Subduction initiation, recycling of lower continental crust, and intracrustal emplacement of subcontinental lithospheric mantle in the westernmost Mediterranean

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Abstract. The geochemistry of high-Mg pyroxenite dykes in the Ronda peridotite (S. Spain) shows that the subcontinental lithospheric mantle in the westernmost Mediterranean evolved above a subducting slab shortly before its intracrustal emplacement. We present new Sr-Nd-Pb isotopic data of crustal rocks in the western Betics that might account for the isotopic signature of Ronda high-Mg pyroxenite. We show that lower crustal garnet granulites from the Alpujarride complex, which overly the peridotites, account for the characteristic relatively high ^{207}Pb-$^{208}Pb/^{204}Pb$ and low $^{206}Pb/^{204}Pb$ subduction component of Ronda high-Mg pyroxenite. The involvement of fluids/melts derived from lower crust in the genesis of high-Mg Ronda pyroxenite indicates that the peridotites in the westernmost Mediterranean were placed in a forearc position above a newly initiated subduction zone, followed by underthrusting of the lower crust. This possibly occurred during the late Oligocene due to the inversion of an extensional back-arc continental basin. As subduction progressed, the thinned subcontinental mantle was emplaced over the foreland following its collision with the trench.

INTRODUCTION

The mechanisms of crustal emplacement of subcontinental lithospheric mantle (SCLM) peridotites in orogens are still poorly known. Their emplacement is often attributed to extension in rifted passive margins or continental back-arc basins, accretion in subduction zones, or a combination of these processes (Bodinier and Godard, 2007, and references therein). The westernmost Mediterranean Alpine orogenic belt hosts one of the largest outcrops of diamond facies, SCLM orogenic peridotites in the world (Fig. 1); unveiling the mechanisms of emplacement of these peridotite massifs into the crust may provide important clues on the processes involved in the destruction of SCLM.

The western Mediterranean underwent a complex Alpine evolution of subduction initiation, slab fragmentation and rollback within a context of slow convergence between Africa and Europe that pervasively affected the so-called, allochthonous ALKAPECA lithospheric domains (Alboran, Kabylides, Peloritani, and Calabria domains) (e.g. Faccenna *et al.*, 2004). In the westernmost Mediterranean, this evolution generated the Gibraltar tight arc, which is bounded by the Betic, Rif and Tell belts that surround the Alboran and Algero-Balearic basins (Fig. 1) (Royden, 1993; Lonergan & White, 1997; Platt *et al.*, 2013). SCLM orogenic peridotites are particularly well exposed in the Betics (Ronda peridotites) (Van der Wal & Vissers, 1993; Lenoir *et al.*, 2001) where they crop out at the basal units of the western Alpujarride complex (Fig. 1).

During Late Oligocene- Early Miocene different domains formed in the region between Iberia and Africa, including thinned continental crust and a Flysh Trough turbiditic deposits likely floored by oceanic crust (Durand-Delga *et al.*, 2000). At this time, the Ronda peridotite (Fig.1) likely constituted the SCLM of the Alboran domain, which was undergoing strong thinning and melting (Lenoir *et al.*, 2001; Garrido *et al.*, 2011) coevally with Early Miocene extension in the overlying Alpujárride-Maláguide stacked crust (Platt *et al.*, 2013).

The refractory composition, the subduction-related trace element affinity, and the radiogenic $^{87}Sr/^{86}Sr$ and unradiogenic $^{143}Nd/^{144}Nd$ isotopic ratios of late, intrusive high-Mg mantle pyroxenite dykes in the Ronda peridotite support they were derived from a depleted mantle source contaminated by a crustal component (Marchesi et al., 2012). To constrain the source of the isotopic crustal component of Ronda high-Mg pyroxenites and its implications for the mechanisms of emplacement of SCLM in the Betic-Rif crust, we present new Sr-Nd-Pb data of the western Alpujarride crustal units that might have underthrusted the Alboran domain before the Miocene emplacement of peridotite. Selected samples include pre-Miocene sediments from the Flysch Trough units, already suggested to account for the crustal isotopic signature of high-Mg pyroxenites (Marchesi et al., 2012), and metasedimentary rocks from the western Alpujarride complex (Fig. 1), specifically the Blanca and

Jubrique units that underlie and overlie the Ronda peridotite, respectively.

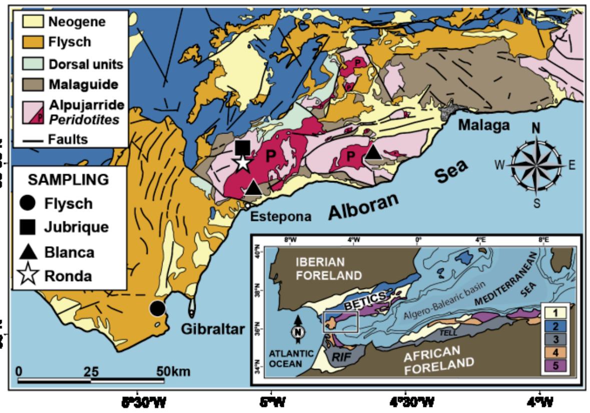

Figure 1. Geological map of the westernmost Betic belt showing sample location. Inset shows the location of the Betic-Rif orogenic belt in the westernmost Mediterranean: 1- Neogene sediments; 2- South-Iberian domain; 3- Maghrebian domain; 4- Flysch Trough domain; 5- Alboran domain.

