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Geochemical characteristics of the Río Verde Complex, Central Hispaniola: Implications for the paleotectonic reconstruction of the Lower Cretaceous Caribbean island-arc

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New geochronological, trace element and Sr–Nd isotope data for metabasalts, dolerites and amphibolites from the Río Verde Complex, Central Hispaniola, are integrated with existing geochemical data for mafic volcanic rocks and metamorphic derivatives from the Los Ranchos, Amina and Maimón Formations, giving new insights into magma petrogenesis and paleotectonic reconstruction of the Lower Cretaceous Caribbean island-arc–back arc system. U–Pb and $^{40}Ar/^{39}Ar$ age data show that the Río Verde Complex protoliths were in part coeval with volcanic rocks of the Los Ranchos Formation (Upper Aptian to Lower Albian). The geochemical data establish the existence of gradients in trace element parameters (Nb/Yb, Th/Yb, Zr/Yb, Zr/Ba, and normalized Ti, Sm, Y and Yb abundances) and Nd isotope compositions from throughout Hispaniola, which reflect differences in the degree of mantle wedge depletion and contributions from the subducting slab. The Río Verde Complex mafic rocks and some mafic sills and dykes intruding in the Loma Caribe Peridotite, have a transitional IAT to N-MORB geochemistry and a weak subduction-related signature, and are interpreted to form in a rifted arc or evolving back-arc basin setting. The Los Ranchos, Amina and Maimón Formations volcanic rocks have arc-like characteristics and represent magmatism in the volcanic front. Trace element and Nd isotope modeling reproduce observed data trends from arc to back-arc and suggest that the variations in several geochemical parameters observed in a SW direction across the Caribbean subduction system can be explained from the progressively lower subduction flux into a progressively less depleted mantle source. The low Nb contents and high $(\varepsilon_{Nd})_i$ values in both arc and back-arc mafic rocks imply, however, the absence of a significant Lower Cretaceous plume enriched component. In order to explain these observations, a model of proto-Caribbean oceanic lithosphere subducting to the SW at least in the 120–110 Ma interval, is proposed to cause the observed magmatic variations in the Lower Cretaceous Caribbean island-arc–back-arc system. In this context, arc rifting and initial sea-floor spreading to form the Río Verde Complex protoliths occurred in the back-arc setting of this primitive island-arc, built on the NE edge of the Caribbean plate.

1. Introduction

Island-arcs develop because of subduction of oceanic lithosphere beneath another oceanic plate. The aqueous fluids and/or hydrous melts released from the subducting slab and their reaction with the overlying mantle wedge provide the prime control on arc magma genesis (Hawkesworth et al., 1993; Pearce and Peate, 1995; Woodhead et al., 1998; Stern, 2002). Magma genesis processes along convergent plate boundaries mainly include: (1) adiabatic upwelling of asthenospheric mantle induced by slab penetration (Peacock and Wang, 1999; Gerya et al., 2004); (2) partial melting of the mantle wedge as a result of the addition of slab-derived fluids (Arculus and Powell, 1986; Pearce and Parkinson, 1993; Schmidt and Poli, 1998; Hochstaedter et al., 2001; Martinez and Taylor, 2002); and (3) melting of the subducted slab and addition of the resultant melts to the mantle wedge (Defant and Drummond, 1990; Yogodzinski et al., 2001; Tatsumi and Hanyu, 2003). The compositions of arc lavas can vary across and along individual arcs. This probably results from: (1) compositional differences in subducted slab rocks (Plank and Langmuir, 1993); (2) differences in the dehydration or melting conditions of slab materials (Defant and Drummond, 1990); (3) differences in degree of partial melting in the mantle wedge (Pearce and Parkinson, 1993); (4) differences in the volume of slab-derived components added to the overlying mantle wedge (Kelemen et al., 2003; Singer et al., 2007); and

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(5) pre-existing mantle heterogeneity (Leat et al., 2004). As such, the composition of island arc lavas can be formed by a variety of processes; however, identifying which processes are involved in the petrogenesis of any particular lava is often difficult.

