Caribbean island-arc rifting and back-arc basin development in the Late Cretaceous: Geochemical, isotopic and geochronological evidence from Central Hispaniola


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Abstract

We present new regional petrologic, geochemical, Sr–Nd isotopic, and U–Pb geochronological data on the Turonian–Campanian mafic igneous rocks of Central Hispaniola that provide important clues on the development of the Caribbean island-arc. Central Hispaniola is made up of three main tectonic blocks—Jicómé, Jarabacoa and Bonao—that include four broad geochemical groups of Late Cretaceous mafic igneous rocks: group I, tholeiitic to calc-alkaline basalts and andesites; group II, low-Ti high-Mg andesites and basalts; group III, tholeiitic basalts and gabbros/dolerites; and group IV, tholeiitic to transitional and alkalic basalts. These igneous rocks show significant differences in time and space, from arc-like to non-arc-like characteristics, suggesting that they were derived from different mantle sources. We interpret these groups as the record of Caribbean arc-rifting and back-arc basin development in the Late Cretaceous. The ~90 Ma group I volcanic rocks and associated cumulate complexes preserved in the Jicómé and Jarabacoa blocks represent the Albian to Cenomanian Caribbean island-arc material. The arc rift stage magmatism in these blocks took place during the deposition of the Restauración Formation from the Turonian–Coniacian transition (~90 Ma) to Santonian/Lower Campanian, particularly in its lower part with extrusion at 90–88 Ma of group II low-Ti, high-Mg andesites/basalts. During this time or slightly afterwards adakitic rhyolites erupted in the Jarabacoa block. These group III tholeiitic lavas represent the initiation of Coniacian–Lower Campanian back-arc spreading. In the Bonao block, this stage is represented by back-arc basin-like basalts, gabbros and dolerite/diorite dykes intruded into the Loma Caribe peridotite, as well as the Peralvillo Sur Formation basalts, capped by tuffs, shales and Campanian cherts. This dismembered ophiolitic stratigraphy indicates that the Bonao block is a fragment of an ensimatic back-arc basin. In the Jicómé and Jarabacoa blocks, the mainly Campanian group IV basalts of the Peña Blanca, Siete Cabezas and Pelona–Pico Duarte Formation, represent the subsequent stage of back-arc spreading and off-axis non-arc-like magmatism, caused by migration of the arc toward the northeast. These basalts have geochemical affinities with the mantle domain influenced by the Caribbean plume, suggesting that mantle was flowing toward the NE, beneath the extended Caribbean island-arc, in response to rollback of the subducting proto-Caribbean slab.

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Keywords: Island-arc; Arc rifting; Back-arc basin; Mantle melting; Hispaniola; Caribbean plate

1. Introduction

Back-arc basins are regions of extension in a subduction zone setting often located between the active and remnant volcanic arc. Modern examples in the Western Pacific, as the Mariana Trough back-arc basin, form by initial rifting of an active intra-oceanic arc and subsequent sea-floor spreading (Karig et al., 1978; Parson and Hawkins, 1994; Hawkins, 1995; Taylor et al., 1996; Larter et al., 2003). During back-arc development a changing style in the petrogenesis of the magmas and nature of the mantle sources occurs, from those characteristic of arcs to...
those typical of sea-floor spreading (Stern et al., 1990; Hert and Hawkesworth, 1994; Gribble et al., 1996, 1998; Ewart et al., 1998; Martínez and Taylor, 2002, 2003). Tectonomagmatic models proposed for this evolution imply a reorganization of mantle convective regimes beneath evolving back-arc basins, from downwelling or lateral flow beneath incipient rifts to upwelling beneath zones of seafloor spreading (Gribble et al., 1998; Taylor and Martinez, 2003). Intrinsic to these models is the occurrence, during initial arc rifting, of magmas derived by high-degree melting of refractory (from previous melting) peridotite sources by slab-derived H$_2$O-rich fluids, which typically gave rise to Mg-rich melts such high-magnesian andesites and boninites (Shervais, 2001; Ishizuka et al., 2006).

Fig. 1. (a) Map of the northeastern Caribbean plate margin modified from Mann (1999). Box shows location of the study area. (b) Schematic geological map of Central Hispaniola. SFZ=Septentrional fault zone; HFZ, Hispaniola fault zone; BGFZ, Bonao–La Guácara fault zone; SJRFZ, San Juan–Restauración fault zone; EPGFZ, Enriquillo–Plantain Garden fault zone; La Meseta (LMSZ), Río Baiguaque (RBSZ) and Hato Viejo (HVFZ) fault/shear zones. LCB, Loma de Cabrera; LTB, Loma del Tambor; MB, Macutico; and ACB, Arroyo Caña batholiths. Encircled number show location of U–Pb geochronological samples.
magmatism with a subduction-related geochemical and isotopic signature to magmatism that lacks this signature is apparently preserved in some ophiolites. This tectonomagmatic relationship has been interpreted as a record of the rifting of an island-arc and the subsequent establishment of a back-arc basin in Appalachian (Swindon et al., 1990, 1997; Bédard et al., 1998; MacLachlan and Dunning, 1998), Tethyan (Robertson, 2004; Dylek and Flower, 2003) and Cordilleran ophiolites (Dickinson et al., 1996; Metzger et al., 2002; Harper, 2003; Shervais et al., 2004). Furthermore, the occurrence of high-Mg mafic volcanic rocks in ophiolites provide important constraints on their tectonic origin, due to the unusual conditions needed to produce these subduction-related magmas, plus possible asthenospheric potential temperatures and significant lithospheric extension requirements (Falloon and Danyushkevsky, 2000). In this context, coeval or slightly younger than the arc/back-arc transition rocks, mafic volcanic sequences of LREE-enriched tholeiites of oceanic island affinity are interpreted as part of the mature back-arc succession (Pouclet et al., 1995; MacLachlan and Dunning, 1998; Shervais et al., 2004).

In this paper, we present new regional petrologic, geochemical, Sr–Nd isotopic, and U–Pb geochronological data on the Turonian–Campanian mafic igneous rocks of Central Hispaniola that provide important constraints on the development of the Caribbean island-arc. We argue that these rocks show significant differences in time and space, from arc-like to non-arc-like characteristics, suggesting that they were derived from different mantle sources. We interpret these groups as the record of Caribbean arc-rifting and back-arc basin development processes in the Late Cretaceous. The geodynamical implications of this tectonomagmatic evolution are also discussed, in particular the flow of magma source domains influenced by the Caribbean mantle plume.

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) the northern South America segment, including Tobago, Margarita, and Colombian/Venezuelan allochthons in the south; and (3) the volcanically active Lesser Antilles in the east, which are on buried remnants of the southeastern extension of the Cretaceous arc. In the Greater Antilles (Fig. 1), 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 (LILE), rare earth (REE), and high field strength element (HFSE) abundances, low Th, U, and 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 in the Greater Antilles, however, have demonstrated that Caribbean island-arc volcanism produced basalt compositions with a broad range of LREE/HREE compositions, reflecting a wide variation in mantle sources and proportions of pelagic sediment subducted beneath the arc during its 80 Ma long eruptive history (e.g., 125 to 45 Ma; Jolly et al., 1998, 2001, 2006; Schellekens, 1998; Iturralde-Vinent and McPhee, 1999; Kerr et al., 1999; Lewis et al., 2002; Escuder Viruete et al., 2006b, 2007b; Marchesi et al., 2006). This persistent Lower Cretaceous to Late Eocene subduction-related volcanism is well preserved in Central and Northeastern Puerto Rico (Jolly et al., 2001, 2006), where volcanic rocks vary in composition from predominantly basalts to rhyolites, and from low-K island-arc tholeiites (Aptian–Early Albian), to calc-alkaline basalts (Late Albian), and finally to high-K, incompatible-element-enriched basalts (Cenomanian–Maastrichtian). Following an eruptive hiatus (Paleocene), volcanism recommenced in the Eocene with renewed eruption of calc-alkaline basalts in Puerto Rico and the Virgin Islands.

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 Eocene to Early Miocene and continues today (Donnelly et al., 1990; Draper et al., 1994; Mann, 1999). 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 in the southern Hispaniola margin (Dolan et al., 1998). Central Hispaniola is a composite of oceanic derived units bound by the left-lateral strike-slip Hispaniola (HFZ) and San Juan-Restauración (SJRFZ) fault zones (Fig. 1). Accreted units mainly include serpentinitized Loma Caribe peridotites, MORB-type gabbros and basalts, Late Jurassic deep-marine sediments, Cretaceous volcanic units related to Caribbean–Colombian oceanic plateau (CCOP; Kerr et al., 1997, 2002; Lapiere et al., 1999; Escuder Viruete et al., 2007a), and Late Cretaceous arc-related igneous and sedimentary rocks (Lewis et al., 1991, 1997, 2002; Escuder Viruete et al., 2004). These units were variably deformed and metamorphosed to prehnite-pumpellyite, greenschist and amphibolite facies conditions, but the textures of the protoliths are often preserved. In the Late Campanian–Maastrichtian, the shallow limestones of the Bois de Lawrence Formation were deposited on top of the extinct arc.

