Bonatti (1994). The mean primitive lherzolite is after Glücklich-Herbas (1992).

Table 6. Selected analyses of plagioclase.

Hole: Core, section: Interval (cm);	897C 64R-5 77–81			897C 66R-4 57-61			7C R-4	897 67F	7C R-3		897C 67R-3	899B 20R-4		
Intervar (em).	C //-	N	C	M	N	C	-70 M		N	C	M	М	C	C
$\begin{array}{ll} \mbox{Major oxides} & \neg \\ \mbox{SiO}_2 & \neg \\ \mbox{TiO}_2 & \neg \\ \mbox{Al}_2 \mbox{O}_3 & \neg \\ \mbox{Fe}_2 \mbox{O}_3 & \neg \\ \mbox{MgO} & \neg \\ \mbox{CaO} & \neg \\ \mbox{CaO} & \neg \\ \mbox{Na}_2 \mbox{O} & \neg \\ \mbox{K}_2 \mbox{O} & \neg \\ \mbox{Total} & \neg \\ \end{array}$	45.01	44.78	45.24	44.85	44.44	44.30	44.40	44.37	44.44	45.36	44.83	44.96	47.46	47.51
	0.00	0.01	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.02	0.03	0.02	0.02
	34.94	34.43	34.58	34.80	35.25	35.18	35.53	35.06	35.09	34.57	34.81	34.18	32.36	32.32
	0.12	0.19	0.15	0.21	0.51	0.22	0.16	0.13	0.13	0.19	0.01	0.11	0.13	0.11
	0.02	0.03	0.00	0.02	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.01	0.02	0.01
	18.87	18.81	18.61	19.23	19.23	19.14	19.63	18.73	18.75	18.66	19.05	19.09	16.07	15.79
	0.96	1.20	0.88	0.65	0.60	0.54	0.42	1.02	0.77	1.12	0.81	1.26	2.57	2.59
	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.0	40.00
	99.91	99.45	99.47	99.76	100.04	99.39	100.20	99.31	99.19	99.89	99.53	99.64	98.67	98.34
Or	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.00
Ab	8.40	10.40	7.90	5.70	5.40	4.80	3.70	8.99	6.90	9.80	7.10	10.60	22.40	22.90
An	91.60	89.60	92.10	94.30	94.60	95.10	96.30	91.01	93.10	90.20	92.90	89.40	77.40	77.10

Notes: Formula unit calculated on the basis of 8 oxygens. C = crystal core, M = crystal margin, N = neoblast. Or, Ar, Ab = molecular proportion of orthoclase, albite, and anothorite.

Table 7. Summary of events that affected the peridotites recovered during Leg 149.

Stage 1: Rise of asthenospheric mantle during stretching of continental lithosphere •High-temperature plastic deformation of mantle rocks •Partial melting •Syntectonic alkali melt impregnation that ended at about 930°C and <1 GPa pressure

Stage 2: Lithospheric accretion

•Static reequilibration of peridotites at about 780°C and <1 GPa pressure •Local mylonitization at about 735°C •Hydrothermal alteration and low-temperature deformation



Figure 16. Photomicrograph of the pervasive impregnation of plagioclase in plagioclase lherzolite (Sample 149-897D-19R-5, 80-86 cm), now completely serpentinized; shown between crossed polars. Scale bar is 5 mm.