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Magmatic relationships between depleted mantle harzburgites, boninitic cumulate gabbros and subduction-related tholeiitic basalts in the Puerto Plata ophiolitic complex, Dominican Republic: Implications for the birth of the Caribbean island-arc

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ABSTRACT

The Lower Cretaceous Puerto Plata ophiolitic complex (PPC) occurs west of the main collisional suture between the Caribbean and North American plates in the northern Dominican Republic, and imposes important constraints on the geochemical and tectonic processes associated with the birth of the Caribbean island-arc. The PPC exposes a tectonically dismembered 3.0-km-thick section of upper mantle harzburgites, lower crustal cumulate gabbroic rocks and upper crustal basaltic pillow lavas, volcanic breccias and pelagic sediments. The harzburgites exhibit a highly depleted signature in terms of their modal compositions, mineral chemistry and whole rock major and trace element contents, suggesting that they are residues after high-degrees of partial melting. Melt modeling suggests that they were similar in trace element characteristics to a boninite. In the crustal sequence, three magmatic episodes have been recognized based on field, mineral and geochemical data. The first phase is composed of the lower layered gabbronorites, which are variably deformed and recrystallized at high-temperature conditions. Trace element modeling suggests that the gabbronorites crystallized from LREE-depleted island-arc tholeiitic (IAT) melts. The second phase is composed of the intermediate layered troctolites (126 Ma), which are undeformed and preserve igneous cumulate textures. Modeling indicates that the troctolites crystallized from boninitic melts. The gabronorite–troctolite substrate was intruded by a third, supra-subduction zone tholeiitic magmatic phase at <126 Ma, which formed the upper olivine gabbros and gabbronorites. These gabbroic rocks formed from melts similar in composition to the IAT basalts and basaltic andesites of the overlying Los Caños Fm. Contemporaneous Aptian to lower Albian mafic volcanic rocks of the Los Ranchos Fm and Cacheal complex have comparable IAT geochemical and isotopic signatures, suggesting that all of them may have erupted over a single piece of the Caribbean oceanic lithosphere.

The Lower Cretaceous PPC is interpreted to have formed during initiation of W/SW-directed subduction in an intra-oceanic island-arc setting. Fast rollback of the subducting slab would have induced extension in the Caribbean upper plate, and upwelling of mantle already depleted by the generation of oceanic crust. Aided by fluid expelled from the downgoing plate, the decompression melting of this previously depleted mantle at shallow levels yielded boninitic melts. The supra-subduction zone tholeiite sequence would have formed from ascending fertile mantle fluxed with subduction-related fluids as rollback continued. This model constrains the initiation and early evolution of a SW-dipping subduction zone that was responsible for the formation of the primitive Caribbean island-arc/back-arc system currently preserved in several locations in the Greater Antilles.

1. Introduction

Ophiolites are relics of oceanic lithosphere that commonly delineate suture zones between former oceanic or continental terranes. Their origin and tectonic evolution thus impose important constraints on geotectonic reconstructions of orogenic belts. The Greater Antilles orogenic belt results from the late Cretaceous–late Eocene closure of the proto-Caribbean oceanic domain, which led to the assembly of the North American plate with a number of collided intra-oceanic arcs, oceanic plateaus, oceanic basins and microcontinents (Escuder-Viruete et al., 2008, 2011c, 2013b; García-Casco et al., 2008; Hastie et al., 2009; Iturralde-Vinent, 1996; Kerr et al., 2003; Mann et al., 1991; Neill et al., 2010, 2012, 2013; Pindell and Kennan, 2009; Pindell et al., 2005; Stanek et al., 2009). As a result, several ophiolitic massifs were emplaced

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in the collisional zone, which are particularly well exposed in Cuba along the so-called "Northern Cuban Ophiolite Belt" (Iturralde-Vinent, 1996; Kerr et al., 1999; Lewis et al., 2006; Marchesi et al., 2006; Proenza et al., 2006).

