Trace-element geochemistry of transform-fault serpentinite in high-pressure subduction mélanges (eastern Cuba): implications for subduction initiation


*Departamento de Mineralogía y Petrología, Universidad de Granada, Granada, Spain; †Instituto Andaluz de Ciencias de la Tierra, CSIC-Universidad de Granada, Granada, Spain; ‡Departamento de Mineralogía, Petrología i Geologia Aplicada, Universitat de Barcelona, Barcelona, Spain; §Department of Earth and Planetary Sciences, American Museum of Natural History, New York, NY, USA; ‡Departamento de Geociencias, Universidad de los Andes, Bogotá, Colombia; Instituto de Geología y Paleontología, San Miguel del Padrón, Cuba

ABSTRACT

The Sierra del Convento and La Corea mélanges (eastern Cuba) are vestiges of a Cretaceous subduction channel in the Caribbean realm. Both mélanges contain blocks of oceanic crust and serpentinite subducted to high pressure within a serpentinite matrix. The bulk composition of serpentinite indicates spinel-harzburgite and -herzolite protoliths. The samples preserve fertile protolith signatures that suggest low melting degrees. High concentration of immobile elements Zr, Th, Nb, and REE contents (from ~0.1 to ~2 CI-chondrite) point to early melt–rock interaction processes before serpentinization took place. Major- and trace-element compositions suggest an oceanic fracture-zone–transform-fault setting. A mild negative Eu anomaly in most samples indicates low-temperature fluid–rock interaction as a likely consequence of seawater infiltration during oceanic serpentinitization. A second, more important, serpentinization stage is related to enrichment in U, Pb, Cs, Ba, and Sr due to the infiltration of slab-derived fluids. The mineral assemblages are mainly formed by antigorite, lizardite, and chlorite, with local minor talc, tremolite, anthophyllite, dolomite, brucite, and relict orthopyroxene. The local presence of anthophyllite and the replacements of lizardite by antigorite indicate a metamorphic evolution from the cooling of peridotite/serpentinite at the oceanic context to mild heating and compression in a subduction setting. We propose that serpentinites formed at an oceanic transform-fault setting that was the locus of subduction initiation of the Proto-Caribbean basin below the Caribbean plate during early Cretaceous times. Onset of subduction at the fracture zone allowed the preservation of abyssal transform-fault serpentinites at the upper plate, whereas limited downward drag during mature subduction placed the rocks in the subduction channel where they tectonically mixed with the upward-migrating accreted block of the subducted Proto-Caribbean oceanic crust. Hence, we suggest that relatively fertile serpentinites of high-pressure mélanges were witness to the onset of subduction at an oceanic transform-fault setting.

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Introduction

The incorporation of up to 15–16 wt.% H₂O into metaultramafic rocks during the serpentinization of lithospheric mantle (e.g. Vils et al. 2008) controls much of the geochemical and geophysical characteristics of the oceanic lithosphere (e.g. Hacker et al. 2003; Hattori and Guillot 2007). This in turn affects the global geochemical cycle of lithosphere creation and consumption (Ulmer and Trommsdorff 1995; Tatsumi 2005). Serpentinized ultramafic rocks occur in a variety of geodynamic settings, including active plate margins, such as mid-ocean ridges, oceanic abyssal fracture zones, mantle zones above subducting plates, fore-arc and back-arc basins, and passive continental margins (ocean–continent transition; OCT). The identification of the geodynamic setting of the ultramafic protolith of exhumed serpentinite bodies is, however, challenging (e.g. Deschamps et al. 2013; Martin et al. 2016).

At (or near) the seafloor, abyssal serpentinites occur at slow-spreading mid-ocean ridges and associated transform-faults (Kerrick 2002) as a result of the exhumation of upper mantle peridotites, which are hydrated after interaction with downwelling seawater (e.g. Cannat et al. 2010; Kodolányi et al. 2012) and/or by hot fluids (~350°C) released from ocean-ridge

CONTACT

J. Cárdenas-Párraga, jcardenas_1@ugr.es
Departamento Mineralogía y Petrología Facultad de Ciencias Avda, Fuentenueva, s/n
Universidad de Granada, Granada, 18002 Spain

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hydrothermal activity (e.g. Früh-Green et al. 2003). At transform-faults, serpentinization reaches great depths below the oceanic Moho (Peacock 1990), creating zones of lithospheric weakness that may be favourable for subduction initiation (Müller and Phillips 1991; Stern 2004; Gerya 2011).

In the subduction scenario, the infiltration of seawater into the subducting oceanic lithosphere at trenches, favoured by normal faults developed during plate bending, causes serpentinization of the underlying oceanic lithospheric mantle (e.g. Ranero et al. 2003). Furthermore, tectonic extension in the fore-arc and the associated infiltration of seawater, in addition to the release of fluids after dehydration of the subducted crust and mantle, are responsible for the serpentinization of the upper-plate fore-arc mantle (Peacock 1993; O’Hanley 1996). Continued subduction during tens of millions of years releases considerable amounts of fluid to the upper-plate mantle as a result of dehydration of subducted serpentinite, hydrated mafic crust, green schist, blueschist, eclogite, and sediments, promoting large-scale serpentinization of the mantle at the slab–mantle interface at moderate to low temperatures (<700°C, <100 km depth) (Poli and Schmidt 2002; Stern 2002; Hacker 2008; Schmidt and Poli 2013). The larger extent of serpentinization across-strike in the upper-plate mantle occurs at shallow depth and low temperature (<50 km; <400°C; Hyndman and Peacock 2003; Savov et al. 2007), in agreement with observed fore-arc serpentinite-mud volcanoes. Clasts of blueschist/green schist rocks contained in serpentinite muds demonstrate that these diapiric structures are rooted to 20 km in the subducted oceanic crust (Maekawa et al. 1993; Yamamoto et al. 1995; Savov et al. 2005; Fryer 2012). The roots of serpentinite diapirs may, however, be located at deeper depths within the upper-plate serpentinitized mantle (Marschall and Schumacher 2012), as proposed for fossil subduction complexes such as the Franciscan (North America; e.g. Ernst 2016), Rio San Juan (the Dominican Republic; Krebs et al. 2008, 2011), and the Motagua (Guatemala; Tsujimori et al. 2006) mélanges that extracted blueschists and eclogites. This scenario is consistent with the development of several tens of kilometres long ‘soft’ serpentinitic subduction channel in the slab–mantle interface that extends down to ca. 100 km depth (Guillot et al. 2001; Gerya et al. 2002). The extent of this slab–mantle interface depends on the spatial distribution of the maximum stability limit of antigorite (Ulmer and Trommsdorff 1995; Wunder and Schreyer 1997; Schmidt and Poli 1998; Bromiley and Pawley 2003). In the serpentinite channel, a low-viscosity/density mélange rises buoyantly along the subduction channel–mantle interface as a self-organized circulating system, and/or as sub-vertically diapirs through the mantle wedge to the crust of the upper plate (Guillot et al. 2015; Li et al. 2015).