Outcrops of Late Aptian to Lower Albian volcanic rocks in the Greater Antilles are the oldest known arc-related strata of the primitive Caribbean island-arc. Geochemical studies of these rocks indicate a broad compositional spectrum across and along the arc that make their interpretation difficult in terms of subduction-related petrogenetic models (Lebrón and Perfit, 1994; Kerr et al., 1999; Jolly et al., 2001, 2006; Marchesi et al., 2006, 2007; Jolly et al., 2007, for example in Hispaniola (Lewis et al., 2002; Escuder-Viruete et al., 2006, 2007a,b,c). Further, these volcanic rocks are of considerable significance in the debated tectonic reconstructions of initial subduction polarity and magma genesis processes, along the long-lived (Early Cretaceous to Mid-Eocene) destructive plate margin separating the North American and Caribbean plates.

In this paper, we present new regional petrologic, U–Pb/Ar–Ar geochronological, trace element and Sr–Nd radiogenic isotope data for the Río Verde Complex mafic igneous rocks in Central Hispaniola, that allow us to relate it to the Lower Cretaceous Caribbean island-arc–back arc system. These data in conjunction with published data of coeval subduction-related units in Hispaniola allow us to address three main questions. These are: (1) nature and age of the Río Verde Complex protoliths; (2) tectonic setting of origin of the complex and relations with coeval magmatic units; and (3) polarity in the intra-oceanic Caribbean subduction system.

2. Geodynamic setting

2.1. The Caribbean island-arc

The Caribbean island-arc is subdivided into three domains: (1) the extinct Early Cretaceous to Paleogene Greater Antilles in the north, including Cuba, Jamaica, Hispaniola, Puerto Rico, and the Virgin Islands; (2) northern South America, including Tobago, Margarita, and Colombian/Venezuelan allochthons in the south; and (3) the volcanically active Lesser Antilles in the east, which rest on buried remnants of the south-eastern extension of the Cretaceous arc. In the Greater Antilles, Early Cretaceous (Aptian) to mid-Eocene island-arc volcanic rocks are traditionally subdivided (Donnelly et al., 1990) into a lower primitive island-arc suite (PIA), consisting predominantly of spilitized tholeiitic basalt and dacitic–rhyolitic lavas, and an overlying basaltic to intermediate calc-alkaline suite (CA). PIA lavas typically have low large-ion lithophile elements (LILE), rare earth elements (REE), and high field strength elements (HFSE) abundances, low radiogenic Pb, and near-horizontal primitive-mantle normalized REE patterns; younger CA lavas are distinguished from PIA by elevated incompatible element abundances and variably enriched REE patterns. Recent studies, however, have demonstrated that Caribbean island-arc volcanism produced basalt compositions with a broad range of LREE/HREE values and Sr–Nd–Pb isotope compositions, reflecting a wide variation in mantle sources and proportions of subducted sediments during its 80 Ma long eruptive history, from Lower Cretaceous to Late Eocene (c.a. 125 to 45 Ma; Kerr et al., 1999; Lewis et al., 2000; Jolly et al., 2001; Lewis et al., 2002; Jolly et al., 2006; Marchesi et al., 2006; Escuder-Viruete et al., 2006; Jolly et al., 2007; Marchesi et al., 2007; Escuder-Viruete et al., 2007a, 2008).

The PIA suite is represented by the Water Island Formation in the Virgin Islands (Rankin, 2002; Jolly and Lidiak, 2006), volcanic phases I and II in Central and Northeastern Puerto Rico (pre-Robles and pre-Santa Olaya Lava units; Jolly et al., 2001, 2006), clasts of PIA rocks in the pre-Camujiro sedimentary rocks near the province de Camagüey and Los Pasos Formation in Central Cuba (Kerr et al., 1999; Proenza et al., 2006), and the Los Ranchos, Amina and Maimón Formations in the Central and Eastern Cordilleras of Hispaniola (Kesler et al., 1990; Draper and Lewis, 1991; Lebrón and Perfit, 1994; Kesler et al., 2005; Escuder-Viruete et al., 2006; Fig. 1). Recent geochemical investigations reveal many PIA basalts in the Greater Antilles, including the Téneme Formation in Eastern Cuba (Proenza et al., 2006; Marchesi et al., 2007), and the Los Ranchos (Escuder-Viruete et al., 2006), Maimón (Lewis et al., 2000, 2002) and Amina (Escuder-Viruete et al., 2007b) Formations in Hispaniola, as well as some Water Island basalts, are regionally comparable low-Ti island-arc tholeiites (IAT) and boninites. Taken together, the timing and geochemical characteristics in the PIA suite suggest a supra-subduction zone setting during the earliest stages of the Aptian to Lower Albian Caribbean island arc development (Escuder-Viruete et al., 2006). In Hispaniola, the Hatillo Formation, a massive reef limestone of upper Lower Albian age (Myczynski and Iturralde-Vinent, 2005), unconformably overlies the Los Ranchos Formation.

2.2. The geology of Central Hispaniola

Located on the northern margin of the Caribbean plate, the tectonic collage of Hispaniola results from the WSW to SW-directed oblique-convergence of the continental margin of the North American plate with the Greater Antilles island-arc system, which began in Cretaceous and continues today. The arc-related rocks are regionally overlain by Upper Eocene to Holocene siliciclastic and carbonate sedimentary rocks that post-date island-arc activity, and record the oblique arc-continent collision in the north, as well as the active subduction along the southern Hispaniola margin (Mann, 1999). Central Hispaniola is a composite of oceanic derived units bound by the left-lateral strike-slip Hispaniola and San José–Restauración fault zones (Fig. 1). Accreted units mainly include serpentinized Loma Caribe peridotites, MORB-type gabbros and basalts, Late Jurassic deep-marine sediments, volcanic units related to Caribbean–Colombian oceanic plateau (CCOP; e.g. the Duarte Complex; Lapierre et al., 1997; Escuder-Viruete et al., 2007c), and Late Cretaceous arc-related igneous and sedimentary rocks (Lewis et al., 2002). These units are variably deformed and metamorphosed to prenhite–pumpellyte, greenschist and amphibolite facies, but the textures of the protoliths are often preserved.

In the study area (Fig. 2), the macrostructure is characterized by several main NNW–SSE to WNW–ESE trending fault zones that bound different crustal domains or tectonic blocks, e.g. Hispaniola (HFZ), Hato Mayor (HMFZ) and Bonao–La Guácara (BGFZ) fault zones. To the north of the HFZ, the Maimón Formation forms a NW-trending belt of schists separating the Los Ranchos Formation, the Hatillo limestone, the Late Cretaceous Las Lagunas Formation and, locally, the Paleocene–Eocene sedimentary rocks of the Don Juan Formation, from the Loma Caribe Peridotite. The belt consists mainly of sub-greenschist and greenschist-facies metabasalt and metadacite/rhyolite, and minor intercalated carbonaceous schist, iron formation and marble. Development of penetrative foliation increases toward the contact with the HFZ, where the rocks are converted to mylonitic–phyllonitic schists (Draper et al., 1996). To the NW, and in a similar structural position, the mafic and felsic Amina schists occur under the neogene sediments of the Cibao Basin (Fig. 1). On the basis of geochemical and Sr–Nd isotopic data, Escuder-Viruete et al. (2007b) argue that the mafic and felsic schists of the Amina and Maimón Formations are foliated and metamorphosed equivalents of the Los Ranchos Formation volcanics.

To the south of the HFZ, Central Hispaniola domain is also bounded by the Hato Mayor fault zone, and comprises the Loma Caribe Peridotite, several related gabbro and dolerite bodies, the Río Verde Complex, and the Peralvillo Sur Formation. Due to the fact that the block is composed of a peridotite basement intruded and/or covered by volcanic mafic rocks, it has been considered to be an ophiolite (Lewis et al., 2002, 2006). The Loma Caribe Peridotite is mainly composed of spinel harzburgite, but clinopyroxene-rich harzburgite, dunite, lherzolite and small bodies of podiform chromitites also occur (Lewis et al., 2006). The peridotites