3. Tectonic blocks in Central Hispaniola

The internal structure of Central Hispaniola is characterized by several main NNW-SSE to WNW-ESE trending fault zones (Fig. 1): La Meseta (LMSZ), Rio Baiguaque (RBSZ), Hato Viejo (HFVZ) and Bonao–La Guácara (BGFZ) fault zones. These faults have broad crustal domains or tectonic blocks, namely: Jicomé, Jarabacoa, and Bonao, characterized by different Turonian–Campanian volcanic stratigraphies, geochemical composition and physical characteristics of their constituent igneous
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rocks (see below). The Loma de Cabrera, Loma del Tambor, Macutico and Arroyo Caña gabbro-tonalitic batholiths were intruded syn-to late-kinematically along these shear and fault zones mainly during the Coniacian–Santonian interval (90–84 Ma;
Escuder Viruete et al., 2006a). Sedimentary basins filled with the
Magua–Tavera Groups and unconformably deposited over these juxtaposed tectonic blocks, indicates that the main ductile structure of Central Hispaniola was pre-Middle Eocene. Late Cretaceous fault zones were variably reactivated during Upper Eocene–Oligocene brittle thrusting and Miocene to Recent uplift of the Cordillera Central (Contreras et al., 2004).

3.1. The Jicomé block

The Jicomé block is bounded to the north by the LMSZ and to the south by the SJRFZ (Fig. 1). It is composed of a 3 km thick sequence of arc-related volcanic, subvolcanic and volcanic-sedimentary rocks of the Tíre Group, and the overlying Peña Blanca and Pelona–Pico Duarte Formations (Fig. 2). The Tíre Group includes two main volcanic sequences with different geochemical characteristics (Escuder Viruete et al., 2007b). The lower Constanza Formation constitutes an Albian to Turonian island-arc tholeiitic suite, dominated by submarine vitric–lithic tuffs and breccias of andesitic to basaltic composition, with minor interbedded basaltic flows. The upper Restauración Formation is characterized by a spatial and temporal association of adakites, high-Mg andesites and basalts, and Nb-enriched basalts, which collectively define a shift in the composition of the subduction-related magmas. This stratigraphic interval is mainly represented by dacitic/rhyolitic explosive volcanism of calc-alkaline affinity, with subaerial to episodic aerial eruptions and emplacement of sub-volcanic domes (Lewis et al., 1991, 2002). Fossil and U–Pb/Ar–Ar geochronological data show that the upper sequence began to accumulate at the Turonian–Coniacian boundary (~89 Ma) and continued in the Santonian to Lower Campanian. In the SE area of the Jicomé block, the Tíre Group is intruded by subvolcanic margin-parallel magmatic foliation and local graded cumulate layering. The laccoliths are connected by dykes with chilled margins against the Loma La Monja assemblage host rocks. The Peña Blanca Formation is composed of a 150–250 m-thick succession of aphyric, non-vesicular basaltic flows, with slightly LREE-enriched theoleitic composition (Escuder Viruete et al., 2004). These contain plagioclase and clinopyroxene microlites and have olivine-satellite textures. The basalts of the Pelona–Pico Duarte Formation are 500 to 1500 m-thick and unconformably overlie the volcanic rocks of the Tíre Group. They are aphyric, vesicular and very homogeneous, with a LREE-enriched transitional to alkaline composition. The rocks contain microphenocrysts of olivine, Ti-augite and plagioclase. A Late Campanian to Maastrichtian 40Ar/39Ar whole-rock age has been obtained for these basalts (68.4±0.7 Ma; Escuder Viruete et al., unpublished).

3.2. The Jarabacoa block

The Jarabacoa block is bounded to the north by the HFZ or HVFZ and to the south by the LMSZ or BGFZ (Fig. 2). It comprises the Loma La Monja volcano-plutonic assemblage, the El Agua Chert, the Duarte Complex, and the Restauración Formation of the Tíre Group, as well as the metamorphic equivalents of the LMSZ amphibolites. The Loma La Monja assemblage is composed of gabbros, dolerites, basalts and pelagic sediments, which represent a dismembered fragment of the Late Jurassic proto-Caribbean oceanic crust (Escuder Viruete et al., in press). The El Agua Chert consists of 150-m thick sequence of ribbon chert with radiolarian microfauna of Oxfordian to Tithonian age (Montgomery et al., 1994). The Duarte Complex comprises a ~3-km thick sequence of picrites and high-Mg basalts of ~6 Ma (probably Aptian), chemically related to plume-generated magmas (Draper et al., 1994) and similar to the more enriched CCOP lavas (Lapierre et al., 1999, 2000; Escuder Viruete et al., 2007a). The El Yujo basal Member of the Restauración Formation consists of ~25 m of interbedded ribbon chert, dark shale and fine-grained tuff. This is overlain by dacite/rhyolite brecciated flows with small volcanicogenic sulphide deposits. The amphibolites of the LMSZ result from ductile shearing during the 88–74 Ma interval (40Ar/39Ar in hornblende; Escuder Viruete et al., 2006a) along the SW boundary of the Jarabacoa block. Mafic protoliths are mainly high-Mg basalts of the Duarte Complex and basalts with flat to slightly LREE-enriched patterns of the Peña Blanca Formation.

A regionally developed suite of distinctive mafic intrusions, referred as the Los Velazquitos gabbros, were preferentially emplaced in the NE area of the Jarabacoa block. Earlier workers assumed that these rocks belonged to the Duarte Complex (Lewis et al., 1991) or to Late Jurassic oceanic crust (Lapierre et al., 1999). The larger bodies of the Los Velazquitos gabbros are lopoliths, up to 3–5 km-long and 1 km-thick, that exhibit a margin-parallel magmatic foliation and local graded cumulate layering. The lopoliths are connected by dykes with chilled margins against the Loma La Monja assemblage host rocks. The gabbros show a wide range of textures and composition, from primitive coarse-grained olivine-gabbro, to medium-grained clinopyroxene-plagioclase gabbro and highly evolved fine-grained Fe–Ti-gabbro and diorite.

In the Villa Altagracia area, the Siete Cabezas Formation unconformably overlies the Duarte Complex directly (Fig. 2). It is composed of massive and pillowed aphyric basalts, with...
minor pyroclastic breccias, vitric tuffs and cherts, intruded by dolerite dykes (de Lepinay, 1987). Radiolarian content in the sediments yields a Middle Campanian to Maastrichtian age (Montgomery and Pessagno, 1999). Ton et al. (1998) obtained consistent 40Ar–39Ar ages for whole-rock (69.0±0.7 Ma) and plagioclase (68.5±0.5 Ma). These ages and the geochemical characteristics of the lavas (tholeiitic basalts with flat REE pattern) led Lewis et al. (2002) to attribute this unit to the CCOP.

3.3. The Bonao block

The Late Oligocene to Present displacement of the HFZ effectively truncates geological features in adjacent Bonao block to the north (Fig. 1). To the south, the block is bounded by the Hato Viejo fault zone, which comprises the Loma Caribe peridotite and the Peralvillo Sur Formation, as well as several gabbro and dolerite bodies. Due to the fact that the block is composed of a peridotite basement intruded and/or covered by igneous mafic rocks, it has been considered of ophiolitic character (Lewis et al., 2002), though it lacks of a complete ophiolite stratigraphy. 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 are typically extensively serpentinized and variably sheared, in particular toward the upper structural contact. The overlying rocks consist of hundred-meter-sized bodies of layered gabbro that pass structurally upward into massive, isotropic gabbro. Individual dolerite dykes intrude serpentinized peridotites and gabbroic rocks, showing chilled margins. They become more abundant upwards in the sequence and to the NE. The Peralvillo Sur Formation forms a narrow belt immediately northeast of the Loma Caribe peridotite (Fig. 2). It is composed of a 1500–2300 m-thick basaltic sequence of massive flows and pillow lavas that host massive sulfide deposits, and is overlain by ~1000 m of volcanioclastic sediments, tuffaceous mudstone and cherts with Campanian fauna of radiolaria (de Lepinay, 1987; Lewis et al., 2002).

3.4. Contemporaneous island-arc related rocks

Caribbean island-arc related rocks of Turonian–Campanian age occur in the Eastern Cordillera of Hispaniola and on Puerto Rico. In the Eastern Cordillera (Fig. 2), the deposits are mainly deep marine and composed of epiclastic graywackes, volcanioclastic mass flows, re-worked carbonates, lavas and tuffs, pelagic radiolitites and limestones of the Las Guayabas (Cenomanian–Lower Campanian), Rio Chavón (Middle-to Upper Campanian), and Loma de Anglada (Maastrichtian) Formations. The interbedded volcanic rocks are basalts of the Loma La Vega Member (Cenomanian age; Bourdon, 1985; Lebron and Perfit, 1994). Recently, García-Senz (2004) interpreted these units as the Late Cretaceous fore-arc basin deposits of the Caribbean island-arc. In Puerto Rico, the Central and Northeastern tectonic blocks were assembled into their actual configuration during mid-Santonian time, by left-lateral Cerro Mula fault zone (Schellekens, 1998). The Cenomanian to Maastrichtian stratigraphic sequence is relevant because it provides insight into lateral correlations of the Greater Antilles island-arc. Volcanic phases III and IV of Jolly et al. (1998) include lavas of the Lapa Lava Member of the Robles Formation (Turonian) and the Perchas Formation (Cenomanian–Turonian) in the Central block, and Santa Olaya Formation (Cenomanian–Lower Santonian), the Martín González Formation (mid-Santonian to Lower Campanian) and Tortugas Andesite (Campanian) members in the Northeastern block (Jolly et al., 1998, 2001, 2006).