As a result of this complex evolving scenario, serpentinites exhumed in suture zones worldwide cover different geodynamic settings including mid-ocean ridges, abyssal transform-faults, fore-archs, OCTs, and passive margins (e.g. Zheng et al. 2005; Hattori and Guillot 2007; Deschamps et al. 2013; Barnes et al. 2014; Guillot et al. 2015). Although the original lithologic associations can be partially preserved (e.g. in the western Alps, Zermatt–Saas, Monviso, and Corsican ophiolites; Angiboust et al. 2009, 2012; Beltrando et al. 2014), the primary contacts of serpentinites and associated with HP rocks (i.e. the initial position with respect to the down-going and upper plates) are generally missing. A more chaotic scenario emerges in exhumed subduction mélanges, varying in diversity among occurrences. Although tectonic-sedimentary processes at the fore-arc involving syn-subduction exhumation of serpentinite and HP slices/blocks, erosion, sedimentation, and re-subduction may explain mélanges with blocks of different pressure-temperature (P-T) conditions and age, serpentinite mélange with blocks recording the same P-T range and age are better explained by tectonic processes at the subduction channel (Wakabayashi 2015).

As an example, serpentinites of varied origins occur in close spatial relationship together with tectonic blocks of subducted crust metamorphosed at various P-T conditions and ages in the northern boundary of the Caribbean plate (García-Casco et al. 2002; Harlow et al. 2004; García-Casco et al. 2006, 2008a; Tsujimori et al. 2006; Hattori and Guillot 2007; Krebs et al. 2008, 2011; Brueckner et al. 2009; Lázaro et al. 2009; Blanco-Quintero et al. 2010; Saumur et al. 2010; Deschamps et al. 2011, 2012; Escuder-Viruete et al. 2011, 2013a, 2013b; Escuder-Viruete and Pérez-Estaún 2013c). Except for rare cases (e.g. western Cuba; García-Casco et al. 2006), sedimentary matrix has not been described in these mélanges, suggesting tectonic origin in the subduction channel. Furthermore, they contain jadeite blocks (also formed at various P-T and ages) documenting fluid fluxes and fluid–rock interactions at the subduction environment (Harlow 1994; García-Casco et al. 2009; Harlow et al. 2011; Cárdenas-Párraga et al. 2012; Schertl et al. 2012; Flores et al. 2013; Hertwig et al. 2016). Subduction initiation in the Caribbean has been explained by forced convergence at the so-called inter-American transform-fault zone at about 135 Ma (Pindell et al. 2012; Boschman et al. 2014). In this contribution, we test this hypothesis assessing the origin of serpentinite rocks and the serpentinization processes in the Sierra del Convento and La Corea serpentinite
mélanges (eastern Cuba), which formed early in the subduction history of the region. Using mineral assemblages, textural relations, and major and trace-element whole-rock compositions, we discuss the geologic setting of serpentinization and of mantle protoliths in an effort to decipher the implications of subducted serpentine for the geodynamic evolution of subduction zones.

**Geological setting**

The Greater Antillean Arc formed by the convergence of the North American and the Farallon/Caribbean plates during the Lower Cretaceous to Tertiary (Burke 1988). After the Jurassic fragmentation of Pangaea and the opening of the Proto-Caribbean oceanic basin, subduction of the latter underneath the Caribbean plate (of Pacific–Farallon plate-origin) created the Caribbean volcanic arc (Pindell et al. 2006; Pindell and Kennan 2009; Boschman et al. 2014; and references therein). Subduction initiation has been dated at ca. 135 Ma in the leading northern edge of the Caribbean plate (Rojas-Agramonte et al. 2011, 2016; Lázaro et al. 2016; see also Torró et al. 2016, 2017, for subduction initiation basaltic magmatism in the Dominican Republic), likely in a transform-fault plate boundary termed the inter-American transform (Pindell et al. 2012; Boschman et al. 2014). This event does not appear to be related to the mid-late Cretaceous plume-induced subduction scenario proposed for the western and southern edges of the Caribbean plate (Gerya et al. 2015; Whattam and Stern 2015). In the northern leading edge, the intra-oceanic Caribbean arc system was tectonically emplaced by northward collision with the Maya block, the Caribeana terrane, and the Bahamas platform during the latest Cretaceous–Tertiary time (Iturralde-Vinent et al. 2008; García-Casco et al. 2008b; Van Hinsbergen et al. 2009; Solari et al. 2013). This collision event is recorded in obducted ophiolite bodies and serpentine mélanges containing high-pressure blocks from Guatemala through Cuba to Hispaniola (Figure 1(a)).

In eastern Cuba, the orogenic belt includes oceanic units of Cretaceous volcanic arcs, ophiolites, and closely associated serpentine-matrix subduction mélanges (Figure 1(b)). All these units constitute tectonic nappes with a general vergence towards the NE and accreted in the late Cretaceous–earliest Palaeocene (Cobiella et al. 1984; Nuñez Cambra et al. 2004; Iturralde-Vinent et al. 2006). The ophiolite belt comprises two allochthonous massifs: the Mayari–Cristal massif to the west, with a mantle section over 5 km thick, and the Moa–Baracoa massif to the east, with about 2.2 km of peridotite section (Proenza et al. 1999; Marchesí et al. 2006). Harzburgitic tectonites are dominant, with subordinate dunites, chromitite bodies, banded gabbros, and discordant microgabbro and pyroxenite, troctolite, wehrlite, and diabase bodies. Basaltic rocks with tholeiitic to boninitic signature and radiolarites tectonically underlie the mantle-plutonic section (Kerr et al. 1999; Iturralde-Vinent et al. 2006; Marchesí et al. 2006, 2007; Proenza et al. 2006). Although Dilek and Furnes (2011) have classified Cuban ophiolites as plume-related, eastern Cuba ophiolites have supra-subduction geochemical signatures (Proenza et al. 1999, 2006; Gervilla et al. 2005; Marchesí et al. 2006, 2007). Recently, Lázaro et al. (2013) and Lázaro et al. (2015) identified the Guira de Jauco amphibolite complex (650–665°C and 8.5–8.7 kbar) as the metamorphic sole of the Moa–Baracoa ophiolite sheet and related it to the inception of a new SW-dipping subduction of Late Cretaceous age (85 Ma) in the back-arc of the Cretaceous Caribbean arc. The ophiolitic massifs were tectonically emplaced over the tholeiitic to calc-alkaline Aptian–Campanian volcanic arc units during the late Campanian–Maastrichtian times (Iturralde-Vinent et al. 2006 and references therein) shortly after the volcanic arc-related El Purial complex subducted to greenschist to blueschist facies (Boiteau et al. 1972; Somin and Millán 1981; Cobiella et al. 1984) during the latest Cretaceous (75 ± 5 Ma; Somin et al. 1992; Iturralde-Vinent et al. 2006).