These ophiolites extend for more than 1000 km along the northern half of the Cuban mainland and comprise dismembered mafic–ultramafic bodies, with diverse supra-subduction, back-arc and mid-ocean spreading-ridge geochemical signatures (Stanek et al., 2009). As a consequence, the Cuban ophiolites have been interpreted as oceanic lithospheric slabs either from a proto-Caribbean back-arc basin related to NE subduction of the Pacific plate, remnants of the SW subducting proto-Caribbean oceanic lithosphere emplaced onto the Pacific paleomargin, or fore-arc lithosphere built on the Pacific paleomargin (Cobiella-Reguera, 2009; García-Casco et al., 2008; Kerr et al., 2003; Pindell et al., 2005, 2006). Marchesi et al. (2006) highlight the need to clarify the Pacific and proto-Caribbean provenance of the different Cuban ophiolites, if the included residual peridotites were affected by subduction-related processes and the genetic links between ophiolitic lower crustal gabbros and upper crustal arc volcanics. In particular, this information is crucial to propose any geodynamic model for the evolution of the Greater Antilles orogenic belt.

The Puerto Plata ophiolitic complex (PPC) occupies a key position in the Hispaniola segment of the Greater Antilles orogenic belt, because it is situated close to the main proto-Caribbean suture zone (Escuder-Viruete et al., 2011a, 2013a). Located in northern Hispaniola, this complex is the westernmost and structurally highest unit in a series of accreted ophiolites, ophiolitic mélanges, intra-oceanic volcanic arcs and fragments of the southern margin of the North American continent, which are here collectively termed the northern Caribbean subduction–accretionary prism (or complex). The prism records, therefore, the Mesozoic history of generation and accretion of intra-oceanic terranes to the southern North American margin, as well as representing an important period of ocean closure and continental growth. However, its tectonic evolution has until recently been poorly constrained due to limited field, structural, petrological, geochemical and geochronological data.

Recent re-evaluation of the Hispaniola segment of the northern Caribbean subduction–accretionary prism has shown that the constituent tectonic units were deformed progressively younger to the east/northeast, indicating a general migration of deformation in this direction from the late Cretaceous to the earliest Miocene (Escuder-Viruete et al., 2011a,b, 2013a). The propagation of the deformation resulted from the initial subduction to the SW of arc, oceanic and continental terranes and their subsequent tectonic incorporation to the developing Caribbean subduction–accretionary prism. In this tectonic context, the PPC holds the key to the early evolution of this subduction zone, because it is the oldest and structurally highest component of the northern Caribbean subduction–accretionary prism.

This paper presents new detailed maps, lithostratigraphy, structure, mineral chemistry, in situ trace element composition of clinopyroxene, and bulk rock geochemical data for mafic and ultramafic rocks representative of all lithological units of the ophiolitic complex. These data allow us to argue that the PPC (a) represent tectonically disrupted crust and mantle sections of oceanic lithosphere, (b) originated during the initiation of subduction at least to 126 Ma, and (c) records a complex history of extreme crustal thinning and related supra-subduction zone magmatism prior to the accretion to North American continental margin. This constrains the age of the early evolution of a W/SW-dipping subduction zone in the northern Caribbean convergent margin and provides an important step in understanding both the formation of the intra-oceanic Caribbean island-arc, and the evolution of the subduction–accretionary prism.

2. Geological framework

Located on the northern margin of the Caribbean plate, the Island of Hispaniola (Fig. 1) is a tectonic collage produced by the oblique convergence to final collision of the Caribbean island-arc/back-arc system with the North American plate, which began in the Lower Cretaceous (Draper et al., 1994; Mann et al., 1991). The presence of ophiolitic mélanges in northern Hispaniola indicates that an intermediate proto-Caribbean oceanic basin was consumed by SW-directed subduction during convergence (Draper and Nagle, 1991; Escuder-Viruete et al., 2011a,c; Lewis et al., 2006; Pindell and Kennan, 2009; Pindell et al., 2005; Saumur et al., 2010). The arc-related rocks of the Caribbean upper plate have ages that span the Cretaceous and are regionally overlain by Paleocene/Lower Eocene to Holocene siliciclastic and carbonate sedimentary rocks (Draper et al., 1994; Escuder-Viruete et al., 2006, 2008; Kesler et al., 1990, 2005). This sedimentary cover post-dates the volcanic activity in the island-arc and records the oblique arc–continent collision in the northern Hispaniola area, as well as the intra-arc and retroarc deformation in the central and southern areas of the island.