RESULTS AND DISCUSSION

Origin of the subducted detrital crustal component in Ronda high-Mg pyroxenites

The age corrected (25 Ma) $^{87}Sr/^{86}Sr$ (0.70794-0.71559) and $^{206}Pb/^{204}Pb$ (18.740-19.141) of Flysch sediments are too low and high, respectively, to explain the composition of high-Mg pyroxenites (Fig. 2). Crustal rocks from Blanca and Jubrique units have similar $^{143}Nd/^{144}Nd$ (0.51195-0.51216) and more radiogenic $^{87}Sr/^{86}Sr$ (0.71698-0.75035) than the Flysch (Fig. 2A), hence are suitable sources in terms of Sr-Nd isotopes for the subduction component of pyroxenites. However, only the high grade granulites from Jubrique unit have low $^{206}Pb/^{204}Pb$ (18.554-18.688) and high $^{208}Pb/^{204}Pb$ (38.940-39.392) that can account for the Pb isotopic compositions of Ronda high-Mg pyroxenites (Fig. 2B and 2C). In particular, modeling indicates that a contribution of up to 15% of fluids/melts liberated from granulites to an orogenic mantle peridotite source can produce isotopic values within the range of high-Mg pyroxenites (Fig. 2). Thus, the parental melts of the latter were most likely produced by melting of subcontinental lithospheric mantle contaminated by crustal fluids/melts released from rocks similar to Jubrique high-grade granulites.

Implications for the emplacement of SCLM in the westernmost Mediterranean

In the Oligocene, SW-W directed rollback of the westernmost branch of the neo-Tethys between the converging African and Iberian plates induced rapid extensional collapse of the Alpujarride-Malaguide orogenic wedge and formed the basement of a continental back-arc Alboran domain (Booth-Rea et al., 2007; Garrido et al., 2011) (Fig. 3A, B).

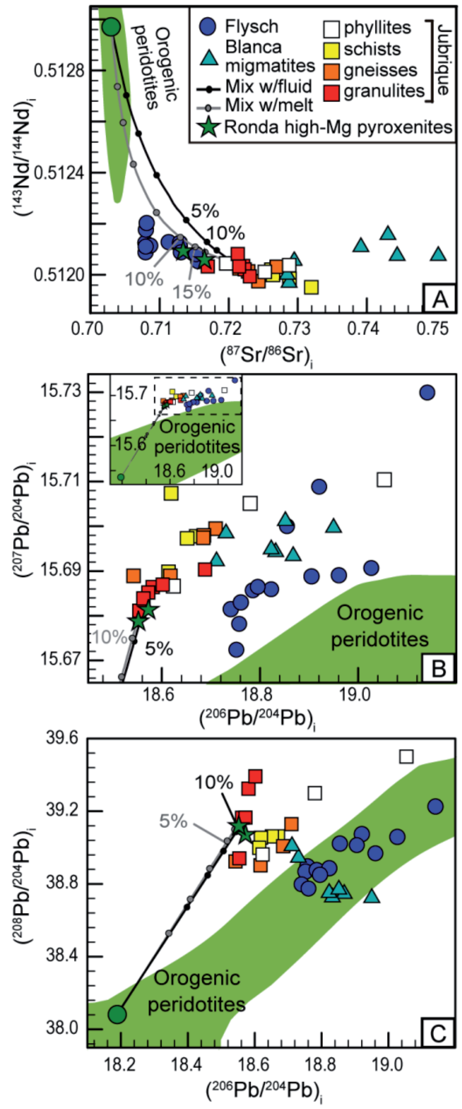

Figure 2. Age-corrected (25 Ma) Sr-Nd (*A*) and Pb (*B*, *C*) radiogenic isotope ratios of Flysch sediments (dark blue circles) and crustal rocks of the Blanca unit (light blue triangles) and Jubrique unit (white, yellow, orange and red squares for low grade phyllites, medium grade schists and gneisses, and high grade granulites, respectively). Isotopic composition of orogenic peridotites (green field) and Ronda high-Mg pyroxenites (green stars) (Marchesi *et al.*, 2012) are also shown. Solid lines model the mixing between a mantle source (dark green circle) and a fluid (black line) or melt (grey line) released from the Jubrique granulites. The modelled mantle source has the average isotopic composition of orogenic peridotites (Bodinier & Godard, 2007) and Sr-Nd-Pb concentrations equal to the average of around 40 Ronda massif peridotites (Lenoir *et al.*, 2001). Fluid/melt

partition coefficients of metasediments are from (Johnson & Plank, 2000). Labels indicate the percentages of fluid/melt contribution. Inset in (B) defines the enlarged area in the $^{207\text{-}206}Pb/^{204}Pb$ space (box).