Zircon from an ophiolitic gabbroic body from Cayo Grande (Moa–Baracoa ophiolitic massif) yielded a 206Pb/238U age of ca. 124 Ma (Rojas-Agramonte et al. 2016). Similar early Cretaceous ages characterize low-pressure serpentine-matrix mélanges containing blocks of fore-arc metabasalt/metamicrogabbro whose basaltic protoliths formed at >123 Ma (Lázaro et al. 2016). The correlated Gaspar–Hernández serpentinite mélangé in the Dominican Republic contains blocks of similar (meta)microgabbrro crystallized at 136 Ma from Mid-Ocean-Ridge Basalt (MORB) mags formed in the proto-Caribbean oceanic lithosphere (Escuder-Viruete et al. 2011) or fore-arc basalts (Lázaro et al. 2016) formed during subduction initiation. These ages predate ages of the exhumed products of subduction recorded in high-pressure subduction mélanges, as described next.

**Subduction mélanges**

Two serpentinitic mélanges bearing high-P blocks, namely the Sierra del Convento and La Corea mélanges (Millán 1996b; Figure 1(b)), record early to late stages of subduction of the Proto-Caribbean below the Caribbean plate (García-Casco et al. 2008a; Blanco-Quintero et al. 2010, 2011d). Both mélanges share similar geological, petrological, and geochemical characteristics. The Sierra del Convento mélangé occurs below a body of partly hydrated
ultramafic rocks lacking high-P tectonic blocks, and above the metamorphosed Cretaceous volcanic arc Purial complex (Iturralde-Vinent 1998; García-Casco et al. 2008a). The distribution of field exposures of the mélange allows defining four sub-mélanges: El Paleñque, Posango, Sabanalamar, and Macambo, respectively, to the north, east, west, and south of the hydrated ultramafic body (Figure 2a). The La Corea mélange is completely surrounded by ultramafic rocks of the Mayarí–Cristal ophiolitic massif and its corresponding footwall rocks are not exposed (Figure 2b). The tectonic relations suggest that the mélange is overridden by the ophiolitic massif, and that both override the Cretaceous volcanic arc Santo Domingo unit.

Chaotic tectonic blocks of subducted material include MORB-derived garnet-epidote amphibolite and lower-grade metavolcanic and metasedimentary blueschist- and greenschist-facies rocks derived from abyssal and volcanic-arc-related settings (Millan 1996b). The earliest product of subduction is garnet-epidote amphibolite that reached supersolidus temperature at mantle depths (700–750°C, 15 kbar, 50 km depth), as documented by anatectic leucocratic segregations and veins of trondhjemitic composition that crystallized at similar depths (García-Casco 2007; Lázaro and García-Casco 2008; Lázaro et al. 2011; Blanco-Quintero et al. 2011b, 2011c, 2011e). SHRIMP U–Pb ages of magmatic zircons from anatectic rocks range from 113 to 105 Ma (Lázaro et al. 2009; Blanco-Quintero et al. 2011e). Blocks of jadeite occur at the Macambo region of the Sierra del Convento mélange (García-Casco et al. 2009; Cárdenas-Párraga et al. 2010, 2012). The rock crystallized
from Al₂O₃-Na₂O-SiO₂-rich fluids in open veins at high temperature (550–625°C, the highest temperature of jadeite reported so far; see review in Harlow et al. 2015). SHRIMP ²⁰⁶Pb/²³⁸U ages of hydrothermal zircon yielded 107–108 Ma (Cárdenas-Párraga et al. 2012), indicating a close temporal/spatial relation between hydrothermal jadeite forming fluids and slab-derived hydrous trondhjemitic melts. All these early subduction-related rocks show retrograde blueschist facies overprint, documenting counterclockwise P-T-t paths. The metamorphic/magmatic/hydrothermal evolution indicates the subduction of young hot oceanic lithosphere (close to a mid-ocean ridge) at ca. 120 Ma, accretion to the upper plate (near-isobaric cooling stage at 50 km depth dated at 115–105 Ma), and slow syn-subduction exhumation to ca. 25 km depth within the evolving serpentinitic channel until ca. 75 Ma (Lázaro et al. 2009; Blanco-Quintero et al. 2010, 2011a, 2011e), when subduction of the Purial volcanic arc complex accreted blocks of greenschist and blueschist to the mélange. At 70 Ma, arc-Caribeana terrane–Bahamas margin collision triggered exhumation to the surface, as documented by the Maastrichtian–Danian olistostromic synorogenic sediments of Micara and La Picota formations containing detrital ophiolitic material (Cobiella et al. 1984; Iturralde-Vinent et al. 2008).

**Serpentinites**

Serpentinites from the Sierra del Convento mélange show similar textural (see below) and field relations. Fourteen fresh serpentinite samples were selected from different outcrops at the Macambo sub-mélange (Figure 2(a)). The samples occur as plastically or brittly deformed bodies (massive to foliated fabrics; Figures 3(a,b)), surrounded by the sheared serpentinite. At the hand-sample scale, they present green-coloured veins in a dark-green matrix, and inherited deformation from peridotite protoliths, which are locally defined by elongated (retrograde) Cr-bearing magnetite/ferrian chrome grains (Figures 3(c)). Other primary minerals are lacking, and only bastite pseudomorphs, after orthopyroxene, as an irregular occurrence of green pseudomorphosed porphyroblasts/clasts (≤8 mm in size), were observed.