4. U–Pb geochronology

4.1. U–Pb samples

The main objective of U–Pb geochronology was to correlate regional data for the onset of the felsic volcanism and gabbroic plutonism in the Jicome and Jarabacoa blocks. Analytical procedures are in the Appendix A and results are reported in Appendix B. All ages are quoted at the 2σ level of uncertainty. The selected U–Pb samples were (sample location in Fig. 1) a) rhyolite flow with albite+K-feldspar+quartz phenocrysts (sample 5JE07), a coarse-grained clinopyroxene-rich plagioclase gabbro (sample 5JE79, Los Velazquitos gabbro), and a subvolcanic medium-grained hornblende-gabbro (sample 6JE29, La Cana gabbro). The rhyolite has an adakitic affinity and belong to the lowermost stratigraphic levels of the Restauración Formation in NW Jarabacoa. Separated zircon grains are clear, pale pink, mostly stubby prisms, with aspect ratios of 1.5–3.5. Four abraded zircon fractions (A, B, D and E) are all concordant (Fig. 3) and give a weighted 206Pb/238U age of 89.1±0.9 Ma. This Turonian–Coniacian (geologic time scale from Gradstein et al., 2004) boundary age is interpreted as the crystallization age of the sample. The gabbro from Los Velazquitos intrusive suite has MORB geochemical characteristics with a weak subduction signature. The sample was collected in the core of a laccolith ~100-thick. Extracted zircon grains are clear, pale pink to colorless, stubby to equant prisms, with aspt ratios of of ~1.5–2.0. Zircon fractions A and C are slightly younger, showing evidence for minor Pb loss. Fractions B, D and E are concordant (Fig. 3) and give a weighted 206Pb/238U age of 89.3±1.6 Ma, which is interpreted as the crystallization age of the gabbro. The La Cana gabbro intrudes the Tíreo Group in the SW Villa Altugracia area. This evolved gabbro (Mg# = 28) is rich in Fe–Ti oxides and Nb (21.1 ppm), and has an E-MORB signature. Zircon grains are yellow, brown and yellow with some clear sectors, euhedral and prismatic. Fractions A, B, C and D are concordant and overlapping (Fig. 3) and give a concordia age (Ludwig, 2003) of 93.35±0.23 Ma, interpreted as the crystallization age of the rock (Cenomanian–Turonian boundary).
Turonian–Coniacian boundary in the Jicomé and Jarabacoa blocks. Also, this felsic volcanism was contemporaneous with the widespread emplacement of the hornblende-bearing tonalite batholiths. The age of the gabbro overlaps, within error, the age of the rhyolite. The mafic intrusive suite of Los Velazquitos gabbros have a geochemical composition similar to other gabbro bodies and dolerite dykes intrusive in the Loma Caribe peridotite, and the volcanic rocks of the Peravilillo Sur Formation (upper levels dated as Campanian) in the Bonao block (this study). Thus, geochronological data supports the synchronicity at ~89 Ma of the subduction-related felsic volcanism, the transitional IAT-MORB type plutonism in the Jarabacoa block, and the basaltic volcanism in the Bonao block (see below). La Cana gabbros and basalts of the Peña Blanca Formation (>74 Ma) have a similar enriched tholeiitic composition without a subduction signature. The 93 Ma age of the La Cana gabbros indicates that this non-arc-like magmatism began in the SE area of the Jicomé block.

5. Geochemistry

5.1. Analytical methods

Samples were powdered in an agate mill, and analysed for major oxides and trace elements by inductively-coupled plasma-mass spectrometry (ICP-MS) analysis with a LiBO₂ fusion. This analytical work was done at ACME Analytical Laboratories Ltd in Vancouver and reported in Table 1 and Appendix C, as well as details of analytical accuracy and reproducibility in Appendix A. For major elements oxides, the detection limits are in general <0.01% (Appendix A). The detection limits for trace elements are typically <0.1 ppm, except for Ba, Ce, La, Ga and Zr (0.5 ppm); for some trace elements, they are as low as 0.05 ppm. A representative subset of samples (Table 2) was also analysed for Sr and Nd isotopic compositions at the Pacific Centre for Isotopic and Geochemical Research at the University of British Columbia. Rb, Sr, Sm and Nd were re-analyzed with a Thermo Finnigan Element2, a double focussing (i.e., high resolution) Inductively Coupled Plasma-Mass Spectrometer. Samples were repeatedly leached with 6N HCl to remove secondary alteration. Separation of Sr and Nd were separated using the method described in Weis and Frey (2002). Isotope ratios were measured on a Thermo Finnigan Triton-TI TIMS in static mode with relay matrix rotation on single Ta filament and double Re-Ta filament for Sr and Nd isotopic analyses respectively. Sr and Nd isotopic compositions were corrected for fractionation using ⁸⁶Sr/⁸⁸Sr=0.1194 and ¹⁴⁶Nd/¹⁴⁴Nd=0.7219. During the course of the analyses, the La Jolla Nd standard gave an average value of 0.511851±0.000008 (n=3) and the NBS987 Sr standard gave an average of 0.710241±0.000027 (n=6). ¹⁴⁷Sm/¹⁴⁴Nd ratio errors are approximately ~1.5%, or ~0.006 (Weis et al., 2006).

5.2. Chemical changes due to alteration and metamorphism

The analyzed mafic igneous rocks have been variably altered, deformed and metamorphosed. Consequently, changes of the bulk-rock chemistry are expected as a consequence of
Table 1
Major and trace element data for the diverse groups of igneous rocks in Central Hispaniola

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**Table 1** Major and trace element data for the diverse groups of igneous rocks in Central Hispaniola

- **Group I**: RDG, GAB, DIQ
- **Group II**: GAB, BAS, PICR
- **Group III**: MAB, BAS, PICR

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- **Group I**: RDG, GAB, DIQ
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- **Group I**: RDG, GAB, DIQ
- **Group II**: GAB, BAS, PICR
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**Note**: The table describes the major and trace element data for the diverse groups of igneous rocks in Central Hispaniola.
Na2O & 2.80 & 3.01 & 2.82 & 3.87 & 3.07 & 3.89 & 4.92 & 3.45 & 4.5 & 1.96 & 1.46 & 1.87 & 2.1 & 3.41 & 2.26 \\
K2O & 0.61 & 0.19 & 0.59 & 0.26 & 0.11 & 0.38 & 0.46 & 0.05 & 0.1 & 0.07 & 0.08 & 0.08 & 0.09 & 0.09 & 0.27 \\
P2O5 & 0.08 & 0.06 & 0.1 & 0.07 & 0.08 & 0.13 & 0.16 & 0.05 & 0.05 & 0.07 & 0.06 & 0.09 & 0.08 & 0.29 & 0.25 \\
MnO & 0.12 & 0.12 & 0.16 & 0.23 & 0.13 & 0.18 & 0.17 & 0.19 & 0.16 & 0.17 & 0.16 & 0.17 & 0.16 & 0.17 & 0.19 \\
CoO & 0.036 & 0.019 & 0.023 & 0.026 & 0.006 & 0.027 & 0.006 & 0.007 & 0.008 & 0.007 & 0.008 & 0.007 & 0.008 & 0.009 & 0.008 \\
LOI & 2.8 & 2.3 & 2.0 & 2.6 & 1.3 & 1.6 & 2.6 & 2.2 & 4.5 & 1.9 & 1.0 & 1.8 & 4.5 & 4.5 & 2.3 \\
MgO & 62 & 60 & 65 & 50 & 70 & 64 & 55 & 66 & 62 & 66 & 57 & 54 & 54 & 60 & 37 \\
Cr & 246 & 130 & 226 & 176 & 137 & 41 & 90 & 582 & 260 & 301 & 496 & 239 & 287 & 62 & 

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Table 1 (continued)

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Major oxides recalculated to an anhydrous basis. Total Fe as Fe2O3. Geochemical rock groups: group I, tholeiitic to calc-alkaline island-arc basalts and andesites; group II, high-Mg andesites and basalts; group III, tholeiitic back-arc basin basalts and gabbros; and group IV, tholeiitic to transitional and alkaline oceanic intra-plate basalts. Unit: LMG, Loma La Vega Member; Cs, Constanza Fm, Tireo Group; Rs, Restauroción Fm, Tireo Group; HMA, high-Mg andesites basalts, Tireo Group; LVS, Los Velazquitos gabbros; LC, La Cana gabbros; PVSur, Peralvillo Sur Fm; PB, Peña Blanca Fm; LMSZ, La Meseta shear zone; 7C, Siete Cabezas Fm; BPPD, Pelona–Pico Duarte Fm.

- Rock type abbreviations: PICR, picritic basalt/picrite; BAS, basalt; BASAND, andesitic basalt; AND, andesite; DOL, dolerite; GAB, gabbro; DAC, dacite; MBAS, metabasalt; MAND, metaandesite; AMPH, Amphibolite; DIQ, mafic dyke.

- Mg# = 100 * mol MgO / mol (FeO + MgO); for Fe2O3/FeO = 0.2.
selected mobility of relevant elements during these processes.

Many major (e.g., Si, Na, K, Ca) and trace (e.g., Cs, Rb, Ba, Sr) elements are easily mobilised by late and/or post-magmatic fluids and under metamorphism; however, the HFSE (Y, Zr, Hf, Ti, Nb and Ta), REE, transition elements (V, Cr, Ni and Sc) and Th, are generally unchanged under a wide range of metamorphic conditions, including seafloor alteration at low to moderate water/rock ratios (Bienvenu et al., 1990). Therefore, the geochemical characterization and the discussion on petrogenesis of the igneous rocks will be based mostly on the HFSE and REE, as well as the Sm–Nd isotopic system, as it can be assumed that they were not significantly affected by alteration or metamorphism at the whole-rock scale.