Contractive tectonic inversion of this back-arc domain initiated in the late Oligocene-early Miocene (Fig. 3C) and lead to crustal thickening of the Alboran domain wedge (Booth-Rea *et al.*, 2007; Platt *et al.*, 2013). The presence of small volumes of subduction-related high-Mg pyroxenites that cut late Oligocene extensional mantle structures in Ronda peridotite, suggests that the thinned SCLM was placed in a forearc position above a newly initiated subduction zone. This implies overthrusting at or close to the locus of back-arc rifting, possibly due to inversion of the extensional basin (Fig. 3C) during the collision with the Maghrebian passive margin. Hidas et al. (2013) proposed that inversion of the back-arc basin in the late Oligocene-early Miocene resulted in km-scale folding and shearing of the attenuated Ronda SCLM peridotite, followed by subduction initiation that ended in the earliest Miocene emplacement of the massif into the Alboran wedge. Folding of SCLM (Hidas et al., 2013) may explain how the lower crustal units, currently overlying the Ronda massif (i.e., Jubrique granulites), could underthrusted the peridotites (Fig. 3C).

In this context, the isotopic signature of Ronda high-Mg pyroxenite can be accounted by flux melting of hot, attenuated back-arc mantle induced by fluid/melts from the underthrusted Alpujarride lower crust (Fig. 3C, stage C1). As subduction progressed in the westernmost Mediterranean, the thinned SCLM could be emplaced over the foreland, following its collision with the trench (Fig. 3C, stage C2). Final obduction resulted in deposition of a turbiditic and olistostromal Flysch, within a flexural trough created ahead of the advancing nappe. In the early to late Miocene, this orogenic wedge migrated westwards driven by slab rollback and collided laterally with the Maghrebian and South Iberian paleomargins, leading to the creation of the Alboran sea basin and the Gibraltar arc.

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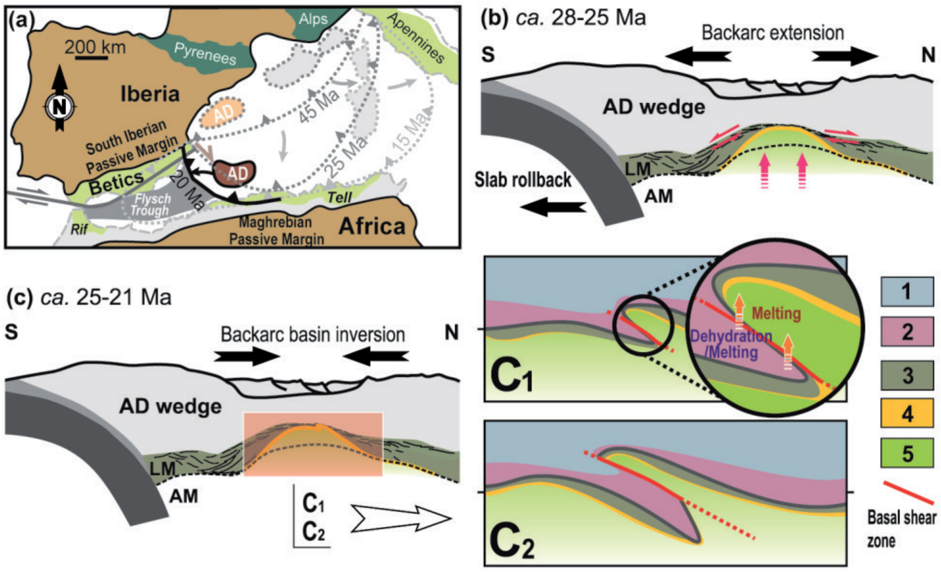

Figure 3. A: Geodynamic reconstruction showing the tectonic scenario proposed for the westernmost Mediterranean during the Oligocene-early Miocene. AD: Alboran domain. B: north–south cross-section for the late Oligocene back-arc extension referring to partial melting at the base of the lithosphere induced by asthenospheric upwelling. AM: asthenospheric mantle; LM: lithospheric mantle. C: Proposed scenario in a north–south cross-section for the late Oligocene–early Miocene back-arc basin inversion that led to km-scale folding, shown in detail in C1 and C2 (area outlined). C1: Subduction initiation of the lower crust followed by dehydration/melting of the crustal slab, and subsequent melting of the contaminated subcontinental mantle. C2: emplacement of the subcontinental mantle lithosphere into the crust. 1-2- Jubrique metapelites with increasing metamorphic grade with depth; 3-4-5 Ronda structural domains (see Lenoir et al. 2001 for more information): 3- Ronda garnet-spinel mylonite and tectonite; 4- Ronda recrystallization front; 5- Ronda granular spinel peridotite.