Blanco-Quintero et al. (2011d) identified two types of serpentinite of harzburgitic protolith in the La Corea mélange (Figure 2(b)) based on petrographic and major-element composition: i) large blocks of massive/sheared antigorite serpentinite interpreted as deep fragments of the channel developed after mantle-wedge peridotite and ii) lizardite–antigorite serpentinite of abyssal origin accreted from the incoming plate at shallow depths. Both types occur intermixed at the dm scale and display massive to foliated textures in the field, with massive serpentinite blocks and other lithologies included as boudins in a strongly sheared serpentinite matrix (Figures 3(d)); Blanco-Quintero et al. 2011d). The lizardite–antigorite type occurs within foliated varieties. In this article, the published major-element and platinum-group element (PGE) data of Blanco-Quintero et al. (2011d) are considered in addition to new trace-element data of these samples.
Analytical procedures

A volume of about 40 cm$^3$ per sample was crushed for major and trace-element analyses. Major elements were analysed with a PHILIPS Magix Pro (PW-2440) X-ray fluorescence (XRF) equipment (Centro de Instrumentación Científica – CIC, University of Granada). Measurements were carried out on glass beads prepared with 0.6 g of powdered sample diluted in 6 g of Li$_2$B$_4$O$_7$. Precision was better than ±1.5–2% and ±4% (relative) for concentrations of ≥10 wt.% and <10 wt.% respectively. Trace-element compositions were determined by ICP-Mass Spectrometry (ICP-MS) at CIC after HNO$_3$+HF digestion of 0.1 g of sample powder in a Teflon-lined vessel at ~180 °C and ~200 psi for 30 min, evaporation to dryness, and subsequent dissolution in 100 ml of 4 vol.% HNO$_3$. Blanks and international standards PMS, WSE, UBN, BEN, BR, and AGV (Govindaraju 1994) were run as unknowns during analytical sessions. Precision was better than ±2% and ±5% for analysed concentrations of 50 and 5 ppm, respectively. PGE concentrations were determined at the Genalysis Laboratory Services Pty. Ltd. at Maddington (Western Australia) following the method described by Chan and Finch (2001) using an ICP-MS isotopic dilution technique after nickel sulphide fire assay with detection limits of 1 ppb for Rh and 2 ppb for Os, Ir, Ru, Pt, and Pd.

Representative samples were selected for micro-Raman study and analysed directly in the polished thin sections with a HORIBA Jobin Yvon LabRam HR 800 dispersive spectrometer equipped with an Olympus BXFM optical microscope in the Serveis Científics i Tecnològics of Barcelona University (CCIT-UB). Raman spectra were obtained by applying a non-polarized 532 nm laser, using a 50x objective (beam size around 2 µm), with three measurement repetitions for 60 s each. The instrument was calibrated by checking the position of the metallic Si band at ~520 cm$^{-1}$. The micro-Raman spectra were processed using the LabSpec® software (JobinYvon). The final spectra were produced by subtracting the background fluorescence.

Samples analysed by powder X-ray diffraction (PXRD) were milled and sieved for <20 µm particle size, and prepared by manual pressing of the powders by means of a glass plate to obtain a flat surface in cylindrical standard sample holders of 16 mm in diameter and 2.5 mm in height. The diffractograms were obtained in a PANalytical X’Pert PRO MPD Alpha1 powder diffractometer in Bragg-Brentano θ/2θ geometry of 240 mm of radius, nickel filtered Cu Kα radiation (λ = 1.5418 Å), and 45 kV – 40 mA, in CCIT-UB. During analysis, the sample was spun at 2 revolutions per second. A variable divergence slit kept an area illuminated constantly (10 mm) and a mask was used to limit the length of the beam (12 mm). Axial divergence Soller slits of 0.04 radians were used. Samples were scanned from 3 to 80º 2θ with a step size of 0.017º and a measuring time of 50 s per step, using an X’Celerator detector (active length = 2.122º). The software X’Pert Highscore® was used to subtract the background of the patterns, to detect the peaks, and to assign mineral phases and their corresponding dhkl to each peak. The data were treated by full-profile Rietveld refinement for the quantitative analyses of mineral phases using the software TOPAS V3.

The ternary Ol-Opx-Cpx diagram in oxy-equivalent units was calculated with CSpace software (Torres-Roldán et al. 2000). Abbreviations of minerals and end-members are after Whitney and Evans (2010).
Petrography

All studied samples are strongly to completely serpentinized peridotites, as supported by the loss on ignition (LOI) values higher than 10 wt.% (Supplementary Table 2 and Blanco-Quintero et al. 2011d). Primary silicates and Cr-spinel are completely absent and only Cr-bearing magnetite and ferrian chromite are found as alteration products of the latter. As in La Corea, most of the samples from the Sierra del Convento mélangé show a general massive to fragmented mesh texture (Figures 4 and 5(a)). Samples 09-SC-3 g and MCB-2f...
show a strong deformation fabric (Figures 3 and 5(c)). Antigorite is the main constituent in all samples (>90%; Supplementary Table 1) forming pseudomorphic microtextures (mesh textures; Figure 5(a,b)), millimetric blades that overprint the original peridotite texture (Figure 5(b)), and non-pseudomorphic massively recrystallized microtextures characterized by interpenetrating needles (interlocking texture; Figure 5(c,d)). Bastite textures are frequent and made of elongate serpentine crystals parallel to the orientation of exfoliation planes/exolution lamellae of former orthopyroxene. These petrographic observations were confirmed with micro-Raman and PXRD spectra obtained from Sierra del Convento samples, which show very intense and sharp bands at ~228, 271–374, ~680, and ~1043 cm⁻¹, a weaker band at 456–459 cm⁻¹, and a shoulder/peak at 636–637 cm⁻¹ in the low-wave-number spectral region (Figure 6(a–d)). According to Rinaudo and Gastaldi (2003), Groppo et al. (2006), and Schwartz et al. (2013), these typical bands of serpentine group minerals are located at relatively low Raman shifts and are assigned to antigorite. In addition, in the high spectral region, two very intense bands at 3663–3670 and 3695–3699 cm⁻¹ are observed (Figure 6(a–d)), which can be related to antigorite, according to Petriglieri et al. (2014). The calculated PXRD profiles of four representative samples are shown in Figure 6(e–h). These samples consist mainly of antigorite (from 100% to 63.9%) associated with talc (up to 35.7% in the sample MCB-2f) or tremolite (4.93% in the sample 09-SC-31b), and minor chlorite (from 0.32% to 0.63%). Notably, brucite is absent in the samples, suggesting higher temperature than in lizardite–brucite-bearing samples from the La Corea mélangé.

Chlorite is present in all studied samples (Supplementary Table 1). It forms fine-grained idioblastic flakes (around 0.3 mm; Figure 5(c,f)) and xenoblastic felt-like aggregates (Figure 5(e)). Both types appear dispersed in the serpentine matrix and usually occur at the edge of mesh texture bodies (Figure 5(a)). Chlorite systematically envelopes ferrian chromite-magnetite that formed after the complete replacement of disseminated primary Cr-spinel (Figure 5(d)). Chlorite is also locally interlocked with calcic amphibole (tremolite) grains (Figure 5(e)) in replacement textures after primary pyroxene(s). Talc is common in all sample types (Supplementary Table 1). It forms fine anhedral granules or dusty grains dispersed in the matrix, which are associated with chlorite and rare fine- to medium-grained sub-idioblastic tremolite (Figure 5(a); Supplementary Table 1). Tremolite (Figure 5(e)) is locally included within carbonates. Anthophyllite occurs in one
sample (09-SC-7k) as dispersed, anhedral granules overprinted by matrix antigorite and associated with magnetite and ferrian chromite after spinel (Figure 5(f)). Fine-grained neo-formed clinopyroxene occurs in sample 09-SC-09d (Figure 5(e)) associated with tremolite and in the cores of pseudomorphic serpentinite textures.