Northern Hispaniola (Fig. 1) is geologically composed of arc, oceanic and continental margin derived units assembled during arc–continent convergence. These units form several inliers, termed El Cacheal, Palma Picada, Pedro García, Puerto Plata, Río San Juan y Samaná complexes, which constitute the pre-Eocene igneous and metamorphic substratum (Draper and Nagle, 1991). These six complexes form the Caribbean subduction–accretionary complex in Hispaniola (Escuder-Viruete et al., 2011a, 2013a), and include, from E to W: metasedimentary rocks of the subducted continental margin of North America; ophiolitic fragments of the proto-Caribbean lithosphere; serpentinitic-matrix mélanges, containing blocks of blueschists and eclogites; plutonic and volcanic rocks related to the Caribbean island-arc; and non-metamorphic rocks deposited in pre-collisional fore-arc sedimentary basins (Escuder-Viruete et al., 2011b,c). In the Puerto Plata and Río San Juan complexes, the first deposits which record the collisional process are the unconformable Paleocene?/Lower Eocene serpentinite-rich olistostromes of the Imbert Formation (Fm; Draper et al., 1994), which contain clastic elements derived from both the uplifted subduction–accretionary complex as the Cretaceous volcanic arc.

The Puerto Plata complex (Figs. 2, 3) is located north of the Camú fault zone and is composed of pre-Eocene ophiolitic basement rocks and Tertiary sedimentary cover composed of clastic and carbonate rocks (de Zoeten and Mann, 1991; Eberle et al., 1982; Hernáiz et al., 2012; Nagle, 1979; Pindell and Draper, 1991). The PPC consists of serpentinized peridotite, layered (cumulate) ultramafic and mafic rocks, massive gabbroic rocks, and volcanics of basic to intermediate composition, locally pillowed with rare inter-pillow cherts and limestones (Pindell and Draper, 1991). These lithologies occur as decametric to hectometric fault-bounded sections of rock in a structurally disrupted or dismembered manner, where fault zones are typically 0.5 to 2 m thick and hydrothermally altered. The basal structural contact of the PPC is not exposed. Saumur et al. (2010) interpreted samples of serpentinite from the complex as hydrated abyssal peridotite.

The ophiolitic basement is overlain by the Paleocene?–Lower Eocene >500-m-thick section of the Imbert Fm (Nagle, 1979), which is composed of fine-grained turbidites interbedded with white and turquoise, very fine-grained tuffs, pelagic sediments, rare radiolarian cherts and basaltic sills. The base of the unit is not exposed. The upper stratigraphic levels are characterized by thick-bedded turbidites of sandstone and conglomerate, which include clasts of all rock types from the ophiolitic basement. Therefore, the Imbert Fm probably rests unconformable over the PPC basement. These lithologies may be contemporaneous or slightly older than the serpentinite clast-rich units of megabreccias, breccias and conglomerates (e.g., Barrabás Mélange), and the shallow-water algal limestones of the La Isla Fm of late Paleocene to early Eocene age (Monthel, 2010; Pindell and Draper, 1991). These rocks are unconformably overlain by the late Eocene to early Miocene Altamira Fm and Luperón Fm, which comprise 1500 m of calcareous mudstones and siltstones, thin-bedded sandstones and conglomerates (Nagle, 1979). These rocks are in turn overlain by the San Marcos chaotic unit, which