5.3. Geochemical characteristics of mafic igneous rocks

Inspection of geochemical data for Turonian–Campanian igneous rocks from throughout Central Hispaniola reveals a heterogeneous assemblage. In the Nb/Y vs Zr/TiO2 plot (Fig. 4), volcanic rocks from Restauración Formation and Loma La Vega Member comprise mainly subalkalic basalt/andesite to rhyodacite, while those from the Peña Blanca, Siete Cabezas and Pelona–Pico Duarte Formation are dominantly tholeiitic subalkaline, transitional and alkalic basalts. In order to subdivide these rocks into petrogenetically-meaningful groups, we have utilized N-MORB normalized multi-element diagrams, which incorporate the incompatible, immobile HFSE, REE and Th. These diagrams reveal the presence and magnitude of positive Th (LFSE) and negative Nb–Ta (HFSE) anomalies with respect to La (REE). Such anomalies in intra-oceanic settings are widely interpreted to primary reflect supra-subduction zone magmatism, involving mantle wedge sources that have been contaminated by mass transfer from the subducting slab (Pearce and Peate, 1995a). Absence of these anomalies is generally interpreted to reflect sources that have not been contaminated by subducted material. The contemporaneous mafic igneous rocks from the different tectonic blocks can be classified into four broad geochemical groups: group I, tholeiitic to calc-alkaline island-arc basalts and andesites; group II, low-Ti, high-Mg andesites-basalts; group III, tholeiitic back-arc basin basalts and gabbros; and group IV, tholeiitic to transitional and alkalic oceanic in-plate basalts. The geochemical groups of igneous rocks recorded in each tectonic block will be reviewed below and summarized in Fig. 5.

Fig. 4. Summary of the geochemical groups of mafic igneous rocks recorded within the different crustal blocks of Central Hispaniola.

Please cite this article as: Viruete, J.E., et al., Caribbean island-arc rifting and back-arc basin development in the Late Cretaceous: Geochemical, isotopic and geochronological evidence from Central Hispaniola, Lithos (2008), doi:10.1016/j.lithos.2008.01.003
5.3.1. Group I, tholeiitic to calc-alkaline island-arc basalts and andesites

The group I is represented by the volcanic rocks of the Restauración Formation of the Jicome and Jarabacoa blocks, and the basalts of the Loma La Vega Member of the Eastern Cordillera. This group is not represented in the intermediate Bonao block. As a suite, the basalts and andesites of these units define a calc-alkaline trend of smoothly decreasing TiO$_2$, Fe$_2$O$_3$, Cr and Ni with increasing fractionation as monitored by MgO (TiO$_2$ shown in Fig. 6). TiO$_2$ content range between 0.7 and 1.1 wt.%. La/Yb ratios are consistently elevated (4.7–11.5), and are similar to those of the contemporaneous volcanic phase III in both Central and Northeast Puerto Rico (Jolly et al., 1998, 2001). In the Fig. 7, the overall trace element characteristics of the Late Cretaceous Caribbean island-arc is shown by representative rocks of the Constanza (Albian–Cenomanian) and Restauración Formation (Turonian–Lower Campanian), the Loma La Vega Member (Coniacian) and, particularly, the volcanic phase III of Puerto Rico. All these mafic volcanic rocks have typical subduction-related trace element features (Pearce and Parkinson, 1993; Woodhead et al., 1998): LILE are enriched relative to HFSE (e.g. Ba/La = 18–80), and both groups are enriched relative to HFSE (e.g. Ba/Nb = 37–460; La/Nb = 2–8), giving the characteristic Nb–Ta anomalies. In Puerto Rico (Fig. 7a), the extent of the LREE enrichment ([La/Yb]$_N$ = 1.4–8.9) increases through time from the tholeiitic lavas of the Lapa Member and Santa Olaya Formation that form the lowermost part in the figure, through the tholeiitic to calc-alkaline lavas of the Lapa Lava Member and Perchas Formation that form the uppermost part of the shaded area (Jolly et al., 2001).

In the Jicome block, massive flows and sync-volcanic dykes of tholeiitic basalts and andesites of the Constanza Formation, display patterns close to the sub-horizontal followed by N-MORB ([La/Yb]$_N$ = 1.1–1.9), though with Nb–Ta negative anomalies, slight depletion in HREE, and a variable enrichment in the most subduction-mobile elements such as Th, Sr, Pb and LREE (Fig. 7c). These subduction-related patterns are similar to those of the older tholeiitic lavas from Puerto Rico. The basalts of the Loma La Vega Member have the moderate to strong LREE enrichment ([La/Yb]$_N$ = 6.2–8.3) typical of the younger calc-alkaline volcanic rocks from Puerto Rico (Fig. 7b), although they show less of a depletion in HREE, probably due to a less depleted source (or a lower degree of partial melting). Therefore, the mafic volcanic rocks of group I represent the Late Cretaceous Caribbean island-arc magmas, where intra-arc variation in the depletion or enrichment patterns can record dynamic melting process within the sub-arc mantle wedge (Pearce et al., 1995b). Following Jolly et al. (2006), the compositional shift from tholeiitic to calc-alkaline in the emitted lavas reflects an increase in proportion of subducted pelagic sediments beneath the arc.

5.3.2. Group II, low-Ti, high-Mg andesites and basalts

The low-Ti, high-Mg andesites and basalts are represented by mafic flows and tuffs, interbedded with the felsic volcanics of the Restauración Formation in the Jicome and Jarabacoa blocks (Escuder Viruete et al., 2006), the compositional shift from tholeiitic to calc-alkaline of MgO (TiO$_2$ shown in Fig. 6). TiO$_2$ content range between 0.7 and 1.1 wt.%. La/Yb ratios are consistently elevated (4.7–11.5), and are similar to those of the contemporaneous volcanic phase III in both Central and Northeast Puerto Rico (Jolly et al., 1998, 2001). In the Fig. 7, the overall trace element characteristics of the Late Cretaceous Caribbean island-arc is shown by representative rocks of the Constanza (Albian–Cenomanian) and Restauración Formation (Turonian–Lower Campanian), the Loma La Vega Member (Coniacian) and, particularly, the volcanic phase III of Puerto Rico. All these mafic volcanic rocks have typical subduction-related trace element features (Pearce and Parkinson, 1993; Woodhead et al., 1998): LILE are enriched relative to HFSE (e.g. Ba/La = 18–80), and both groups are enriched relative to HFSE (e.g. Ba/Nb = 37–460; La/Nb = 2–8), giving the characteristic Nb–Ta anomalies. In Puerto Rico (Fig. 7a), the extent of the LREE enrichment ([La/Yb]$_N$ = 1.4–8.9) increases through time from the tholeiitic lavas of the Lapa Member and Santa Olaya Formation that form the lowermost part in the figure, through the tholeiitic to calc-alkaline lavas of the Lapa Lava Member and Perchas Formation that form the uppermost part of the shaded area (Jolly et al., 2001).

In the Jicome block, massive flows and sync-volcanic dykes of tholeiitic basalts and andesites of the Constanza Formation, display patterns close to the sub-horizontal followed by N-MORB ([La/Yb]$_N$ = 1.1–1.9), though with Nb–Ta negative anomalies, slight depletion in HREE, and a variable enrichment in the most subduction-mobile elements such as Th, Sr, Pb and LREE (Fig. 7c). These subduction-related patterns are similar to those of the older tholeiitic lavas from Puerto Rico. The basalts of the Loma La Vega Member have the moderate to strong LREE enrichment ([La/Yb]$_N$ = 6.2–8.3) typical of the younger calc-alkaline volcanic rocks from Puerto Rico (Fig. 7b), although they show less of a depletion in HREE, probably due to a less depleted source (or a lower degree of partial melting). Therefore, the mafic volcanic rocks of group I represent the Late Cretaceous Caribbean island-arc magmas, where intra-arc variation in the depletion or enrichment patterns can record dynamic melting process within the sub-arc mantle wedge (Pearce et al., 1995b). Following Jolly et al. (2006), the compositional shift from tholeiitic to calc-alkaline in the emitted lavas reflects an increase in proportion of subducted pelagic sediments beneath the arc.

The low-Ti, high-Mg andesites and basalts are represented by mafic flows and tuffs, interbedded with the felsic volcanics of the Restauración Formation in the Jicome and Jarabacoa blocks (Escuder Viruete et al., 2006). These rocks are characterized by anomalously high MgO (14.3–4.8 wt.%), Cr (978–226 ppm) and Ni (186–20 ppm) contents for a basalts–andesite range of SiO$_2$. The TiO$_2$ content are low and range between 0.2 and 0.6 wt.% (Fig. 6a), which is lower than group I rocks at a given value of MgO. The REE patterns of these rocks are similar to the tholeiitic rocks of group I, having a consistent LREE enrichment ([La/Yb]$_N$ = 1.7–4.2) and pronounced negative Nb–Ta anomalies (Fig. 7d), but the absolute abundances are lower (HREE 0.1–0.5×N-MORB) and the negative Zr and Hf anomalies are greater ([Zr/Sm]$_N$ = 0.3–1.1; average 0.78). The more primitive samples can be classified as high-Ca boninites according to the definitions of Crawford et al. (1989), and the more evolved sample exhibits intermediate characteristics between the high-Ca and low-Ca series. However, the alteration or metamorphism could change the composition of major elements composition. The lower TiO$_2$ and HREE contents (particularly Yb), and negative Zr and Hf anomalies suggest that the source for group II rocks was more enriched relative to LREE (e.g. Ba/La = 18–80), and both groups are enriched relative to HFSE (e.g. Ba/Nb = 37–460; La/Nb = 2–8), giving the characteristic Nb–Ta anomalies. In Puerto Rico (Fig. 7a), the extent of the LREE enrichment ([La/Yb]$_N$ = 1.4–8.9) increases through time from the tholeiitic lavas of the Lapa Member and Santa Olaya Formation that form the lowermost part in the figure, through the tholeiitic to calc-alkaline lavas of the Lapa Lava Member and Perchas Formation that form the uppermost part of the shaded area (Jolly et al., 2001).

In the Jicome block, massive flows and sync-volcanic dykes of tholeiitic basalts and andesites of the Constanza Formation, display patterns close to the sub-horizontal followed by N-MORB ([La/Yb]$_N$ = 1.1–1.9), though with Nb–Ta negative anomalies, slight depletion in HREE, and a variable enrichment in the most subduction-mobile elements such as Th, Sr, Pb and LREE (Fig. 7c). These subduction-related patterns are similar to those of the older tholeiitic lavas from Puerto Rico. The basalts of the Loma La Vega Member have the moderate to strong LREE enrichment ([La/Yb]$_N$ = 6.2–8.3) typical of the younger calc-alkaline volcanic rocks from Puerto Rico (Fig. 7b), although they show less of a depletion in HREE, probably due to a less depleted source (or a lower degree of partial melting). Therefore, the mafic volcanic rocks of group I represent the Late Cretaceous Caribbean island-arc magmas, where intra-arc variation in the depletion or enrichment patterns can record dynamic melting process within the sub-arc mantle wedge (Pearce et al., 1995b). Following Jolly et al. (2006), the compositional shift from tholeiitic to calc-alkaline in the emitted lavas reflects an increase in proportion of subducted pelagic sediments beneath the arc.
5.3.3. Group III, tholeiitic back-arc basin basalts and gabbros

The group III is represented by the Los Velazquitos gabbros and related dolerite dykes in the Jarabacoa block and the basalts of the Peralvillo Sur Formation in the Bonao block. The Los Velazquitos gabbros have a restricted range in SiO₂ contents, from 50.2 to 53.8 wt.% (Table 1), for TiO₂ contents between 0.8 and 1.5 wt.% (Fig. 6b). In Fig. 4b, the samples cluster mainly in the subalkaline andesite/basalt field. These gabbros show an increase of SiO₂, Fe₂O₃TOT, alkalis, TiO₂, Zr and Nb, and a decrease in Cr and Ni for decreasing MgO. Al₂O₃ and CaO increase slightly to reach a maximum at about 7–8 wt.% MgO, then decrease in the evolved basalts. These trends are tholeiitic and can be attributed to low-pressure fractionation of olivine plus Cr-spinel, plagioclase and clinopyroxene (Tribuzio et al., 2009), which is compatible with the observed mineralogy. The gabbros are more Ti-rich than rocks of groups I and II, defining a mid-Ti trend in Fig. 6b, but are less titaniferous than most of the younger group IV basalts. In the Fig. 8, all samples display a flat HREE pattern ([Sm/Yb]N = 0.9–1.1) and a slight LREE depletion ([La/Nd]N = 0.6–0.84), characteristic of normal mid-oceanic ridge basalts (e.g. Natland, 1991). Relative to N-MORB, however, these rocks have negative Nb-Ta anomalies and higher abundances of LILE such as Rb, Ba, K, Pb and Sr. Trace element patterns of the Los Velazquitos gabbros are sub-parallel to those of the group I samples, although these Caribbean volcanics are more enriched in Th, LILE and LREE. By their transitional IAT to N-MORB geochemistry and weak subduction-related signature (Fig. 6f), we interpret these gabbros to...
form in a back-arc basin setting. The high Zr/Nb ratio of these rocks suggest a source slightly more depleted than an N-MORB source.

Volcanic rocks of the Peralvillo Sur Formation also have a restricted range of SiO$_2$ (48.5–53.4 wt.%) for 7.3–5.0 wt.% MgO (Table 1) and cluster with the Los Velazquitos gabbros in the subalkaline andesite/basalt field (Fig. 4b). These basalts show a tholeiitic trend of increasing of SiO$_2$, Fe$_2$O$_3$T, TiO$_2$, Nb and Zr with decreasing MgO (not all shown in Fig. 6). The TiO$_2$ content ranges between 0.8 and 2.2 wt.%. These rocks define a mid-Ti trend with the Los Velazquitos gabbros in Fig. 6b, but the evolved basalts are slightly more Ti-rich. The Peralvillo Sur Formation volcanic rocks also display subhorizontal multi-element patterns similar to N-MORB (Fig. 8c). They are slightly LREE-depleted ([La/Nd]$_N$ = 0.7–0.8) and have flat HREE ([Sm/Yb]$_N$ = 1.0–1.5). Moreover, they have small enrichments in the most subduction-mobile elements (Rb, Ba, K and Pb), slight depletions in Nb–Ta with no negative Zr–Hf anomalies ([Zr/Sm]$_N$ = 1.0–1.4). All these characteristics are typical of back-arc basin basalts (e.g. Hawkins, 1995). A weak subduction signature is indicated by Nb/Th ratios of 8–16 (Fig. 6f). These features also suggest that the mantle source for Peralvillo Sur Formation was similar to both those of the Los Velazquitos gabbros of the Jarabacoa block and to N-MORB source (i.e. depleted mantle). The source for group III rocks was therefore more depleted than for both the arc rocks of group I and, particularly for the high-Mg andesites of group II.

5.3.4. Group IV, tholeiitic to transitional and alkaline oceanic intra-plate basalts

Group IV is represented by basalts of the Peña Blanca, Siete Cabezas and Pelona–Pico Duarte Formation of the Jicomé and Jarabacoa blocks. Some sampled amphibolites of the LMSZ also belong to this group (Table 1). The TiO$_2$–MgO variation (Fig. 6b) shows at least two distinct trends in Ti-contents, where Pelona–Pico Duarte basalts are more TiO$_2$-rich than Peña Blanca and Siete Cabezas basalts, as well as LMSZ amphibolites. The basalts of Peña Blanca Formation have 47.7–53.4 wt.% of SiO$_2$ for ranges in TiO$_2$ = 0.8–1.1 wt.%, CaO = 9.8–11.7 wt.% and Al$_2$O$_3$ = 13.5–14.8 wt.%. Mg# values of 60–42 indicate that these lavas are low to moderately fractionated. In Fig. 4b, these basalts and LMSZ amphibolites cluster between the subalkaline basalt and andesite basalts fields, but some samples plot close to the boundary of the alkali basalts field. In the Fig. 9, Peña Blanca basalts and LMSZ amphibolites have slightly LREE-enriched ([La/ Nd]$_N$ = 1.0–1.8) and flat HREE ([Sm/Yb]$_N$ = 1.0–1.3) patterns, with a positive Nb anomaly and some samples have a slight negative Eu an Ti anomalies related to plagioclase and Fe–Ti oxide fractionation. These characteristics are MORB-like but the rocks have higher concentrations of incompatible elements than group III rocks, indicative of a more enriched mantle.
source. Further, they do not have positive Pb, K and Sr spikes, and negative Nb-Ta anomalies, typical of subduction-related rocks. All these features, as well as their incompatible element ratios (Zr/Nb<15 and La/Sm>1.5) are characteristics of enriched MORB (Donnelly et al., 2004). However, some samples have a small selective enrichment in some fluid-mobile LILE (Rb, Ba, Th and U), most apparent in the positive Pb spike in the Peña Blanca Formation of the Jarabacoa block, which probably results from seafloor alteration. Relatively high-Ti contents, Nb/Th ratios (4–22; Fig. 6f) and flat-HREE indicate that these magmas were derived from a relatively enriched spinel mantle source (Donnelly et al., 2004), which had not been contaminated by a subducting slab. Probably, these basalts represent a tholeiitic volcanism in distal areas from the arc or dorsal segments affected by mantle plume activity (see below).

The basalts of the Siete Cabezas Formation have been described by Sinton et al. (1998) and Lewis et al. (2002). Our samples have 48.3–55.3 wt.% of SiO₂ for ranges in TiO₂ = 0.9–1.2 wt.%, CaO = 10.2–12.8 wt.% and Al₂O₃ = 11.4–14.6 wt.%, and cluster in the sub-alkaline basalt field (Fig. 4b). The Mg# values of 61–53 indicate that these lavas have undergone small amounts of fractionation. The basalts have slightly LREE-enriched ([La Nd]N = 1.2–1.6) and flat HREE ([Sm Y]bN = 0.9–1.5) multi-element patterns, with a positive Nb anomaly. These patterns are similar to the Peña Blanca basalts, the gabbros and dolerites dredged from the Beata Ridge (Révillon et al., 2000), and basalts of the Dumisseau Formation (Sen et al., 1988), suggesting a similar CCOP plume-related source (Fig. 9d). For similar Mg#, the Siete Cabezas basalts have higher TiO₂, Nb and Zr contents and LREE abundances than island-arc and HMA volcanic rocks of previous groups (Fig. 6). These contents are related to distinct, non-subduction related enriched sources (see below).

For a restricted range of 47.6–50.2 wt.% SiO₂, the Pelona–Pico Duarte basalts have low CaO (10.1–12.0 wt.%) and Al₂O₃ (12.8–13.7 wt.%) contents, and high contents in alkalis (2.0–2.6 wt.%), P₂O₅ (0.15–0.32 wt.%), TiO₂ (1.5–3.6 wt.%), and Fe₂O₃T (10.7–12.8 wt.%). They are all significantly Ti enriched relative to the older lavas, defining a high-Ti trend in Fig. 6b. The Mg# values of 58–52 indicate that these lavas have undergone low to moderate amounts of fractionation. Fig. 4b shows that these basalts are transitional and alkalic, which is consistent with their Qtz or Ol normative composition. These rocks show a typical tholeiitic trend of increasing TiO₂, Fe₂O₃T, CaO, Al₂O₃, Zr and Nb, for decreasing MgO (Cr or Ni). These trends can be attributed to the fractionation of olivine plus Cr-spinel, clinopyroxene (Ti-augite) and plagioclase, observed as microphenocrysts in the lavas. The basalts have LREE enriched ([La Nd]N = 1.5–2.2; Fig. 10) and depleted HREE ([Sm Y]bN = 2.1–3.7) patterns, with very high Nb contents (11–30 ppm). The negative Eu and positive Ti anomalies are related to plagioclase and Fe–Ti oxide fractionation/accumulation. These patterns and other trace element ratios are characteristic of modern day alkalic oceanic-island basalts (Frey et al., 2002). The higher TiO₂ and [Sm Y]bN ratios suggest that the mantle...
source for these basalts was the most enriched in group IV and contained garnet. These rocks are interpreted as partial melts of a plume-related, deep enriched source, which have not been contaminated by active subduction (Nb/Th in Fig. 6f).

5.4. Nd and Sr isotope variations and interpretation

The different geochemical groups identified on the basis of their trace element contents and ratios also possess characteristic radiogenic isotopic ratios. In the ($^{87}\text{Sr}/^{86}\text{Sr}$) vs ($\varepsilon_{\text{Nd}}$) diagram of Fig. 11, Caribbean island-arc rocks are represented by the diagonal field of Loma La Vega basalts of group I (Lebrón and Perfit, 1994) and Late Cretaceous lavas from Eastern Puerto Rico block, which is subparallel to a calculated
mixing line between pelagic sediments and a representative arc basalt (Jolly et al., 2001). The Sr–Nd isotopic data for Loma La Vega basalts of group I are consistent with the presence of a subducted sediment component. In Fig. 11, samples of the groups III and IV are restricted to high (ɛNd) values between +7.0 and +10.0 (where $i = 89$ Ma; Table 3), similar to mid-ocean ridge basalts (Su and Langmuir, 2003). The 87Sr/86Sr ratios are highly variable (0.70283 to 0.70557) at very restricted ranges of (ɛNd) values between +9.6 and +10.0 in group III and between +7.0 and +7.2 in group IV. This is consistent with seawater alteration (e.g. Sinton et al., 1991), which shift the samples from the MORB array to the right, and (87Sr/86Sr) ratios therefore are not primary.

The (ɛNd) values of the group III Los Velazquitos gabbros and dolerite dykes intrusive in the peridotite are high and homogeneous, compatible with a source dominated by depleted mantle, similar to Depleted MORB Mantle composition (DMM, Su and Langmuir, 2003) without incorporation of pelagic sediments; the (ɛNd) values of group IV pillow lavas and fine-grained dolerites/gabbros are lower, also compatible with a depleted source, but more enriched than for group III rocks. Fig. 11 also show that this enriched source had a similar range of (ɛNd) values to the CCOP units, as such the Dumisseau Formation and 146–150–156 sites of DSDP Leg 15. The high (ɛNd) values of basalts of groups III and IV are also inconsistent with a large pelagic sediment component in the source as in subduction-related group I. In summary, during the Late Cretaceous, the source changed from relatively enriched and affected by a sedimentary component in group I, to depleted and unaffected by sediments in groups III and IV. With respect to group III, the source of group IV was slightly more enriched and similar to those of the Caribbean plume-related units.

6. Discussion

6.1. Mantle and slab contributions

One way to assess the relative contribution of source composition and subduction component in arc-related igneous rocks is to plot ratios of incompatible elements, in which the effects...

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**Fig. 12.** Plots of Zr/Yb versus Nb/Yb for the defined geochemical groups of Late Cretaceous igneous rocks in Central Hispaniola. The Caribbean island-arc trend is represented by the Aaptian to Eocene volcanic rocks of Puerto Rico (data from Jolly et al., 2001, 2002, 2006; Schellekens, 1998). A Caribbean MORB-OIB array is defined by the subduction-unmodified lavas from the East Pacific Ridge (data from Su and Langmuir, 2003, PETDB, 2007; and references therein) and completed by samples from the Late Cretaceous Caribbean–Colombian oceanic plateau (Hauff et al., 2000; Kerr et al., 1997, 2002; Sinton et al., 1998; Lapierre et al., 1999, 2000). The Caribbean plume enriched component probably increases in magnitude with proximity to the plume. Representative basalts from the Dumisseau Formation and DSDP Leg 15, as well as gabbros and dolerites from the Beata Ridge, are also shown (data from Révillon et al., 2000; Sen et al., 1988; Sinton et al., 1998). In the plot, there are three principal types of trend (vector), described in detail by Pearce et al. (1995a): A = variable subduction component; B = variably enriched mantle wedge; C = variable melt extraction. See text for explanation. N-MORB, E-MORB and OIB values are from Sun and McDonough (1989).
of pooled melting or fractional crystallization/accumulation are minimized. Following the approach of Pearce and Parkinson (1993), a Caribbean MORB-OIB array of increasing Zr/Yb, Th/Yb and La/Yb with increasing Nb/Yb, is defined by the subduction-unmodified lavas from the East Pacific Ridge (Figs. 12 and 13; data from Su and Langmuir, 2003, PETDB, 2007; and references herein), considered on the basis of trace element/isotopic fingerprinting and plate reconstruction models (Pindell et al., 2005), to belong to the same mantle domain. The Caribbean MORB-OIB array is completed by samples from the CCOP (Hauff et al., 2000; Kerr et al., 1997, 1999, 2002; Sinton et al., 1998; Lapiere et al., 1999, 2000), which generally have higher Nb/Yb ratios than the global average N-MORB, and suggest the influence of a Late Cretaceous Caribbean plume in the source enrichment. This influence means that CCOP samples are enriched relative to N-MORB, and probably this enriched component decreases in magnitude with distance from the plume. In the figures, the Caribbean island-arc trend is represented by the volcanic rocks of Puerto Rico, which constitute a complete record of subduction-related volcanism in the area, spanning >70 Ma from Aptian to the Eocene (data from Jolly et al., 1998, 2001, 2006; Schellekens, 1998). The Caribbean island-arc lavas are displaced from the MORB-OIB array to much higher concentrations of the subduction-mobile elements Th and La. The inference is that Zr/Yb and Nb/Yb ratios are little or unaffected by additions of components during subduction, whereas increases in Th/Yb and La/Yb reflect addition of slab-derived components (Pearce et al., 1995b).

In the Zr/Yb vs Nb/Yb plot, samples of groups I and II collectively form a linear trend that passes near average N-MORB and extend along the Caribbean island-arc trend. Following Pearce et al. (1995a), the plot shows that for these groups both Zr and Nb are not present in significant concentrations in the subduction component. This plot also indicates that samples from the Peralvillo Sur Formation and the Los Velazquitos gabbros are generally distinctive from arc-related group I and II in that they have low Zr/Yb and Nb/Yb ratios (and higher [εNd]). The mantle source for group III is therefore depleted relative to N-MORB and interpreted to have experienced previous partial melt extraction, and hence depletion in incompatible elements. Such depleted mantle was also unaffected by hotspot and/or plume influences. Samples from the group IV are variably enriched (higher Nb/Yb) relative to average N-MORB; amphibolites of the LMSZ and basalt from the Peña Blanca, Pelona–Pico Duarte and Siete Cabezas Formation are all significantly enriched and trend to average E-MORB composition. This, together with their slightly lower (εNd) values, appears to reflect the influence of the Caribbean plume component in the group IV basalts, which also displaced CCOP samples from the MORB-OIB array to higher Nb/Yb values (opposite to vector B in Fig. 12). In terms of incompatible element ratios, this enriched component is similar to representative basalt of the Dünsueze Formation and DSDP Leg 15, as well as gabbros and dolerites from the Beata Ridge (Fig. 12d) all considered as integral part of the CCOP (Révillon et al., 2000; Sen et al., 1988; Sinton et al., 1998).

Addition of a constant subduction component to a mantle source of constant composition results in a vertical trend on the ɛNd diagrams of the Fig. 13, as only Th and La are added, while Nb and Yb remain nearly constant (Pearce et al., 1995a). Arc-related samples of the Loma La Vega Member, Restauración Formation and group II particularly follow this vertical trend, whereas group IV samples of the Peña Blanca, Siete Cabezas and Pelona–Pico Duarte Formation (plus LMSZ amphibolites) do not. In the Fig. 13, the subduction vector A extends vertically from the Caribbean MORB-OIB array, with the subduction contribution estimated by contour lines drawn parallel to the array (Pearce et al., 1995b). Fig. 13 reveals that the subduction contributions for Th and La range up to 95 and 80% for Loma La Vega Member, respectively, being generally smaller for Restauración Formation and group II basalts and anodesites. Addition of a subduction component followed by variable degrees of melting, such as dynamic melting, gives a trend parallel to but displaced from the MORB-OIB array (vector C; Pearce et al., 1995a). The trends formed by the group I and II, in particular basalts of the Loma La Vega Member, run subparallel to the regional MORB-OIB array for Th and La (Fig. 13). Therefore, the arc-related rocks of groups I and II result from a combination of variable subduction component added to a variable mantle wedge composition.

Addition of a constant subduction component to a variable mantle source gives a negative, flat or shallow positive slope as depleted mantle (with lowest Nb) is affected more than enriched mantle (Pearce et al., 1995a; Leat et al., 2004). In Fig. 13, basalt of the Peralvillo Sur Formation and Los Velazquitos gabbros plot close to the Nb/Yb ratio of mean N-MORB or within the depleted part of the array. Some samples extend to slightly high contents of Th and La indicating a small subduction input. Therefore, group III samples are interpreted as being derived from depleted mantle with minor or no subduction component addition. In contrast, group IV samples from the Peña Blanca and Siete Cabezas Formation plot in the enriched part of the MORB array (but more depleted than E-MORB), with no subduction addition. Basalts of the Pelona–Pico Duarte Formation plot even more higher Nb/Yb values, and approach average OIB composition. In Fig. 13, the Peña Blanca and Siete Cabezas Formation basalts plot as a tight cluster with a similar composition to the CCOP, which implies that group IV samples have a similar enriched Caribbean plume component and also were unaffected by subduction influences. In summary, Th/Yb–La/Yb vs Nb/Yb relationships indicate a subduction component decrease and an enriched Caribbean plume component increase trough time in the Jicome, Jarabacoa and Bonao blocks.

6.2. Tectonomagmatic evolution of Central Hispaniola in the Late Cretaceous

In the models proposed for island-arc rifting and subsequent back-arc basin development (e.g. the northern Mariana Trough...
back-arc basin), systematic changes in magma geochemical and isotopic compositions reveal a progressive transition from early arc rift lavas, that are indistinguishable from arc lavas, to later basalts produced by decompression melting in spreading centres, as response to a reorganization of mantle convective regimes (Taylor et al., 1996; Gribble et al., 1998; Martínez and Taylor, 2002; Taylor and Martinez, 2003). The arc-like to non-arc-like magma evolution recorded in the different blocks of Central Hispaniola. The mantle flow convective regimes beneath rifted arcs and evolving back-arc basins are based on Gribble et al. (1998) and Taylor and Martinez (2003). (a) The motion of the subducting proto-Caribbean slab drives corner flow advection in the mantle wedge. Water released by the slab promotes partial melting in the mantle above the solidus (heavy dashed lines), which is progressively depleted of a melt component toward the volcanic front. Melts rises and gave rise group I tholeiitic basalt/andesite suite and ultramafic/mafic cumulates in the lower arc crust. (b) When Caribbean island-arc extension commences, the lithosphere rifts near the rheologically weak volcanic front. Hydrated mantle is advected upward into the stretching and thinning lithosphere, leading to high degrees of melting in the rift phase. As the mantle was previously depleted, the melts are group II low-Ti, high-Mg andesites and basalts. Arc rifting could be triggered by ridge subduction/collision in the forearc, as suggested the contemporaneous adakitic magmatism (Escuder Viruete et al., 2007b). (c) With increasing extension a seafloor spreading centre is established near the volcanic front advecting highly hydrated mantle. As consequence, back-arc basin basalt-like group III magmas result. (d) With continued spreading the extension axis separates from the volcanic front and mantle hydration from the slab decreases. Eventually, the back-arc spreading system separates sufficiently from the volcanic front that it is not significantly affected by hydration and slab-derived geochemical components. Spreading centre is now advecting shallow mantle and melts are group IV MORBs, modified by a Caribbean plume enriched component incorporated by lateral flow bellow the extended arc from the SW. Melts derived from a similar but deeper, Caribbean plume enriched source gave rise to OIB-type off-ridge magmatism in the back-arc area.

Fig. 14. Schematic tectonomagmatic model for Late Cretaceous Caribbean island-arc rifting and subsequent back-arc basin development, based on the magmatic evolution recorded in the different blocks of Central Hispaniola. The mantle flow convective regimes beneath rifted arcs and evolving back-arc basins are based on Gribble et al. (1998) and Taylor and Martinez (2003). (a) The motion of the subducting proto-Caribbean slab drives corner flow advection in the mantle wedge. Water released by the slab promotes partial melting in the mantle above the solidus (heavy dashed lines), which is progressively depleted of a melt component toward the volcanic front. Melts rises and gave rise group I tholeiitic basalt/andesite suite and ultramafic/mafic cumulates in the lower arc crust. (b) When Caribbean island-arc extension commences, the lithosphere rifts near the rheologically weak volcanic front. Hydrated mantle is advected upward into the stretching and thinning lithosphere, leading to high degrees of melting in the rift phase. As the mantle was previously depleted, the melts are group II low-Ti, high-Mg andesites and basalts. Arc rifting could be triggered by ridge subduction/collision in the forearc, as suggested the contemporaneous adakitic magmatism (Escuder Viruete et al., 2007b). (c) With increasing extension a seafloor spreading centre is established near the volcanic front advecting highly hydrated mantle. As consequence, back-arc basin basalt-like group III magmas result. (d) With continued spreading the extension axis separates from the volcanic front and mantle hydration from the slab decreases. Eventually, the back-arc spreading system separates sufficiently from the volcanic front that it is not significantly affected by hydration and slab-derived geochemical components. Spreading centre is now advecting shallow mantle and melts are group IV MORBs, modified by a Caribbean plume enriched component incorporated by lateral flow bellow the extended arc from the SW. Melts derived from a similar but deeper, Caribbean plume enriched source gave rise to OIB-type off-ridge magmatism in the back-arc area.

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Central Hispaniola can be related to a similar tectonomagmatic model, which is conveniently described in terms of four broad stages illustrated in Fig. 14.

6.2.1. Pre ∼90 Ma, Caribbean island-arc

The Tireo Group has been interpreted as record of an extended episode of volcanic and associated sedimentary activity in the suprasubduction zone setting of the Caribbean island-arc (Escuder Viruete et al., 2007b). In the Jicomé block, the Constanza Formation consists of a ∼2500-thick sequence of andesites and basalts that accumulated from the Albian to Turonian (>90 Ma). This sequence can be correlated with contemporaneous tholeiitic basalt–andesite suites elsewhere in the Greater Antilles (Kerr et al., 1999; Lewis et al., 2002; Jolly et al., 2006). The associated gabbroic to ultramafic cumulate igneous complexes of the Jarabacoa block, which represent the exhumed roots of the magmatic arc (Escuder Viruete et al., 2004), also belong to this stage. However, the stratigraphic base of the sequence is not exposed, and so a considerable section of pre-Albian geological history is missing.

6.2.2. 90–88 Ma, Caribbean island-arc extension and rifting

In the Jicomé and Jarabacoa blocks, the overlying Restauración Formation is characterized by contemporaneous adakites (93–83 Ma), high-Mg andesites and basalts and Nb-enriched basalts, around the Turonian–Coniacian boundary (∼90 Ma) to Santonian/Lower Campanian (Escuder Viruete et al., 2007a,b). High-Mg mafic lavas were sheared by La Meseta shear zone (88–74 Ma; Ar–Ar in hornblende) and intruded by syn-kinematic hornblende-bearing tonalites (87.9 ± 1 Ma; U–Pb in zircon; Joubert et al., 2004), and their extrusion at 90–88 Ma therefore provides a critical constraint on our model. In a context of arc magmatism,
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Mg-rich melts (high-Mg andesites and boninitic rocks) have been related to the subduction of a spreading ridge or young oceanic lithosphere, crustal arc rifting and the initiation of normal back-arc spreading (e.g. Calmus et al., 2003; McCarron and Smellie, 1998; Tamura and Tatsumi, 2002; Taylor and Martinez, 2003; Shervais et al., 2004; Ishizuka et al., 2006).

The extrusion of low-Ti, high-Mg andesites and basalts in Central Hispaniola is related to an anomalous heat injection at the base of the Caribbean plate, resulting in elevated geotherms and promoting hydrous partial melting of subduction-contaminated depleted mantle sources. To fulfil these thermal and chemical requirements, the group II rocks are interpreted as result of melting in an unusual tectonic setting such as arc rifting/back-arc opening and contemporaneous subduction of young lithosphere, similar to the high-Mg andesite-adakite association in the Setouchi Belt of SW Japan (Shimoda et al., 1998; Furukawa and Tatsumi, 1999; Tatsumi and Hanyu, 2003). The high temperatures required to produce the Mg-rich melts of group II rocks and the relatively rapid transit of the magmas through the crust can also be explained by arc rifting and induced heating (Yogodzinski et al., 2001). From 90–89 Ma, hornblende-totanites with juvenile geochemical characteristics, inherited either through partial melting of the lower primitive arc crust by the high heat flow, or through fractionation of adakitic magmas, also intruded the arc sequences in Central Hispaniola (Escuder Viruete et al., 2004).

6.2.3. 90–80 Ma, Trench migration of the Caribbean island-arc and opening of the Loma Caribe back-arc basin

Immediately following or, as indicates the 5JE79 gabbro age, temporally overlapping the extrusion of the adakitic dacies-rhyolites in the Jicomé and Jarabacoa blocks, a long-lived episode of tholeiitic basaltic volcanism was initiated in Central Hispaniola. This event is mainly represented by the Peralveloro Sur and the Los Velazquitos basalts, as well as mafic dykes and sills intruded in the serpentinitized Loma Caribe peridotite. In modern arcs, this change from intermediate to acid volcanism, particularly ignimbrites and associated pyroclastic deposits, to eruption of tholeiitic basalts and dolerite feeder dikes, characterize the transition from the extensional to the rift stages (Busby et al., 1998; Fackler-Adams and Busby, 1998). In the Bonao block, the Peralveloro Sur Formation and associated igneous rocks, form several <2 km-thick dismembered sheets, structurally adjacent to the Loma Caribe peridotite. Collectively, the sheets have an ophiolitic stratigraphy of layered to massive gabbros, dolerites/diorites, flow and pillow basalts, fine-grained volcaniclastic tuffs, shales and Campanian cherts. As the Los Velazquitos basalts of the Jarabacoa block, these tholeiitic igneous rocks were derived from a depleted mantle source less affected by a subduction component. Therefore, the Bonao block is considered to represent a fragment of an emigmatic Loma Caribe back-arc basin. Microgabbro/diorite and dolerite dykes intruded in the peridotite are also interpreted to have formed during this magmatic event. They display a wider range of geochemical types between back-arc basin basalts, N-MORB and E-MORB, and 6JE66e dolerite has a $(\epsilon_{Nd})=+9.2$ value indicating derivation from a depleted mantle source.

6.2.4. 80–70 Ma, Arc rollback and sea-floor spreading influenced by the Caribbean plume

In the Jicomé and Jarabacoa blocks, the basalts of the Peña Blanca, Siete Cabezas and Pelona–Pico Duarte Formation, as well as amphibolites of the LMSZ, imply magmatic activity further removed from the influence of the subducting slab. Group IV rocks therefore represent the subsequent stage of back-arc spreading and off-axis magmatism, and are a consequence of the arc volcanic axis migration toward the northeast by rollback processes. In the Jicomé block, the highly fragmental nature of the dacites-rhyolites of the Restauración Formation, with accretionary lapillies preserved, suggests that volcanic rocks were the product of Surtseyan-style eruptions and, hence, were erupted in a shallow-water environment. In contrast, the tholeiitic basalts of the overlying Peña Blanca Formation are dominantly nonvesicular flow and pillow basalts. These relationships suggest that the Peña Blanca Formation was deposited in a deep water marine environment produced by crustal arc extension-related subsidence. The Siete Cabezas Formation basalts were extruded over the Duarte Complex directly, through a thinner crust, and probably they represent a more mature stage of back-arc development.

The enrichment in Nb/Yb ratio (and in LREE/HREE) relative to both N-MORB and Caribbean island-arc in the group IV rocks, suggests that an enriched plume mantle component was present in the back-arc. These rocks also have significantly different trace element compositions and generally higher $(\epsilon_{Nd})$ values than the arc-related samples, which rules out derivation of the magmas by dynamic melting processes from the same sources. Therefore, these rocks are melts sampling an enriched component that has migrated into the back-arc basin. Due to the similar values of petrogenetic tracers (incompatible trace element ratios and $(\epsilon_{Nd})$ values) and geological evidence, the most likely source of this plume material is the nearby Late Cretaceous Caribbean mantle plume. The absence of a Caribbean plume component in the sources of the pre-Campanian arc-related lavas in Central Hispaniola, suggests that flow of enriched mantle to the Caribbean arc mantle wedge region was not fully effective until the establishment of a zone of mantle upwelling beneath a spreading ridge (i.e. a mantle flow regime typical of back-arc basins). However, the plume sources were in detail heterogeneous. Applying the melting models developed by Kerr et al. (2002) reveals that the Peña Blanca and Siete Cabezas magmas were derived from a high degree of melting (10–18%) of a relatively enriched spinel lherzolite mantle source. Depresssion melting in a back-arc spreading centre, could thus form the E-MORB-type magmas characteristic of the CCOP. The Pelona–Pico Duarte basalts are derived from a lower melting degree (3–5%) of a more enriched mantle.
source containing garnet. This source was therefore deeper and underwent a lower degree of melting than the source of Peña Blanca basalts. Spatially restricted to the Jicome block, the Campanian Peña–Pico Duarte transitional and alkaline basalts probably result from off-axis magmatism in the back-arc area.

6.3. Tectonic implications

The exposed stratigraphic, geochronological and geochemical data indicates that Central Hispaniola is made up of several different tectonic blocks. These blocks are characterized by unique Turonian–Campanian volcanic stratigraphies, indicating they represent separated, ensialic to ensimatic portions of a Loma Caribe back-arc basin. Their structural juxtaposition took place during the closure of the back-arc basin, probably in the Middle Eocene arc-continent collision. This is consistent with Caribbean island-arc burial beneath the unconformable Eocene–Oligocene rocks of the Magua–Tavera Groups and with the evolution of the Late Eocene–Early Miocene syn-collisional turbiditic El Mamey Group farthest to the northeast (Mann, 1999).

Fig. 15 schematically illustrates the model for the opening of the Loma Caribe back-arc basin. It is based on the models of Gribble et al. (1998) for the opening of the northern Mariana Trough, combined with the more recent plate tectonic reconstructions for the Caribbean of Pindell et al. (2005). The tectonic evolution involves (a) intra-arc extension in the Caribbean island-arc; (b) intra-arc rifting starts forming the Peralvillo Sur Formation in the Bonao block, while the Jicome and Jarabacoa blocks (Restauración Formation) are still in an extensional phase; and (c) active sea-floor spreading is propagated sub-parallel to a NNW–SSE trench and associated a strike-slip fault system (in present coordinates), induced by arc rollback and the oblique motion of the subducting plate. In (a), the high-Mg andesites and basalts of the Restauración Formation constitute the first mafic magmatic products of arc extension and rifting. In this tectonic setting, collision of a ridge or other buoyant feature with the subduction-zone forearc at ~90 Ma could give rise arc rifting with subsequent opening of a back-arc basin, and/or collision of the Cuban forearc with the Yucatán continental fragment in the Santonian–Campanian could cause that Caribbean plate to rotate rapidly and trigger back-arc opening by arc rollback forces, similar (inset in Fig. 15b) the mechanism proposed by Wallace et al. (2005).

The non-arc-like magmatism of the Peña Blanca and Pelona–Pico Duarte Formation suggests that the Jicome block had drifted away from the active Caribbean arc magmatism by the Santonian–Campanian. Therefore, this arc crustal block represent part of the remnant arc crust left behind when the Caribbean island-arc started to rift and opened into a back-arc basin during the Santonian–Lower Campanian, while the Loma La Vega Member basalts and correlatives in Central and Eastern Puerto Rico, probably represent a younger phase of the Caribbean arc formed after migration of the volcanic axis toward the northeast by trench rollback. It is consistent with the 40 km northward migration of the principal volcanic axis in Central Puerto Rico during Cretaceous subduction described by Jolly et al. (2001). A similar succession from arc-like to non-arc-like magmatism is also recorded in the Jarabacoa block. The BABB-like Los Velazquitos gabbros intrude an older oceanic basement composed of remnants of Late Jurassic crust and/or Lower Cretaceous Duarte complex, and suggest that the block represents transitional rather than true back-arc oceanic crust.

The tholeites and associated pelagic sediments of the Campanian Peralvillo Sur Formation are probably the older crustal rocks in the Bonao block. The trace element composition of these basalts incorporate a weak subduction-related component, and are similar to basalts erupted in other mature back-arc basins. Therefore, the Bonao block represents true back-arc oceanic crust formed by seafloor spreading. This agrees with the cr-number [molar Cr/(Cr+Al) = 0.38 ± 0.44] vs mg-number [molar Mg/(Mg+Fe²⁺) = 0.59 ± 0.64] of analysed Cr-spinels from Iherzolite bodies of the Loma Caribe peridote that fall within the abyssal peridotite array and back-arc basin basalt fields (Dick and Bullen, 1984). However, a more complex fusion history has been proposed for this mantle fragment (Lewis et al., 2006) and further research is in progress. The peridotite is intruded by undated E-MORB gabbros and dolerites which are derived from sources unaffected by subduction. Like Peña Blanca, Siete Cabezas and Pelona–Pico Duarte basalts, their enriched trace element patterns reflect subsequent back-arc spreading and off-axis magmatism influenced by the Caribbean plume.

7. Conclusions

Based on the Turonian–Campanian volcanic history of the blocks, geochemical composition and physical characteristics of their constituent volcanic rocks, the blocks in the Central Hispaniola are interpreted to represent the remnants of extended island-arc and oceanic plateau (Jicome), transitional (Jarabacoa) and oceanic (Bonao) crust, which formed part of a Loma Caribe back-arc basin. This back-arc basin formed in response to rifting of the Caribbean island-arc that started at ~90 Ma. The group I volcanic rocks of the Constanza Formation and associated cumulate igneous complexes preserved in the Jicome and Jarabacoa blocks, represents the previous Alban–Cenomanian Caribbean island-arc. The<90 Ma igneous rocks in Central Hispaniola provide an evolutionary sequence of arc rifting and subsequent back-arc basin development. The arc-like magmatism of the rift stage in the Jicome and Jarabacoa blocks took place from the Turonian–Coniacian transition to Santonian–Lower Campanian, particularly in its lower part with extrusion at 90–88 Ma of group II low-Ti, high-Mg andesites and basalts. Immediately following or temporarily overlapping the extrusion of adakites in the Jicome and Jarabacoa blocks, a Coniacian–Lower Campanian back-arc spreading stage of group III tholeitic magmatism was initiated. In the Bonao block, this event is represented by back-arc basin basalts-like magmas intruded in the Loma Caribe peridotite, as well as the Peralvillo Sur Formation basalts capped by tuffs, shales and Campanian cherts. This dismembered ophiolitic stratigraphy indicates that the Bonao block is a fragment of an ensimatic back-arc basin. In the Jicome and Jarabacoa blocks, the mainly Campanian group IV basalts of the Peña Blanca, Siete Cabezas and Pelona–Pico
Duarte Formation, imply a magmatic activity further removed from the influence of the subducting slab. These rocks therefore represent the subsequent stage of back-arc spreading and off-axis magmatism, consequence of the arc volcanic axis migration by rollback processes. The group IV basalts have geochemical affinities of a mantle domain influenced by the Caribbean plume. Our data thus suggest that mantle was flowing toward the NE, beneath the extended Caribbean island-arc, in response to roll-back of the subducting proto-Caribbean slab.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.lithos.2008.01.003.

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