Antigorite serpentinite from La Corea mélangé is characterized by non-pseudomorphic textures of interpenetrating needles of antigorite, which is locally partially replaced by dolomite. Talc is variably abundant. Primary Cr-spinel grains are completely altered to ferrian chromite and magnetite generally surrounded by chlorite. On the other hand, antigorite–lizardite serpentinite from this mélange shows pseudomorphic features, such as the hourglass texture of lizardite and antigorite replacing the orthopyroxene in bastite, fine-grained clinopyroxene, chlorite, magnetite, and ferrian chromite that overgrew/replaced primary clinopyroxene porphyroblasts, and spinel. Veins of andradite garnet crosscut these rocks (see Blanco-Quintero et al. 2011d for additional petrographic information).

**Whole-rock composition**

**Major-element geochemistry**

The bulk composition of the analysed samples from Sierra del Convento has LOI values from 9.69 wt.% to 12.36 wt.% (Supplementary Table 2). The contents of MgO and SiO$_2$ are variable, in the range of 36.59–42.93 wt.% and 46.13–50.79 wt.%, respectively (Supplementary Table 2, Figure 7(a,c)), as a likely consequence of mobilization during serpentinization (Snow and Dick 1995; Niu 2004). The content of Al$_2$O$_3$ varies in the range of 1.62–3.66 wt.% (Figure 7). Narrower ranges are observed for Fe$_{tot}$ (7.0–8.95 wt.%, (Figure 7(b)), Mg# (100 × Mg/(Mg+Fe$^{2+}_{tot}$), 88.48–91.55; Supplementary Table 2), and TiO$_2$ (0.02–0.17 wt.%; Figure 7(d)). The CaO contents are generally low, but one sample reaches 1.10 wt.% (09-SC-27t) as a likely consequence of limited carbonation, whereas the typical values are around 0.5 wt.% (09-SC-27t) as a likely consequence of limited carbonation, whereas the typical values are around 0.5 wt.% (09-SC-27t) as a likely consequence of limited carbonation, whereas the typical values are around 0.5 wt.% (09-SC-27t) as a likely consequence of limited carbonation, whereas the typical values are around 0.5 wt.% (09-SC-27t) as a likely consequence of limited carbonation, whereas the typical values are around 0.5 wt.% (09-SC-27t) as a likely consequence of limited carbonation.

We have classified the samples in the Ol-Opx-Cpx ternary diagram calculated in oxy-equivalent or (gram-oxygen) units (Figure 8). This measure of mineral proportions was obtained from the molecular proportions of oxides in whole-rock samples using standard algebraic methods and has the advantage of being a measure of the volume of solids in which oxygen is the only major anion (Brady and Stout 1980; Thompson 1982).

The rare earth element (REE) contents of the Sierra del Convento serpentinites (Supplementary Tables 2 and 3) range from ~0.1 to ~2 times CI-chondrite (Figure 10(a,b)). The abundance of other trace elements is, in general, depleted relative to estimates of the primitive mantle (PM), with exceptions in the large ion lithophile elements (LILE) (Figure 10(c,d)). The REE patterns vary from nearly flat with a mild negative Eu anomaly to slightly HREE-enriched (>CI-Chondrite) and LREE-depleted (Figure 10(a)). PM-normalized trace-element patterns of serpentinites are characterized by similar or slightly enriched Cs, Ba, U, and Rb contents and Th depletion (Figure 10(c,d)). In general, all samples show marked Hf and Sr depletion and Pb enrichment (Pb was not analysed for the La Corea mélange), although a local prominent positive spike in Sr and a negative spike in
Rb characterize some samples, suggesting mobilization of fluid-mobile trace elements during serpentinization.

**PGE composition**

The total concentration of PGE in the Sierra del Convento serpentinite samples ranges from 18 ppb to 36 ppb (Supplementary Table 4). These low values are characterized by concentrations of Ir-type PGE (IPGE) from 10 ppb to 15 ppb (Os = 1–3 ppb; Ir = 3–4 ppb; Ru = 6–9 ppb) and concentrations of Pd-type PGE (PPGE) from 8 to 21 ppb (Rh = 1–2 ppb; Pt = 5–10 ppb; Pd = 2–9 ppb; Supplementary table 4). The samples have similar values to the primitive upper mantle (PUM; Becker et al. 2006) for Ir, Ru, Pt, and Pd, although one sample shows depletion in Pt and Pd and all samples show depletion in Os (Figure 11). Serpentinites from the La Corea mélange have similar concentrations of IPGE (Os, Ir, Ru) and PPGE (Rh, Pt, Pd), although they do not show a marked depletion in Os and Pd and have higher values of PPGE.
Discussion

The mineral assemblages and textures characterized by antigorite±lizardite, chlorite, tremolite, diopside, talc, and, importantly, anthophyllite, with antigorite replacements after lizardite, and the composition of the analysed samples indicate a complex geodynamic history of serpentinite from both mélanges. In this section, we discuss the geochemical characteristics of the studied samples and their P-T evolution, and propose a tectonic model within the framework of Cretaceous Caribbean tectonics, which may be extended to other regions.

Environment of formation

Since extensive serpentinization is characteristic of the studied mélanges, the mobility of elements during the alteration/metamorphic processes may obscure protolith provenance (e.g. Niu 2004). Serpentinization is characterized by MgO loss, as illustrated by the trend of serpentinized peridotites from the fracture zone/abyssal (Figure 9). In a similar way, enrichment of SiO$_2$ and/or CaO in several samples (Figures 4(b), 7(a,d) and 9) may be related to the serpentinization of oceanic peridotite by seawater (e.g. Marchesi et al. 2011). Indeed, the samples have PGE concentrations similar to PUM, denoting only local variations in the extent of residual character (Becker et al. 2006), except for Os, Pt, and Pd in the Sierra del Convento mélange (Figure 11), which shows depletions likely caused by limited mobility during serpentinization (Lorand et al. 2003; Luguet et al. 2003; Pearson et al. 2004; Harvey et al. 2006; Wang et al. 2008; Liu et al. 2009; Lorand and Alard 2010; Marchesi et al. 2013; Penniston-Dorland et al. 2014). Talc, found in some deformation textures (Figures 5(a) and 2(b,c) in Blanco-Quintero et al. 2011d), is present in the mineral assemblage of several antigorite and antigorite–lizardite serpentinites of both mélanges. The local presence of talc can be related to the variable degree of infiltration of metasomatic fluids. This type of alteration causes a mildly negative Eu anomaly, as shown by most analysed samples (Figure 12; cf. Paulick et al. 2006; Boschi et al. 2006). We hence suggest that a secondary Eu anomaly caused by alteration in the oceanic environment is still preserved.

Despite the effects of alteration, the abundance of major and trace elements suggests that serpentinite from both mélanges has similar geochemical signatures (Figures 7–12) and that all samples broadly conform to the compositional evolution trend of mantle melt residues (terrestrial array; Figure 9) with only a somewhat refractory Al$_2$O$_3$/SiO$_2$ signature (>0.03). Furthermore,
major- and trace-element compositions show no coincidence with the drilled/dragged serpentinites/peridotites from the mantle wedges (Pearce et al. 2000; Kodolányi et al. 2012). Importantly also, they do not show coincidence with the drilled/dragged abyssal serpentinites derived from harzburgite (Paulick et al. 2006), except if melt-related re-fertilization processes affected these rocks (Figures 7, 9, and 12; see below).

Immobile trace elements must be used to gain additional insight. Titanium and La/Yb versus Yb relations (Figure 13(a,c)) confirm a less-refractory composition (enrichment in Ti and Yb) than drilled/dragged harzburgitic abyssal and mantle wedge serpentinites/peridotites and are similar to the compositions of fracture-zone/abyssal serpentinized peridotites and drilled/dragged abyssal serpentinites with melt impregnation processes. In a similar way, the Nb versus La diagram (Figure 13(b)) shows a positive trend and moderate fit to the linear regression for abyssal peridotites (Paulick et al. 2006). These characteristics may be related to re-fertilization controlled by melt–rock interaction processes. Mafic and differentiated melts percolating and reacting with mantle peridotite are identified as

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**Figure 10.** Trace-element patterns normalized to CI-chondrite (a and b) and silicate earth/primitive mantle (c and d) (McDonough and Sun 1995) for the La Corea (a and c) and Sierra del Convento mélanges (b and d). Subducted, abyssal, and mantle wedge harzburgite serpentinites data compiled by Deschamps et al. (2013; samples from exhumed interpreted bodies and drilled/dragged in oceanic basins) are plotted for comparison.

**Figure 11.** CI-chondrite-normalized PGE patterns of eastern Cuba mélanges. PGE of oceanic and continental peridotites compiled by Marchesi et al. (2013) are plotted for comparison. Normalizing values are from Palme and Jones (2003). Primitive upper mantle (PUM) is from Becker et al. (2006).
responsible for HFSE and REE enrichment in samples drilled from transform settings (Niu 2004; Paulick et al. 2006). Higher REE, Zr, Th, and Nb contents than abyssal and mantle wedge fields, as illustrated in Figure 10(c,d) and 13(b), would suggest melt impregnation processes that cannot be related to serpentinization due to their immobility in aqueous solutions (e.g. Paulick et al. 2006; Augustin et al. 2012). Thus, the enriched patterns displayed by the studied samples, with REE and IPGE concentrations close to 1 CI-chondrite (Figures 10(a,b) and 12(a,b)) and PUM (Figure 11), respectively, and the relatively high concentrations in HFSE can be interpreted as fracture-zone/abyssal peridotites that experienced modest percentages of partial melting and likely re-fertilization processes (Pearce et al. 2000; Niu 2004; Choi et al. 2008a; Chen et al. 2015).

Enriched patterns of Cs, Rb, and Ba with respect to drilled/dragged abyssal serpentinites, on the other hand, might have been related to the influence of metasomatic fluids in the mantle wedge by slab-derived agents (Figure 10(c,d); for example, Schmidt and Poli 1998; Bebout and Barton 2002; Hyndman and Peacock 2003; Scambelluri et al. 2004). Eastern Cuba serpentinites are similar to serpentinites from the subduction environment and show strong enrichment in Ba relative to serpentinized peridotites from fracture zones (Figure 14(b)), pointing to an influence of fluids evolved from subducted crust. Indeed, they also show depletion in U and Li (Figure 14(a,c)) relative to fracture-zone/abyssal serpentinized peridotite, indicating the effects of subduction-related fluids (e.g. Vils et al. 2011). Thus, despite their fracture-zone/abyssal origin, serpentinites were hydrated in a subduction scenario where they experienced interactions with slab-derived fluids (cf. Choi et al. 2008a, 2008b; Deschamps et al. 2012).

**Metamorphic evolution**

A first seafloor serpentinization event is documented by the presence of low-pressure mineral phases. Anthophyllite, present locally in the Sierra del Convento mélangé (Supplementary Table 1; Figure 5(f)), is typical of metultramafic rocks formed at a relatively high temperature of 600–700ºC and a relatively low pressure of <7 kbar (Figure 15). These conditions
Figure 13. (a) Ti versus Yb, (b) Nb versus La, and (c) La/Yb versus Yb diagrams for the studied samples. Re-fertilization, magmatic depletion, fluid–rock interaction, and melt–rock interaction trends are after Deschamps et al. (2013) and the references therein. Linear regression for abyssal peridotites is shown by a dashed line (Paulick et al. 2006). PM is from McDonough and Sun (1995) and GLOSS after Plank and Langmuir (1998). Note the rupture of the Ti and La scales in A and B, respectively.

Figure 14. Fluid mobile element compositions of the studied serpentinites, (a) Li, (b) Ba, and (c) U versus Yb content (ppm). PM is from McDonough and Sun (1995) and GLOSS after Plank and Langmuir (1998).
are incompatible with the mature and warm subduction-related thermal gradients (Figure 15). Instead, they may be related to a hot subduction scenario related to the subduction initiation of the young oceanic lithosphere (as in eastern Cuba mélanges) or to ocean-floor metamorphism characterized by high thermal gradients. The evidence from the associated tectonic blocks of MORB-derived amphibolite in the studied mélanges indicates a hot thermal gradient of ca. 15ºC/km related to the subduction of the young oceanic lithosphere (García-Casco et al. 2008a; Lázaro et al. 2009; Blanco-Quintero et al. 2010). This gradient is however incompatible with >31.2ºC/km, expected for the formation of anthophyllite at <7 kbar and ca. 675ºC. Still hotter gradients are expected for the subduction initiation of a very young oceanic lithosphere, as in Oman, where the associated metamorphic sole records up to 850ºC and 10–15 kbar (granulites of the Bani Hamid area, United Arab Emirates; Searle and Cox 2002) and a 18.3–27.5ºC/km gradient (3.3 g/cc density), still low compared with >31.2ºC/km. For this reason, and the lack of evidence of such a high thermal gradient in eastern Cuba mélanges, our preferred interpretation is that anthophyllite represents a relict of mid-ocean ridge metamorphism. Other minerals, like antigorite, talc, tremolite, and diopside, might have also formed upon cooling of the oceanic lithosphere down to 300–400ºC and further fluid infiltration (Figure 15). However, heating is documented by lizardite transformation to antigorite (Blanco-Quintero et al. 2011d; cf Schwartz et al. 2013). This prograde metamorphic event can hardly be related to the thermal evolution at a transform-zone.

Figure 15. P-T diagram showing the metamorphic evolution of the serpentinite rocks of the Sierra del Convento and La Corea mélanges from the oceanic to the subduction environments. The red lines represent the reaction relationships in the CaO-MgO-SiO$_2$-H$_2$O system after Spear (1995) and Padron-Navarta et al. (2012). The thick red reaction curves denote the calculated maximum stability of antigorite in the MgO-SiO$_2$-H$_2$O system. This reaction is almost coincident with the experimental stability limit of MSH-antigorite (denoted as ‘MSH-Atg out (BP)’ in the figure, after Bromiley and Pawley 2003). Also shown is the experimental stability limit of Al-rich antigorite (denoted as ‘MASH-Atg out (UT)’ after Ulmer and Trommsdorff 1995). The orange shaded region encompasses additional experimental stability limits of antigorite with variable Al after Bromiley and Pawley (2003), Wunder and Schreyer (1997), and Wunder et al. (2001). The phase relations between lizardite and antigorite (green and blue reaction bands) are from Evans et al. (2013) and Schwartz et al. (2013). For reference, the thermal gradients of the top (slab–mantle interface) and bottom of the subducted oceanic crust in cold and warm subduction scenarios (Peacock and Wang 1999) and the wet basaltic solidus (Green 1982) are shown. The P-T paths of subducted MORB Grt-amphibolite blocks of the Sierra del Convento and La Corea mélanges followed counterclockwise P-T paths, reaching peak conditions appropriate for partial melting at ca. 750ºC at 15 kbar (García-Casco et al. 2008a; Lázaro et al. 2009; Blanco-Quintero et al. 2010, 2011e). Note that the related abyssal serpentinite from the down-going plate subducted at this stage would have been transformed into metaharzburgite/meta-olivine orthopyroxenite, which is lacking in the mélanges. The timing and P-T conditions of jadeite formation in the Sierra del Convento mélanges are after García-Casco et al. (2009) and Cárdenas-Parraga et al. (2012). Retrograde hydration of peridotite down to ca. 300ºC in the context of a transform-fault zone and the ensuing down-drag of the upper-plate serpentinite (which experienced limited subduction down to ca. 30 km, up to 450ºC after the onset of subduction) are indicated by deep-red arrows. Massive antigorite formed at depths of ca. 15 kbar (Blanco-Quintero et al. 2011d). Exhumation of all types of blocks and serpentinite along the subduction channel allowed the formation of the mélanges with low-T serpentinite at <10 kbar in a fore-arc setting before the final collision-related exhumation during the latest Cretaceous (García-Casco et al. 2008b).
environment characterized by cooling and must be related to the subduction of serpentinite (Figure 15).

Tectonic blocks in eastern Cuba serpentinite mélanges record subduction of the oceanic and volcanic arc lithosphere. The earliest subducted metamorphic blocks are MORB-derived garnet-epidote amphibolite and associated partial melting-derived segregations and veins of trondhjemite to tonalite composition. They formed at high temperature and moderate pressure (700–750°C, 15 kbar; Figure 15) as the result of subduction of a near-ridge lithosphere (García-Casco 2007; Lázaro and García-Casco 2008; Blanco-Quintero et al. 2011b; e; Lázaro et al. 2011). At similar depth (50 km) but lower temperature (550–625°C), jadeitite rocks were formed in the Sierra del Convento subduction channel (García-Casco et al. 2009; Cárdenas-Párraga et al. 2012; Figure 15). Metamorphic overprints bearing glaucophane and lawsonite document counterclockwise P-T paths and progressive cooling of the channel during accretion (Figure 15). Subduction of the Purial volcanic arc complex during the latest Cretaceous (75–70 Ma) provided blocks of blueschist and greenschist to the mélanges, shortly before arc–terrane collision exhumed the ophiolitic units and the associated mélanges (García-Casco et al. 2008b). In this context, before 75 Ma, lizardite-free antigorite serpentinites formed at an imprecise range of 10–14 kbar and 450–600°C (Blanco-Quintero et al. 2011d; Figure 15). On the other hand, since lizardite is locally preserved and antigorite replaced lizardite in some samples, this material reached less than 30 km depth during heating and compression in the channel (<10 kbar, ca. 400°C; Figure 15). This difference in the P-T-path implies that high- and intermediate-grade metamorphic blocks and antigorite serpentinite were brought back to the surface from depth and mixed with the down-going lizardite-bearing serpentinite at intermediate depth (Figure 16).

Figure 16. (a and b) Cretaceous geodynamic reconstruction of the Caribbean region after Pindell and Kennan (2009) and Pindell et al. (2012). Cretaceous spreading of the Proto-Caribbean oceanic basin separated North and South America. Subduction of the Proto-Caribbean below the abyssal Farallon lithosphere started in the early Cretaceous in the context of the inter-American transform. Ridge subduction formed the partially melted metabasaltic crust of the Sierra del Convento and La Corea mélanges. Location of cross-section is shown. (c and d) Schematic cross-sections (not to scale) showing early Cretaceous evolution from the transform-fault zone to subduction. (e) Numerical thermal-chemical experiment of ocean–ocean subduction initiation of the young oceanic lithosphere (age 10 million years; initial convergence rate of 4 cm/year) appropriate for hot subduction and the development of aborted cold plumes (subducted melt-bearing metabasaltic crust crystallized at ca. 50 km depth – ca. 15 kbar – 10.9 million years after the onset of subduction) as an analogue of the partially melted subducted MOR basaltic amphibolites of the Sierra del Convento and La Corea mélanges (after Blanco-Quintero et al. 2011b). Flow of matter is shown by black arrows. See text for details.
As a result of the plastic behaviour of serpentinite, large-scale convective circulation is a process documented in subduction channels predicted by numerical models (Gerya et al. 2002; Gorczyk et al. 2007). A natural example of large-scale convective circulation in mélanges was first presented by Blanco-Quintero et al. (2011a), who documented large P-T recurrences in amphibolite blocks from the La Corea mélanage coupled with counterclockwise P-T paths documenting cooling and exhumation from ca. 50 km depth (García-Casco et al. 2008a; Lázaro et al. 2009; Blanco-Quintero et al. 2011b, 2011e). Metasomatic rinds of actinolite- and chlorite-bearing rocks associated with amphibolite and jadeite blocks document, in turn, a long-lasting history of fluid–rock interactions in the subduction channel (Blanco-Quintero et al. 2011d; Cárdenas-Párraga et al. 2012). These evidences point to the large-scale tectonic transport of blocks and matrix in the subduction channel involving mixing of the deeper parts of the channel with the shallower parts where a large volume of low-grade serpentinite forms (Shervais et al. 2011; Shervais and Choi 2012), rather than exhumation, sedimentation, and re-subduction (Wakabayashi 2012, 2015).

**Tectonic model**

In the model of Figure 16, a scenario of subduction and mixing in a subduction channel mélanage is conceptualized within the current models of plate tectonic evolution of the Caribbean region. Pindell et al. (2012) proposed that subduction nucleated at an inter-American transform-fault system developed upon the detachment of North America from Gondwana related to Pangea break-up in the region. Boschman et al. (2014) discussed the plate-tectonic configuration of this fault and concluded that it separated the Proto-Caribbean and Panthalassa (Farallon) lithospheres and that subduction of the former below the latter initiated along it during the early Cretaceous. Transform-fault is one possible general scenario for the onset of subduction (Stem 2004; Stern et al. 2012) that has been proposed in mélanges, such as the proto-Franciscan subduction zone (Shervais and Choi 2012).

Our data and inferences support a transform-fault scenario for subduction initiation in the northern Caribbean during the early Cretaceous (Figure 16(a,b)). Serpentinitic masses formed along the inter-Americas transform contributed to the mechanical weak zone needed for subduction inception (Figure 16(c,d); cf. Blanco-Quintero et al. 2011b and references therein). In an ideal model with only one transform-fault plate boundary (rather than a fault zone), once subduction initiated, the fault-bounded Proto-Caribbean lithosphere rich in serpentinite was dragged down, whereas the Caribbean- (Farallon-) plate counterpart was trapped in the fore-arc region close to the trench at a relatively shallow depth (Figures 15 and 16(d); cf. Shervais and Choi 2012). In a more realistic wider fault boundary zone, fragments of subducted serpentinite accreted to the upper plate and contributed to the evolving serpentinitic channel. Upon development at 50 km depth (ca. 10 million years after subduction initiation, Blanco-Quintero et al. 2011b), subducted oceanic crust (partially melted garnet amphibolites) accreted to the channel. Further development of the channel allowed the shallower part formed by the lizardite-bearing serpentinite to be dragged down to <30 km depth, where it mixed with up-rising deeper parts of the mélanges (Figures 15 and 16(e)).

It is notable that similar fertile compositions as those of the eastern Cuba mélanges characterize serpentinized harzburgites from the Dominican Republic and central Cuba mélanges. These rocks are classified as abyssal by Hattori and Guillot (2007), Saumur et al. (2010), and Deschamps et al. (2012), but show similar flat patterns of normalized REE, a weak negative Eu-anomaly, and linearly increasing concentrations from LREE to HREE (Figure 12). Such coincidence strengthens the view of a transform-fault environment for subduction initiation in the Caribbean.

The model presented here would indicate that fertile subducted serpentinite, as opposed to non-re-fertilized harzburgite serpentinites/peridotites from abyssal and mantle wedge environments as defined by Deschamps et al. (2013), may have formed in similar transform-fault environments. Geochemical enrichments in subducted serpentinite may be related to fluid-mediated processes in the subduction environment, but they may also simply reflect that subducted serpentinites are dominated by fracture-zone lithologies. Indeed, it may be no coincidence that subducted serpentinite shows similar REE, Th, Nb, Zr, and Hf compositions as fracture-zone serpentinized peridotites (Pearce et al. 2000; Niu 2004; Chen et al. 2015; Figures 12 and 13). Hence, fertile subducted serpentinite can be considered the footprint of onset of subduction at the transform-fault zones, as identified in the Sierra del Convento and La Corea mélanges and in other subduction mélanges (e.g. Casey and Dewey 1984; Choi et al. 2008a; 2008b; Shervais and Choi 2012).

**Conclusions**

Serpentinite from the subduction-related Sierra del Convento and La Corea mélanges (eastern Cuba) derives from oceanic fertile peridotite with REE-enriched flat patterns and HFSE enrichment. The protoliths correspond to abyssal mantle rocks affected by a small degree of melting and possibly re-fertilization at an oceanic fracture zone.
Serpentinization affected peridotite in this tectonic context as a consequence of the infiltration of seawater, triggering the formation of talc, tremolite, diopside, anthophyllite, and lizardite and the remobilization of elements (SiO$_2$, CaO, Sr, and Pb enrichment, and Mg, Os, Pt, Pd, and Eu depletion). Subduction initiation along the transform-fault zone at ca. 135 Ma, identified as the inter-Americas transform zone, caused subduction of the Proto-Caribbean half-fault zone serpentinite (antigorite serpentinite) and capture of the Caribbean (Farallon) counterpart at the shallow upper plate close to the trench (lizardite-serpentinite). Upon establishment of mass flow in the channel shortly after the onset of subduction, subducted oceanic crust accreted and shallower serpentinite was dragged down to <30 km depth where they mixed with the up-rising deeper parts of the mélange. At the cooler mature subduction stage, the influence of slab-derived infiltrating fluids caused enrichment in Pb, Cs, Ba, and likely Sr. Other subduction mélanges bearing fertile serpentinite may record similar processes and represent the footprint of subduction initiation at the fracture zones.

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**ORCID**

J. Cárdenas-Párraga [http://orcid.org/0000-0002-2787-0829](http://orcid.org/0000-0002-2787-0829)
A. García-Casco [http://orcid.org/0000-0002-8814-402X](http://orcid.org/0000-0002-8814-402X)
J. A. Proenza [http://orcid.org/0000-0001-8738-7305](http://orcid.org/0000-0001-8738-7305)
G. E. Harlow [http://orcid.org/0000-0003-2580-2635](http://orcid.org/0000-0003-2580-2635)
I. F. Blanco-Quintero [http://orcid.org/0000-0001-9644-1916](http://orcid.org/0000-0001-9644-1916)
C. Lázaro [http://orcid.org/0000-0002-8140-1660](http://orcid.org/0000-0002-8140-1660)
Cristina Villanova-de-Benavent [http://orcid.org/0000-0002-3973-2271](http://orcid.org/0000-0002-3973-2271)

**References**


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Hacker, B.R., 2008, H2O subduction beneath arcs: Geochemistry, Geophysics, Geosystems, v. 9, no. 3.


Lázaro, C., and García-Casco, A., 2008, Geochemical and Sr-Nd isotope signatures of pristine slab melts and their residues (Sierra del Convento mélange, eastern Cuba): Chemical Geology, v. 255, p. 120–133. doi:10.1016/j.chemgeo.2008.06.017


Li, Z.H., Liu, M.Q., and Gerya, T., 2015, Material transportation and fluid-melt activity in the subduction channel: