5

Geological Constraints for the Geodynamic Evolution of the Southern Margin of the Caribbean Plate

Giuseppe Giunta
Dipartimento di Geologia e Geodesia, Università di Palermo, Italy

Michele Marroni
Dipartimento di Scienze della Terra, Università di Pisa, Italy

Elisa Padoa
Dipartimento di Scienze della Terra, Università di Firenze, Italy

Luca Pandolfi
Istituto di Geoscienze e Georisorse, Consiglio Nazionale delle Ricerche, Pisa, Italy

ABSTRACT

The southern margin of the Caribbean plate, cropping out in the Venezuela belt, consists of an assemblage of four main terranes: the Dutch-Venezuelan Islands, Margarita Island, Cordillera de la Costa, and Serrania del Interior. These terranes have been located, since the middle Cretaceous, along the transform boundary between the Caribbean and South American plates. On the basis of both new data and the literature, a critical review of the complex and long-lived evolution recorded in different units of these terranes is herein provided in order to highlight the Mesozoic–early Tertiary geodynamic evolution of the southern Caribbean.

The analysis of the lithostratigraphic, petrologic, and tectono-metamorphic features of the terranes, as well as their regional correlations, allows us to define the main geotectonic elements (as oceanic basins, magmatic arcs, subduction zones, continental margins, continental microplates, etc.) involved in the evolution of the southern Caribbean margin. The magmatic, tectonic, and metamorphic histories of these elements provide valuable constrains for the evolution of the southern Caribbean, as, for instance, the beginning of the convergence during the Early Cretaceous, the atypical evolution of the suprasubduction system during the middle Cretaceous, the role of the middle Cretaceous strike-slip tectonics, the exhumation histories of the high-pressure/low-temperature (HP-LT) units. The collected data suggests a Middle Jurassic–Early Cretaceous location

of these elements in a westernmost, "near mid-America" position, almost at the northwestern corner of the South American plate. Starting from the middle Cretaceous, the elements have been affected by a right-oblique convergence along the transform boundary connecting the two oppositely dipping subduction zones of the Andes and Aves–Lesser Antilles. According to the geologic constraints, three possible geodynamic scenarios can be proposed for the beginning of the convergence during the middle Cretaceous, taking into account the different locations of the transform fault in the geodynamic setting of the southern Caribbean. The collisional belt, resulting from the middle Cretaceous tectonics, has been dissected in different terranes, progressively rotated clockwise, reciprocally juxtaposed, and then eastward displaced. The geodynamic framework was closely related to the progressive eastward motion of the Caribbean plateau which, in turn, was associated with the development of a west-southwest-dipping, intraoceanic subduction of the proto-Caribbean oceanic crust below the plateau, and related island-arc calc-alkaline magmatism, today preserved in the Dutch–Venezuelan Islands and Aves–Lesser Antilles. At that time, the terranes were already emplaced onto the South America continental margin. Northward, the dextral strike-slip tectonics of the Caribbean southern margin increasingly involved the southern part of the magmatic arc, which gradually became inactive and underwent a progressive rotation clockwise. In contrast, the Aves–Lesser Antilles were gradually bent eastward by the oblique convergence occurring at the southern end of the magmatic arc. Since the late Paleocene, the whole marginal belt was already completely identifiable with the large shear zone occurring today at the transform boundary between the Caribbean and South American plates.

INTRODUCTION

The Caribbean plate is an independent lithospheric fragment located between the North and South American plates. The northern and southern margins of the Caribbean plate are characterized by east-west-trending orogenic belts, today constituted by deformed terranes bounded by major strike-slip shear zones.

The evolution of the Caribbean plate margins has been the subject of scientific debate during the last two decades. The major disagreements currently concern : (1) the origin of the Caribbean plate, (2) the polarity of the Cretaceous subduction zones, (3) the possibility of a subduction polarity reversal, and (4) the paleogeography, as well as the number of magmatic arcs. All the proposed models are founded on both large-scale palinspastic reconstructions based on geophysical data and preliminary geologic and petrological evidence not fully correlated on a large scale.

Studies have been carried out recently (mainly in the framework of the International Geological Correlation Project (IGCP)-Project 433) in order to characterize the units preserved in the belts of the northern and southern Caribbean margins. In this paper, the results of detailed geologic and petrological investigations carried out at the southern margin of the Caribbean plate are considered. New data are reported, along with those of the literature. Particular attention is focused on the complex magmatic, tectonic, and metamorphic evolutions of the units (mainly of the Northern Venezuela terranes), which provide important geologic constraints for a reconstruction of the geodynamics of the Caribbean–South America boundary. Possible models of the evolution of the southern margin of the Caribbean plate are thus presented in order to integrate all the available data in a common paleotectonic reconstruction.

PLATE TECTONIC SETTING

The present-day arrangement of the Caribbean region results from a complex plate-tectonic evolution that began in the Mesozoic. During the Late Jurassic, in response to the Central Atlantic opening and related rifting and drifting of the North American (NOAM) and South American (SOAM) plates, several spreading centres developed in a "near mid-America"
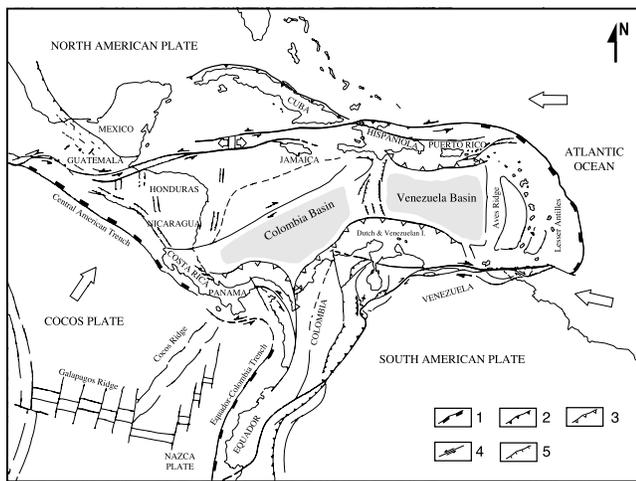
Figure 1. Tectonic sketch of the Caribbean plate. Arrows indicate the prevalent directions of the plate movements. The main active tectonic features are also shown: (1) trenches and subduction zones; (2) frontal thrusts; (3) Tertiary accretionary prism; (4) strike-slip faults; (5) extensional faults.

position and led to the development of the proto-Caribbean oceanic lithosphere. This hypothesis, proposed by several authors (Dengo, 1985; Frisch et al., 1992; Giunta, 1993; Iturralde-Vinent, 1994; Meschede and Frisch, 1998; Giunta et al., 2002), is in contrast with the Pacific origin model proposed by Pindell and Barret (1990) and Pindell (1993). The western portion of this oceanic domain subsequently underwent thickening and evolved to an oceanic plateau structure (B″ horizon of the Caribbean: Donnelly, 1975; Burke et al., 1984) as a result of different pulses related to large-scale magmatic events occurring over 91–88 Ma, with local episodes also at 76 and 63 Ma (Sinton et al., 1998). In addition, starting from the middle Cretaceous, the opening of the South Atlantic Ocean and the related northwestward movement of the SOAM with respect to the NOAM induced convergent tectonics in the Caribbean. From the Late Cretaceous onward, the continuous convergence between the NOAM and the SOAM produced the eastward drifting of the Caribbean plateau, giving rise to the development of both a stronger strike-slip stress field (as well as further shortening) at its northern and southern boundaries, and shortening and opposite subductions at the eastern and western margins.

The present-day Caribbean plate (Figure 1) mainly consists of a relatively undeformed central portion (Colombia and Venezuela basins) generally constituted by thick oceanic crust (8–20 km: Edgar et al., 1971; Case et al., 1990) overlain by flat-lying sediments (Bowland and Rosencrantz, 1988); its margins

correspond to strongly deformed belts of variable width. In particular, the western (Central America Isthmus) and the eastern (Lesser Antilles) margins are represented by magmatic arcs associated with active convergent systems, in which the Caribbean lithosphere is thrust over the Pacific and Atlantic oceanic lithospheres, respectively. In turn, the northern (Guatemalan Motagua Belt and Greater Antilles) and southern (Northern Venezuelan Cordilleras) margins are affected by active strike-slip tectonics characterized by west-east-trending shear zones dismembering narrow orogenic belts, as well as by suture zones generated during the Cretaceous–early Tertiary convergent tectonic phases.

The peri-Caribbean marginal belts are the result of complex interaction between several first-order geotectonic elements, characterized by different tectonomagmatic features and originated in different paleodomains. These geotectonic elements of the Caribbean region are (Giunta et al., 2002):

- continental margins (e.g., North and South America, and the minor blocks of Maya, Chortis, Escambray, Cordillera de la Costa) including a pre-Mesozoic basement that was often affected by Jurassic–Early Cretaceous rifting episodes, characterized by within-plate tholeiitic (WPT) magmatism
- Jurassic–Early Cretaceous oceanic (proto-Caribbean) crust with mid-ocean ridge (MOR) affinity that subsequently evolved into an oceanic plateau structure with related ocean island basalts (OIB) during the Cretaceous
- Cretaceous intraoceanic and/or subcontinental subduction systems, in which both oceanic and continental crustal units were deeply involved, undergoing high-pressure/low-temperature (HP-LT) metamorphism
- middle and Late Cretaceous magmatism with island arc tholeiitic (IAT) and/or calc-alkaline affinities
- foredeep basins developed since the latest Cretaceous onto both the NOAM and SOAM margins

THE SOUTHERN MARGIN OF THE CARIBBEAN PLATE

Northern Venezuela mainly represents the southern margin of the Caribbean plate (Figures 2 and 3) with the exception of its southwesternmost corner, which was probably connected to the ophiolitic belt of Ecuador and Colombia (i.e., Romeral); this latter
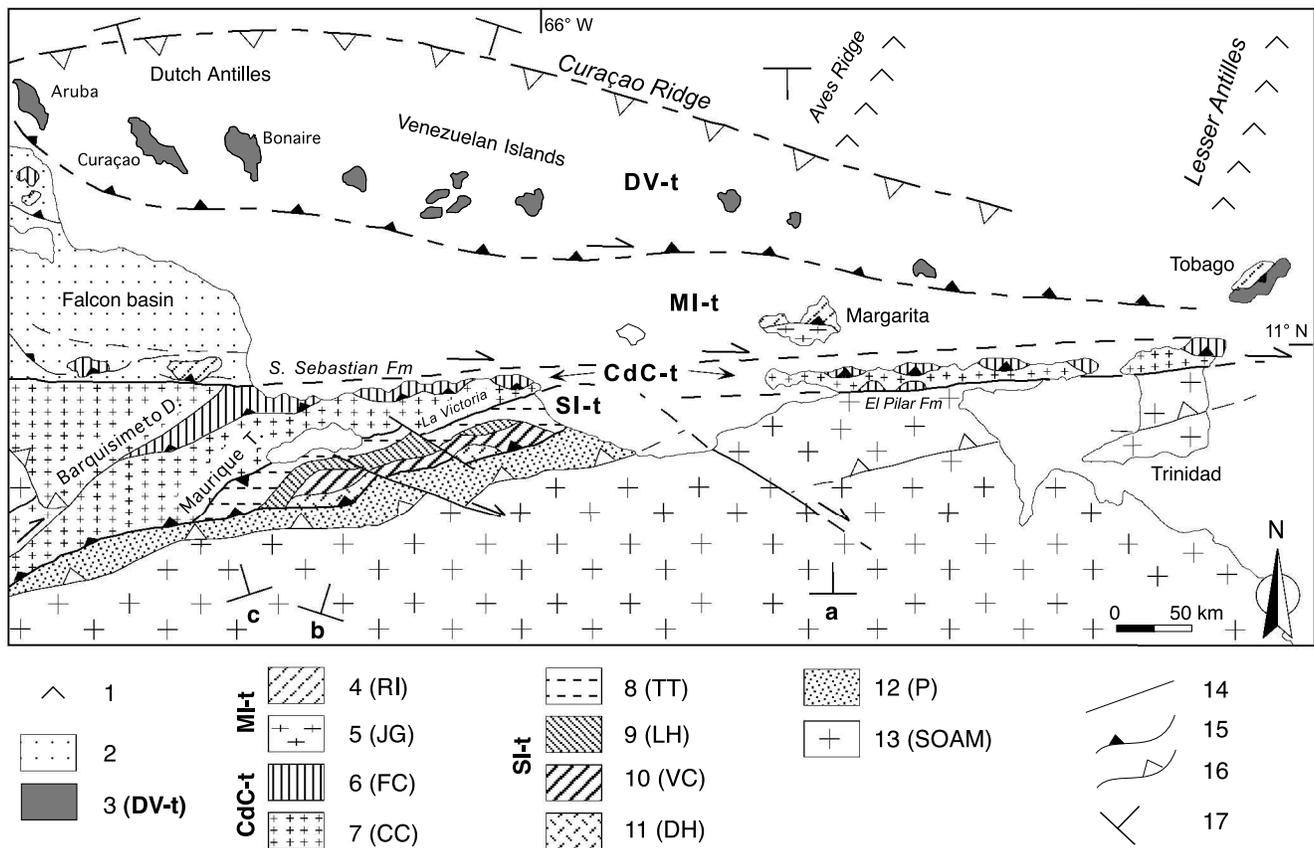
Figure 2. Geologic sketch map of the southern margin of the Caribbean Plate (modified after Giunta et al., 1997). (1) Volcanic arcs of the Aves–Lesser Antilles system. (2) Tertiary siliciclastic deposits. **Dutch–Venezuelan Islands terranes (DV-t):** (3) Cretaceous thickened oceanic crust and scattered sedimentary covers intruded by Late Cretaceous calc-alkaline magmatism. **Margarita Island terrane(MI-t):** (4) subcontinental mantle peridotites, layered gabbros, and doleritic dykes with WPT affinity (La Rinconada unit, RI); (5) Paleozoic orthogeneiss, paragneiss, and schists (Juan Griego unit, JG). **Cordillera de la Costa terrane (CdC-t):** (6) Late Jurassic–Early Cretaceous HP-LT MORB ophiolitic units (Franja Costera group, FC); (7) Precambrian-Paleozoic orthogneiss, Late Jurassic–Cretaceous paragneiss, marbles, and schists (Cordillera de la Costa group, CC). **Serrania del Interior terrane (SI-t):** (8) sub-continental mantle peridotites, layered gabbros, pre-Mesozoic high-grade gneiss, Cretaceous volcano-sedimentary metasequence with WPT affinity (Caucagua–El Tinaco unit, TT); (9) Late Jurassic–Early Cretaceous MORB ophiolites and related sedimentary covers (Loma de Hierro unit, LH); (10) middle Cretaceous HP-LT island-arc sequences with IAT affinity (Villa de Cura unit, VC); (11) middle Cretaceous island-arc volcanics with IAT affinity (Dos Hermanas unit, DH). **South America plate (SOAM):** (12) Late Cretaceous–Paleocene terrigenous flysch sequences (Piemontine Nappe, P); (13) pre-Mesozoic continental crystalline basement and Mesozoic sedimentary covers (Guayana shield). **Symbols:** (14) strike-slip fault; (15) thrust; (16) active trench and frontal thrust; (17) lines of cross sections represented in Figure 3.

peculiar region corresponds to the northern end of the Andes in the present day. The plate boundary, which extends from the Barquisimeto depression to the Trinidad and Tobago Islands (Bellizzia, 1986; Bellizzia and Dengo, 1990), represents an important geodynamic linkage zone between two convergent margins with opposite subduction directions, since it links the Merida Andes with the Lesser Antilles volcanic arc.

The southern boundary of the Caribbean plate corresponds to an elongated belt (1000 km long and 350 km wide), mainly cropping out in the Dutch and Venezuelan Antilles and in the Northern Venezuelan Cordilleras, and interposed between the Cretaceous oceanic plateau of the Venezuelan basin (Caribbean plate) and the SOAM continental plate. In particular, it is delimited offshore to the north by the Neogene north-verging accretionary prism of the Curaçao Ridge (Stephan et al., 1986); to the south, it either overthrusts the Piemontine foredeep of the SOAM foreland, or it is directly in contact with the SOAM foreland by transpressional faults.

This marginal belt consists of several units derived from the previously mentioned geodynamic elements (see Plate Tectonic Setting) that have been irregularly juxtaposed and/or overthrust since the Late Cretaceous, as well as progressively displaced by ductile to brittle deformation (Beck, 1986; Bellizzia, 1986; Ostos, 1990). The west-east dextral simple-shear regime affecting the southern Caribbean margin has developed first-order strike-slip faults (e.g., Oca, San Sebastian, La Victoria, El Pilar) and associated conjugate synthetic (e.g., Tacata, Charallave) and subordinate antithetic faults (Audemard and Singer, 1996). The Northern Venezuela belt has thus been dismembered in separate blocks that are typically bounded by strike-slip faults and rotated clockwise, especially along restraining zones delimited by high-angle net-slip faults thatrepresent inverted thrust faults of earlier deformational phases.

Relics of different geotectonic elements today are scattered as fault-bounded crustal blocks, each showing an internal structural and tectonic homogeneity.

Among different crustal blocks, normal facies or tectonic changes cannot explain the discontinuities of the stratigraphic, structural, and metamorphic features of the geotectonic elements.

Similar associations of different crustal blocks in the Cordillera belt of North America have been regarded by Coney et al. (1980) as "displaced terranes." Similarly, four main terranes have been identified in the southern margin of the Caribbean Plate (Figures 2 and 3): (1) Dutch–Venezuelan Islands, (2) Margarita, (3) Cordillera de la Costa, and (4) Serrania del Interior.

Dutch–Venezuelan Islands Terrane (DV-t)

The DV-t is exposed in the east-west-trending alignment of the Dutch Antilles, Venezuelan Islands, and Tobago Island between the Curaçao Ridge to the north and the Margarita Island terrane to the south. It seems to be bordered by high-angle strike-slip fault systems that display a positive flower structure.

The DV-t is represented mainly by a thick (more than 5 km) volcanic sequence consisting of pillow
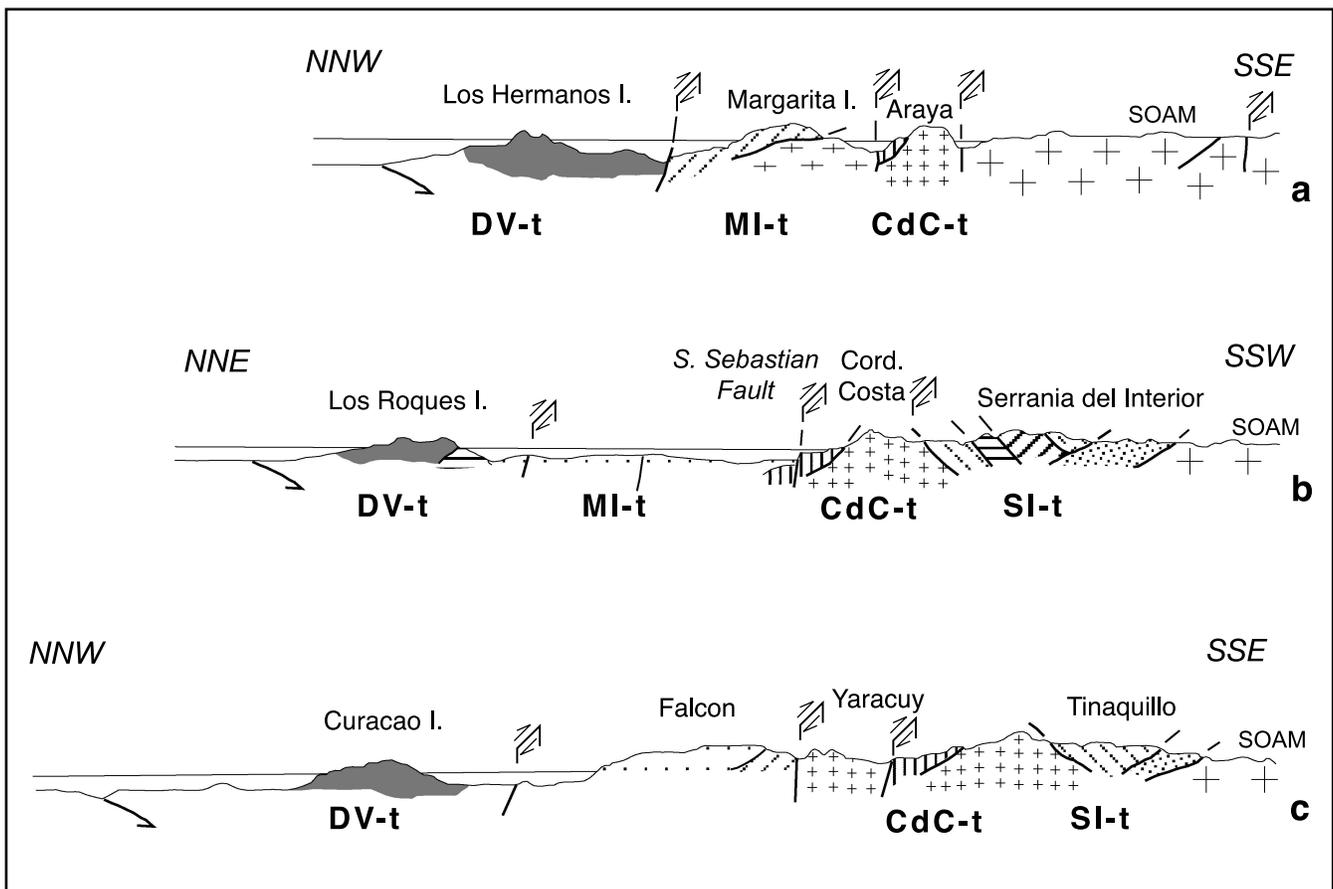
Figure 3. Cross sections showing the main tectonic features of the southern margin of the Caribbean plate. See Figure 2 for legend.

and subordinated massive basalts and dolerites passing upward to vulcanoclastics (e.g., Cretaceous Aruba and Curaçao Lava Formations) (Sinton et al., 1998; White et al., 1999). These volcanic rocks are covered by scattered radiolarites and cherty limestones (e.g., Late Cretaceous Knip Group in Curaçao Island) and, finally, by terrigenous deposits (e.g., Paleocene Midden Curaçao Formation in Curaçao Island).

The whole basic sequence shows geochemical characteristics quite similar to those of the basalts of the Venezuela Basin, and generally is considered to be part of the Caribbean oceanic plateau generated between 91–88 Ma (Kerr et al., 1996; Giunta et al., 1997; Sinton et al., 1998; White et al., 1999).

The oceanic plateau basement of the DV-t is commonly sheared and, in places, subdivided in different tectonic units (e.g., Los Roques Island).

In addition, almost undeformed tonalitic (e.g., in Aruba Island) and quartz-dioritic to granitic (e.g., in Gran Roche Island) intrusions crosscut the oceanic plateau sequence of the DV-t. This magmatism shows calc-alkaline geochemical affinity (Beets et al., 1984; Stephan et al., 1990; Sinton et al., 1998; White et al., 1999) of a possible island-arc origin and has been dated at 85–82 Ma in Aruba (White et al., 1999). The Washikemba Formation of Bonaire Island (basalt-andesites to rhyolites and related Cretaceous pelagic or volcanoclastics covers) shows IAT geochemical affinity (Jackson and Robinson, 1994). Moreover, in Tobago Island (Snoke et al., 2001), at the eastern ending of DV-t, a diorite-gabbro and tonalite plutonic suite intrudes basalts and andesitic volcanic breccias, with IAT magmatic affinity (Jackson and Donovan, 1994).

Subordinate differences in the described general tectonic setting of the DV-t can be observed in the Gran Roque Island, where the oceanic plateau basement thrusts over a tectonic slice composed of gabbros and dolerites, referred to as an unthickened MOR crust (Giunta et al., 2002). Two main penetrative structures have been recognized. They developed under amphibolite to greenschist facies conditions and are characterized by tight to isoclinal folds and axial-plane foliations, which trend, respectively, in northwest-southeast and northeast-southwest directions.

The late-stage brittle deformational phase affecting the DV-t is characterized by Riedel-like fault systems with synthetic northwest-southeast-trending faults, as well as antithetic north-northeast–south-southwest- and north-south-trending faults. An exception is represented by the DV-t easternmost outcrops (i.e., Tobago Island), where the main tec-

tonic directions trend northeast-southwest, almost parallel to the Lesser Antilles volcanic arc.

In conclusion, the DV-t can be interpreted as a fragment of oceanic crust thickened to a plateau structure that subsequently was deformed partially in an intraoceanic subduction zone setting, and was intruded by the Late Cretaceous intraoceanic subduction-related calc-alkaline and IAT magmatism.

Margarita Terrane (MI-t)

From a structural point of view, Margarita Island can be interpreted as a tectonically separate terrane, being detached from the Dutch–Venezuelan Islands (to the north) and the Cordillera de la Costa (to the south) terranes by two high-angle, east-west-trending dextral strike-slip faults. Margarita Island is composed principally of two main outcrops (Macanao and Paraguachoa) of metamorphic rocks (Margarita Complex: Stockhert et al., 1995), locally overlain by Eocene unmetamorphosed sedimentary rocks.

The Margarita Complex is represented by several deformed sheets ascribed to three main tectonic units (the Juan Griego Group, Los Robles, La Rinconada). The stratigraphic relationships between these three units have been the subject of several different reconstructions (Navarro, 1974, 1997; Maresch, 1975; Maresch et al., 2000). In general, the present-day structure of the Margarita Complex may be ascribed to an antiformal stack of tectonic units. It includes at its core the Juan Griego unit (JG), enveloped by the La Rinconada (RI) unit. The Los Robles (LR) unit seems discontinuously associated with the other units or overthrust by the RI. In the Paraguachoa Peninsula, large sheets of RI mantle peridotites (La Sierra–Cerro Matasiete sheets) overthrust both the JG and the RI units.

The JG unit is represented by quartz-feldspar-rich schist, as well as ortho- and paragneisses; a greenschist facies overprint is widespread generally, although eclogitic boudins and lenses commonly occur. U/Pb radiometric dating on zircons from the JG orthogneisses yield an age of 315 ± 35 Ma (Stockhert et al., 1993), suggesting that the JG unit represents a continental lithospheric fragment that includes an older Palaeozoic basement and its related cover.

The RI unit mainly consists of HP-LT amphibolites and eclogites derived from gabbroic cumulates and doleritic dykes (in places intruded in the JG group: Giunta et al., 1997; 2002), and meta-ultrabasites made of harzburgitic, dunitic, and clinopyroxenitic protoliths.

MORB affinities recognized for the basic lithotypes (Mottana et al., 1984; Bocchio et al., 1990) commonly have induced authors to consider the RI unit as a fragment of the proto-Caribbean oceanic lithosphere. By contrast, strong geochemical and petrographic similarities between the RI and Tinaquillo mafic-ultramafic subcontinental sequences in the Serrania del Interior terrane have been documented recently (Giunta et al., 1997, 2002). The RI unit is likely a fragment of subcontinental mantle and related crust, representing a rifted continental margin that probably is related directly to the JG continental lithosphere.

Despite these different interpretations, similar maximum pressures (between 10 and 19 kb) and similar temperature conditions (in the range 450–650°C) have been estimated for both the JG and RI eclogites (Maresch and Abraham, 1980; Bocchio et al., 1996), indicating that these two units must already have been juxtaposed in the deep structural level of the accretionary complex (Stockhert et al., 1995). By contrast, only low-grade phyllites, schists, and marbles constitute the LR unit; the lack of evidence for HP-LT metamorphism in this unit testifies that it was coupled with the other HP-LT units after the accretionary event, probably during their exhumation.

Instead, HP-LT assemblages have been found in magmatic rocks (the Matasiete meta-trondhjemite and Guayacàn orthogneiss) that intrude both the JG and RI units. These two lithotypes share similar geochemical features, suggesting a common magmatic origin, probably as differentiates of the RI cumulates (Giunta et al., 1997); magmatic ages of 114–105 Ma have been obtained for the Matasiete meta-trondhjemite (U-Pb method on zircons: Stockhert et al., 1993).

According to Stockhert et al. (1995), the Margarita Complex underwent, after the HP-LT events, cooling below 400°C at about 90–80 Ma (Avé Lallemant and Sisson, 1993; Stockhert and al., 1993). At about 55–50 Ma, the whole subduction complex of the MI-t cooled below 300°C. In addition, radiometric ages (86 Ma, U-Pb method on zircons: Stockhert et al., 1993) are available for the calc-alkaline arc-related El Salado granites that intruded the RI unit, which were previously metamorphosed under HP-LT conditions. The transition from the former ductile regime under greenschist facies conditions to brittle deformation and normal faulting indicates the final exhumation at a shallow crustal level. Finally, the complex was unconformably overlain by sediments starting in the Eocene. Basaltic to andesitic dykes intruded (between 52 and 47 Ma) the MI-t along fractures generated in an east-northeast/west-southwest- trending extensional setting.

In conclusion, the MI-t could be interpreted as a rifted continental margin accreted at the deep levels of a middle Cretaceous subduction system and intruded by calc-alkaline plutons and dykes both during and after exhumation.

Cordillera de la Costa Terrane (CdC-t)

The CdC-t crops out along the Northern Venezuela coast and is bounded by dextral strike-slip fault systems: westward by the San Sebastian fault to the north and the La Victoria fault to the south; and eastward by the extension of the San Sebastian fault to the north and the El Pilar fault to the south of the Araya-Paria peninsulas. The tectonic setting of this terrane is represented by a narrow, elongated metamorphic belt (probably related to uplift along a restraining zone), where low-grade rocks of continental origin (Cordillera de la Costa group) are overlain, mainly to the north, by slices of HP-LT ophiolites (Franja Costera group).

In the Cordillera de la Costa group (CC), orthogneisses (Sebastopol complex) of Precambrian-Paleozoic age (Pimentel et al., 1985) represent the basement of a sedimentary metasequence (Caracas complex) that includes four different units characterized by paragneisses, marbles, and micaschists of Late Jurassic to Cretaceous age. On the whole, these complexes are interpreted as continental margin basement and related sedimentary cover that underwent deformation associated with greenschist facies metamorphism (Ostos, 1990). The only available radiometric dating for the Cordillera de la Costa group (Ostos, 1990) is represented by slightly reliable metamorphic ages (varying from 79 to 30 Ma) obtained by the K-Ar age method. In addition, fission tracks on apatite indicate ages ranging from 24 to 16 Ma.

The Franja Costera group (FC) consists of two main units, known as the Tacagua and Nirgua units. Although the Tacagua unit is strongly tectonized, a complete sequence (consisting of metaperidotites, metagabbro, and metabasalt covered by a monotonous sequence of calc-schist) can be reconstructed. The Nirgua unit, in turn, displays a more deformed and metamorphosed ophiolitic sequence, represented mainly by ultrabasic eclogite facies and basic boudins in a sequence of marbles interfingering with paragneisses and calc-schists. These sequences commonly are interpreted as oceanic fragments, as also suggested by the MOR magmatic affinities of the

basic lithotypes (Beccaluva et al., 1996; Giunta et al., 1997, 1998).

The Nirgua unit is characterized mainly by relics of barroisite- and garnet-bearing eclogites, indicating about 1800–2200 MPa pressure and 500°–700°C temperature conditions (Sisson et al., 1997). Eclogitic rocks, which record the occurrence of a first HP-LT tectono-metamorphic phase (D1), occur as boudins in a foliated matrix. This main foliation (S2) developed under the epidote-amphibolite facies metamorphic conditions during the second deformational phase (D2). East-west-trending mineral and stretching lineations, as well as rootless isoclinal folds, are associated with the S2 foliation. The S2 foliation is, in turn, deformed by closed-to-isoclinal, overturned folds (F3) characterized by a well-developed crenulation cleavage, which is represented by a greenschist facies subhorizontal foliation (S3).

Radiometric ages from the FC are scarce. An age of 84.5 ± 0.2 Ma (^{40}Ar/^{39}Ar method) for the epidote-amphibolite rocks in the Nirgua unit (D2 phase) has been provided by Avé Lallemant (1997). In addition, ^{40}Ar/^{39}Ar dating on white micas (Smith et al., 1999) point out a 35–37 Ma age for the greenschist facies tectono-metamorphic phase (D3). Fission tracks on zircons and apatite indicate ages, respectively, of 20 and 15 Ma (Sisson and Avé Lallemant, 1999) that are related to different steps of the exhumation process. The Tacagua unit shows a similar deformation history, probably acquired in the same geodynamic setting, but it seems affected only by blueschist facies metamorphism. The metamorphic evolution of the two FC units probably is related to different depths of accretion in the subduction zone complex.

Structural evidence suggests that the Tacagua and Nirgua units, as well as the whole FC and CC, were coupled between the D2 and D3 phases (i.e., during exhumation), because the tectonic contacts between them were refolded during the D3 phase. Typical ''Alpine-type'' (Ernst, 1988) retrograde paths have been recognized for the whole CdC-t, suggesting that exhumation probably occurred after the subduction was shut off, in a collisional setting (Sisson et al., 1997).

In conclusion, the CdC-t seems to correspond to a subduction complex in which both oceanic and continental slices had been accreted at different crustal depths. The CC represented a continental margin during the Cretaceous; the FC assemblage has been compared by Beccaluva et al. (1996) and Giunta et al. (1997) to a type of melange with ophiolitic blocks such as those of the Northern Franciscan belt. The oceanic units experienced the climax of HP-LT

metamorphism before the Santonian, followed by a long-lasting exhumation history. The exhumation of the FC group began in the Late Cretaceous, when the subduction already was terminated (Sisson et al., 1997; Smith et al., 1999). From the Paleocene onward, the FC and CC groups experienced the same evolution as a consequence of their tectonic coupling.

Serrania del Interior Terrane (SI-t)

The SI-t represents a 250-km-long, east-west-trending belt cropping out as a thrust synform. To the north, it is separated from the CdC-t by the La Victoria fault zone; to the west, it rests on the CdC-t along the Maurique thrusts; to the south, it overthrusts the Late Cretaceous–Paleocene sedimentary sequences of the SOAM (Piemontine Nappe). Paleomagnetic data (Skerlec and Hargraves, 1980) indicate that the entire terrane underwent a 90° clockwise rotation from an original north-south trend; this rotation probably occurred between about 95 Ma and the early Paleocene emplacement onto the SOAM (Beets et al., 1984) in response to the transpressional tectonics related to the southern Caribbean boundary.

In the SI-t, several main tectonic units corresponding to different geotectonic elements have been recognized (Beccaluva et al., 1996). These units generally are separated by high-angle, southward-dipping thrusts, which were partially obliterated or reactivated by later-stage faults. They are (from north to south) the Caucagua–El Tinaco, Loma de Hierro, Villa de Cura, and Dos Hermanas units.

The Caucagua–El Tinaco (TT) unit mainly consists of wide tectonic sheets of foliated and recrystallized gabbroic cumulates and mantle peridotites, which were intruded or interlayered with various felsic, mafic, and ultramafic rocks (Tinaquillo complex) that overthrust high-grade gneisses (the La Aguadita orthogneisses of the El Tinaco complex). According to Seyler et al. (1998), the Tinaquillo complex was originally emplaced at the base of the El Tinaco complex, which, in turn, is overlain by a volcano-sedimentary metasequence (Cretaceous Tucutumeno Formation), including basaltic pillow lavas (Los Naranjos member) and gabbroic breccias (Sabana Larga member).

Both the tectono-metamorphic evolution reconstructed in the Tinaquillo and El-Tinaco complexes, commonly regarded as a subcontinental lower crust–upper mantle fragment (Seyler et al., 1998), and the WPT magmatic affinity of the overlaying volcanic rocks (Giunta et al., 1997; 2002) suggest that the TT unit originated during rifting of a continental margin. Geochronologic and thermobarometric data

(Seyler et al., 1998) indicate that the continental lithospheric thinning (from about 40 km to 22 km) began between 150 and 125 Ma (U-Pb zircon dating), whereas the breakup and related passive-margin formation probably occurred between 125 Ma and 90–87 Ma. Subsequently, the TT was involved in the tectonogenesis of the Northern Venezuela belts; the emplacement of the TT unit in the SI-t was accompanied by low greenschist facies metamorphism, as well as by thrusting and faulting.

The Loma de Hierro (LH) unit outcrops in a tectonic contact with the TT unit along a high-angle strike-slip fault (Santa Rosa fault system) or, in places, overthrusts it. The reconstructed stratigraphic sequence of the LH (Beck, 1978; Bartock et al., 1985; Beck, 1986) consists of Middle–Late Jurassic ophiolitic basement rocks (serpentinized mantle peridotites and gabbroic cumulates) covered by: Late Jurassic–Early Cretaceous basaltic flows intercalated in silicic limestones and cherts (Capas del Rio Guare Formation); middle–Late Cretaceous basalts and dolerites, crosscut by gabbroic dykes (Tiara Formation); and a Late Cretaceous sequence of shale, sandstone, limestone, and subordinate conglomerate and volcanoclastic siltstone (Paracotos Formation). The lithostratigraphic and petrologic features clearly indicate that the LH unit represents a lithospheric fragment generated in a mid-ocean-ridge setting (Girard et al., 1982; Loubet et al., 1985; Donnelly et al., 1990; Beccaluva et al., 1996; Giunta et al., 1997).

The LH unit records two main phases of orogenic deformation. The first is characterized by greenschist facies foliation that generally shows a southward dip coherent with the regional structure of the SI-t; the second is represented by a crenulation cleavage developed only in the less-competent lithotypes.

The Villa de Cura (VC) unit overthrusts the LH unit along the Agua Fria fault; it consists mainly of metavolcanic sequences ranging in composition from basalts to rhyolites that are affected by deformations developed under blueschist facies metamorphic conditions. These sequences rest upon wehrlite-clinopyroxenite cumulates and serpentinized mantle peridotites (Chacao complex). In places (Morros de San Juan), the VC is unconformably covered by Late Cretaceous reefal limestones. Petrologic and lithostratigraphic data indicate that the VC lavas originated in a suprasubduction zone setting as a primitive island-arc or back-arc environment (Donnelly and Rogers, 1978, 1980; Navarro, 1983; Beets et al., 1984). The ages of the magmatic protoliths are interpreted variably as middle Cretaceous (Maresch, 1974; Beets

et al., 1984; Loubet et al., 1985; Pindell, 1993) or before (Smith et al., 1999), and Campanian (Burke, 1988).

In the VC unit four main formations (i.e., El Caño, El Chino, El Carmen, and Santa Isabel) first were recognized by Shagam (1960); subsequently, the distinction of six metamorphic zones (i.e., pumpellyite-actinolite, lawsonite-albite, lawsonite-glaucophane, glaucophane-epidote, barroisite, and galucophane-barroisite) was proposed (Navarro, 1983). More recently, Smith et al. (1999) reduced the VC to four subunits that are, from north to south: pumpellyite-actinolite, glaucophane-lawsonite, glaucophane-epidote, and barroisite. According to these authors, the first three subunits record metamorphic peak conditions that gradually increased from 240–275°C at 550 MPa to 300–370°C at 700 MPa, probably reflecting different depths of accretion in the subduction complex. By contrast, a more complex scenario is suggested by the higher temperature (420–450°C) at similar pressure conditions (700 MPa) recorded in the barroisite belt, as well as by the partial overgrowth of sodic amphibole around the barroisitic amphibole, which indicates that this subunit underwent cooling without any significant decompression (Smith et al., 1999). These particular features of the barroisite subunit may be explained by the subduction of an anomalously hot (young?) lithosphere and subsequent natural cooling after underplating; by contrast, the other three subunits were subducted later, when they already had reached the normal geothermal gradient. The 96.3 ± 0.4 Ma age of peak metamorphism for the barroisite subunit, with respect to the 79.8 ± 0.4 Ma radiometric ages obtained for the other subunits (Ar/Ar ages: Smith et al., 1999), seems to support this interpretation.

Structural data suggest that the four subunits experienced the same deformational history. Actually, all the subunits are mesoscopically characterized by the same east-west-trending, south-dipping main foliation that represents a composite foliation that developed under metamorphic climax conditions (D1 phase) and subsequently was isoclinally refolded, as well as recrystallized, under retrograde greenschist facies conditions (D2 phase). Mineral and stretching lineations associated with these two phases provide further indications. L1 downdip lineations record (in present-day geographic orientations) a north-south tectonic transport during the HP-LT phases, whereas L2 strike-slip lineations suggest east-west shearing during exhumation. In this framework, the ''Franciscan-type'' (Ernst, 1988) decompressional history characterizing the whole VC

unit commonly is attributed to exhumation that occurred during continuous subduction in an intra-oceanic setting (Smith et al., 1999). Finally, at least one further folding event (D3 phase) is superimposed on the previous structures, as verified by the widespread development of closed-to-open, south-verging folds and axial-plane crenulation cleavages.

The Dos Hermanas (DH) unit represents the highest unit of the SI-t, tectonically overlying both the VC unit to the north and the Piemontine Nappe to the south. It consists mainly (Navarro, 1983; Bellizzia, 1986) of a more than 400-m-thick sequence of basalts and basaltic-andesitic breccias interbedded with volcanic conglomerate and tuff. The whole-rock geochemical characteristics and the pyroxene compositions indicate island-arc tholeiite affinity, suggesting that the DH represents part of an arc complex generated in an intraoceanic suprasubduction setting (Navarro, 1983; Ostos, 1990; Beccaluva et al., 1996). Available geochronologic data (Navarro, 1983; Ostos and Navarro, 1986) indicate a middle Cretaceous age for this magmatism.

No significant ductile deformation affected the DH unit; by contrast, prehnite-pumpellyite and pumpellyite-actinolite facies metamorphic assemblages indicating pressures of less than 400 MPa at 200–320°C (Smith et al., 1999) have been recognized. Controversial K-Ar radiometric ages of 52 and 35 Ma (Beck, 1978) and 104 ± 10 Ma (Piburn, 1967) have been obtained previously, but at present they generally are not considered significant.

The data presented on the SI-t support a complex geodynamic history. During the early (middle Cretaceous) convergent phases that affected the Jurassic–Early Cretaceous proto-Caribbean ocean, a fragment of oceanic lithosphere (i.e., LH), probably located near a rifted continental margin (i.e., TT), was involved in an intraoceanic subduction zone characterized by the development of suprasubduction/IAT magmatism (VC and DH). From the middle Cretaceous, portions of the suprasubduction zone became involved in the subduction and underwent varying degrees of HP-LT metamorphism in relation to the P-T conditions at the depth of accretion. Subsequently, the deformation that accompanied the initial stage of exhumation of the HP-LT rocks started to affect the whole system, resulting in coupling between the different units. Finally, the strike-slip tectonics of the Caribbean-SOAM plate boundary, probably already active at the beginning of the exhumation, caused the rotation of the terrane and its emplacement onto the SOAM continental margin.

CONSTRAINTS FOR A GEODYNAMIC MODEL

The records of a complex and long-lived magmatic-tectono-metamorphic evolution preserved in the deformed terranes of the southern margin of the Caribbean plate have been reviewed in the previous section, as well as summarized in Figure 4. These geodynamic features are critically analyzed below, since they provide important geologic constraints that are useful for a detailed reconstruction of the evolution of the southern Caribbean.

Geotectonic Elements

In the terranes of the southern Caribbean margin, different geotectonic elements have been recognized (Giunta et al., 1997): (1) continental lithospheres (CC and JG units); (2) rifted continental margins (TT and RI units); (3) oceanic lithospheres characterized by basalts showing both MORB (LH and FC units) and OIB (DV-t substratum) magmatic affinities; (4) suprasubduction and island-arc systems (middle Cretaceous VC and DH units; DV-t Late Cretaceous magmatism); and (5) deep subduction zones (HP-LT assemblages in the FC, VC, RI, and JG units).

Regional Correlations

Regional correlations, suggested by the occurrence of similar geotectonic features, allow us to define the original paleogeographic domains of the main terranes of the southern Caribbean margin.

- The JG continental group in the MI-t generally is considered analogous to the CC unit in the CdC-t (e.g., Bellizzia and Dengo, 1990).
- An equivalent of the mafic-ultramafic complex of the TT unit (SI-t) has been recognized in the RI unit of the MI-t (Giunta et al., 1997, 2002).
- The calc-alkaline El Salado granites and related dykes that intruded the RI unit (MI-t) are comparable to the Late Cretaceous calc-alkaline magmatic activity recorded in the DV-t (Beets et al., 1984; Stockhert et al., 1993; 1995; Giunta et al. 1997).
- The MORB ophiolitic units of the LH (SI-t) and FC (CdC-t), despite different degrees of orogenic tectono-metamorphic imprinting, probably represent remnants of the same oceanic lithosphere.

Double-arc Magmatism

The occurrence of Cretaceous island-arc magmatic activity at the southern margin of the Caribbean plate is recorded in the DV-t, MI-t, and SI-t. None

theless, 85–82 Ma and 86 Ma radiometric ages have been obtained, respectively, for the Aruba intrusions in the DV-t (White et al., 1999) and the El Salado granites in the MI-t (Stockhert et al., 1993), whereas the VC suprasubduction complex of the SI-t already was undergoing HP-LT metamorphism from 96.3 ± 0.4 Ma (Smith et al., 1999).

These data indicate that the DV-t and MI-t calc-alkaline magmatism is significantly younger than the SI-t IAT magmatism. The data also suggest the presence of two distinct intraoceanic volcanic arc systems: first, a middle Cretaceous magmatic arc (e.g., VC and DH units in the SI-t) developed before 96 Ma; and second, a Late Cretaceous magmatic arc (e.g., in the DV-t and MI-t) was present from 86 Ma.

Early Convergence

The oldest available radiometric age for the HP-LT metamorphic peak of the Northern Venezuela terranes is 96.3 ± 0.4 Ma (Smith et al., 1999), obtained from the VC unit. Given that the VC most likely was generated in a suprasubduction setting, this radiometric age constrains the beginning of subduction as being older than this HP-LT event. The peak of the HP-LT metamorphism that affected the MI-t probably is younger than 114–105 Ma, which represents the age of the magmatic crystallization of the Matasiete meta-trondhjemite (Stockhert et al., 1993). In addition, a time span of about 11–16 Ma, during which the subduction continued, is suggested by the other (younger) radiometric ages reported for the peak conditions (e.g., 79.8 ± 0.4: Smith et al., 1999), as well as the oldest radiometric ages of the retrograde conditions (84.5 ± 0.2 Ma: Avé Lallement, 1997).

On the whole, the available data suggest a middle Cretaceous age for the beginning of the convergence in the southern Caribbean realm.

Subduction Settings

The MI-t, CdC-t, and SI-t contain HP-LT relics that testify to the occurrence of well-developed subduction complexes. The lack of evidence for suprasubduction magmatism in the MI-t and CdC-t, with respect to the development of an island-arc system in the SI-t, suggests that the terranes have been involved in different middle Cretaceous subduction settings.

Several independent lines of geologic evidence clearly indicate that the VC and DH units (SI-t) developed in an intraoceanic subduction zone environment, whereas the subduction complex of the MI-t and the CdC-t probably developed in a subcontinental setting.

HP-LT Assemblages in Both Oceanic and Continental Lithospheres

The widespread occurrence of blueschist and eclogitic assemblages in the terranes of the southern margin of the Caribbean plate requires a geodynamic model where both oceanic and continental lithospheres have been subducted at least partially while undergoing HP-LT metamorphism. Development of HP-LT conditions in MORB-type units (e.g., FC units of CdC-t) is commonly related to the subduction of dense oceanic lithosphere in either subcontinental or intraoceanic settings. The metamorphism of units that represent remnants of continental margin (e.g., CC-JG and TT-RI units) requires more complex subduction mechanisms (e.g., continental collision, tectonic erosion) that include underthrusting of thinned continental crust.
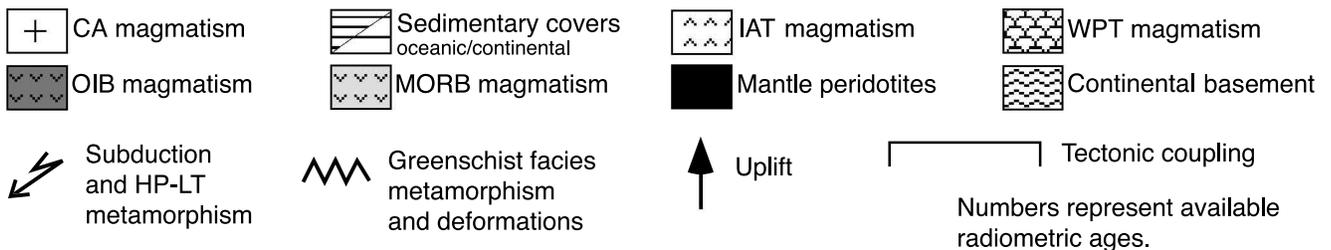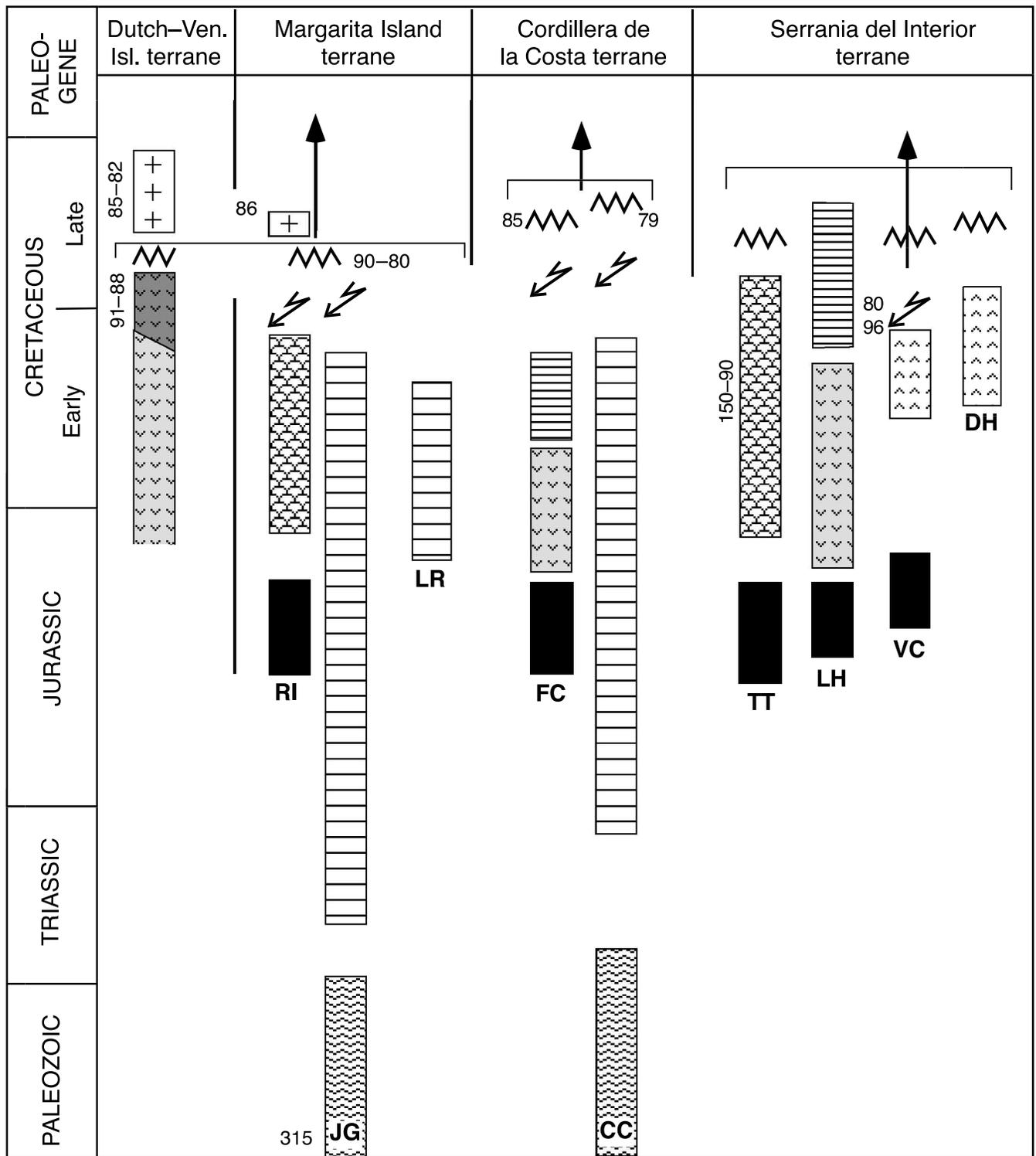
Atypical Evolution of the Early Volcanic Arc

The VC and DH units in the SI-t represent an early island-arc system involved in the development of the southern Caribbean margin. In general, rocks generated in suprasubduction zone settings tend to be obducted onto the continental margins, escaping the involvement in the deep part of the subduction complex. High-temperature metamorphism often develops in a narrow zone (i.e., the amphibolitic sole) below the obducting, relatively hot slab. The DH unit most likely experienced a similar evolution to this mechanism, whereas the VC unit was deeply subducted and affected by blueschist facies metamorphism.

An unusual geodynamic evolution must be supposed, since the VC unit did not experience the typical evolution of an intraoceanic suprasubduction system. Reversals in the lithospheric sinking, as proposed by Smith et al. (1999), generally require the presence of a geodynamic element that acted as a stopper for the previous subduction complex. Nonetheless, a simpler solution that maintains the same dip direction may be involved, as evidenced by the consumption of the edge of the overriding plate through progressive landward shifting of the convergence (i.e., tectonic erosion).

Distribution of the Second-arc Magmatism

The Late Cretaceous Caribbean calc-alkaline magmatic arc, as seen on the northern margin of the Caribbean plate (e.g., Cuba, Hispaniola, and Puerto Rico), probably can be attributed to the westward

		Dutch–Ven. Isl. terrane	Margarita Island terrane	Cordillera de la Costa terrane	Serrania del Interior terrane

Legend:

+ CA magmatism

OIB magmatism

Sedimentary covers oceanic/continental

MORB magmatism

IAT magmatism

Mantle peridotites

WPT magmatism

Continental basement

Subduction and HP-LT metamorphism

Greenschist facies metamorphism and deformations

Uplift

Tectonic coupling

Numbers represent available radiometric ages.

subduction of the proto-Caribbean/Atlantic oceanic lithospere, and be diachronously connected to the Aves–Lesser Antilles arc system (e.g., Burke, 1988; Lewis and Draper, 1990; Meschede and Frisch, 1998; Beccaluva et al., 1999; Giunta et al., 2002). On the southern margin, the calc-alkaline magmatism is intruded in the poorly deformed oceanic plateau of the DV-t, as well as in the HP-LT metamorphic complex of the MI-t, whereas no younger calc-alkaline magmatism is recorded in the deformed units of the CdC-t and SI-t. This implies that, at 86 Ma, the CdC-t and SI-t were still geodynamically disconnected from the active subduction setting, which involved both the DV-t and the MI-t. Subsequently, the MI-t and DV-t also became independent and were later juxtaposed to the other terranes.

Differences in Retrograde Evolutions

Apparent contrasts in the P-T histories have been recognized for the HP-LT metamorphic units of the Venezuelan terranes (Sisson et al., 1997). These differences probably indicate that the converging zones, in which the HP-LT units of the southern Caribbean evolved during the middle Cretaceous, were subdivided into different sectors that were characterized by different tectonic settings.

Actually, the MI-t and CdC-t eclogites and blueschists followed an "Alpine-type" retrograde P-T trajectory, suggesting that the shutoff of the subduction occurred before the beginning of exhumation. In contrast, the VC blueschists (SI-t) show a "Franciscan-type" P-T path, which commonly characterizes decompression in intraoceanic settings during still active subduction processes.

Strike-slip Exhumation

Complex decompressional paths, from the Campanian onward, are recorded in the MI-t, CdC-t, and SI-t (Sisson et al., 1997; Stockhert et al., 1995; Smith et al., 1999). Various deformation phases developed under P-T retrograde conditions during exhumation. In this framework, the beginning of exhumation (referable to the second D2 tectono-metamorphic event) was characterized by a well-developed foliation showing mineral and stretching lineations, as well as transected folds. The current east-west trend of the L2 lineations suggests that displacement during the early stage of exhumation was nearly perpendicular to the subduction direction (characterized by almost north-south-trending L1 lineations), as well as roughly parallel to the Caribbean-SOAM plate boundary.

According to Avé Lallement (1997), these structural features can be explained by an exhumation dominated by strike-slip tectonics. Moreover, they provide further support to the hypothesis that strike-slip tectonics largely have ruled the geodynamic evolution of the southern Caribbean boundary, controlling its tectonic evolution since at least the beginning of exhumation of the HP-LT units in the middle Cretaceous.

Reworking of VC and DH Blocks in the Piemontine Sequence

The Piemontine Nappe (Beck, 1978; Bellizzia, 1986; Bellizzia and Dengo, 1990) represents the south-vergent foreland thrust belt that developed during the early Tertiary. To the south, it is emplaced onto the Guayana shield (SOAM plate), whereas to the north, it is overthrust by the SI-t. The Piemontine sequence is characterized (Bellizzia, 1986) by Late Cretaceous terrigenous deposits with pelagic and hemipelagic intercalations, followed by thick, coarse Paleocene turbidites. In the lowest siliciclastic deposits of the Piemontine sequence (Late Cretaceous Garrapata Formation), variably sized pebbles of magmatic and metamorphic rocks derived from both the DH and VC units can be found.

This occurrence testifies to a tectono-sedimentary coupling between the VC and DH units (SI-t) and the Piemontine basin and also suggests that the VC unit had been completely exhumed since the latest Cretaceous, and that the SI-t was thrusting over the SOAM continental margin.

TENTATIVE MODELS: A DISCUSSION

In the various plate-tectonic reconstructions proposed for the Caribbean (e.g., Burke, 1988; Pindell et al., 1988; Ross and Scotese, 1988; Morris et al., 1990; Pindell, 1993; Stockhert et al., 1995; Meschede and Frisch, 1998; Giunta et al., 2002), there is general

Figure 4. Summary of the main magmatic, sedimentary, metamorphic, and deformational events recorded in the terranes of the southern Caribbean margin. RI = La Rinconada unit; JG = Juan Griego unit; LR = Los Robles unit; FC = Franja Costera group; CC = Cordillera de la Costa group; TT = Caucagua–El Tinaco unit; LH = Loma de Hierro unit; VC = Villa de Cura unit; DH = Dos Hermanas unit.

agreement that the evolution of the boundary between the Caribbean plate and the SOAM was dominated, starting from the latest Cretaceous, by development of a large transform zone caused by the relatively eastward motion of the Caribbean plateau (Meschede and Frisch, 1998; Sinton et al., 1998; Giunta et al., 2002).

The terranes of the southern Caribbean were progressively rotated clockwise (Skerlec and Hargraves, 1980; Burmester et al., 1996), thrust onto the SOAM, juxtaposed to one another, and finally displaced by the east-west-trending dextral strike-slip system. In addition, from the Late Cretaceous, the eastward drifting of the Caribbean plateau was associated with the development of an approximately north-south-trending intraoceanic subduction zone, which was characterized by both the west-southwest-dipping subduction of the proto-Caribbean/Atlantic, unthickened, oceanic crust below the plateau, and the related well-developed, calc-alkaline, arc magmatism (Beets et al., 1984; Sinton et al., 1998; White et al., 1999; Beccaluva et al., 1999; Giunta et al., 2002). The distribution of this calc-alkaline magmatism records the progressive eastward motion of the plate; Late Cretaceous granitoids crop out in the Dutch-Venezuelan Islands (White et al., 1999) and in the Aves Ridge (Holcombe et al., 1990), suggesting that they belonged at that time to the same arc system. Subsequently (latest Cretaceous-Paleocene), the dextral strike-slip tectonics at the Caribbean and SOAM plate boundary increasingly involved the southern part of the arc (Dutch-Venezuelan Islands), which gradually become inactive and progressively underwent both clockwise rotation (Burmester et al., 1996) and east-west displacement. By contrast, the Aves–Lesser Antilles arcs continued to migrate eastward to their present-day position and increased their eastward bend as a result of the oblique convergence imposed at the end of the arc (Giunta et al., 2002). Finally, during the Neogene, further approach between the NOAM, SOAM, and Caribbean plate produced the north-verging accretionary prism of the Curaçao Ridge (Stephan et al., 1986), resulting in northward, high-angle overthrusting of the whole deformed Venezuelan belt onto the oceanic plateau of the Colombia-Venezuela basins.

Major controversy arises regarding the Middle Jurassic–Early Cretaceous geodynamic reconstruction, since two different hypotheses exist on the origin of the Caribbean lithosphere. The ''Pacific origin'' model (e.g., Burke et al., 1978, 1984; Ross and Scotese, 1988; Burke, 1988; Pindell et al., 1988; Pindell and Barrett, 1990; Stephan et al., 1990; Ostos, 1990; Pindell, 1993) infers that the Caribbean oceanic crust was generated as part of the Pacific realm and subsequently was inserted between the NOAM and SOAM. The ''proto-Caribbean origin'' model (e.g., Sykes et al., 1982; Aubuoin et al., 1982; Frisch et al., 1992; Giunta, 1993; Beccaluva et al., 1996, 1999; Meschede and Frisch, 1998, Giunta et al. 2002) interprets the Caribbean oceanic crust as forming in a near mid-America position, close to the NOAM and SOAM margins.

According to this latter interpretation, the palinspastic restoration of the terranes of the southern margin of the Caribbean implies that the geotectonic elements, from which the terranes derive, were originally (Middle Jurassic–Early Cretaceous) located at about the northwestern corner of the SOAM (Duncan and Hargraves, 1984). Since the middle Cretaceous, the southern Caribbean realm has been affected by a convergent regime related to the opening of the South Atlantic oceanic basin and the consequent relatively northwestward movement of the SOAM plate.

Any realistic reconstruction of the Cretaceous geodynamics of the Caribbean southern margin should take into account that the Northern Venezuela belt developed between the two main convergent systems of the Andes and the Lesser Antilles, which were characterized by opposite dips of the subductions to the east and to the west, respectively. The future terranes initially evolved close to an important tectonic linkage, probably represented by a first-order transform fault system connecting the two main opposite subductions. Several lines of geologic evidence indicate that the history of the Caribbean southern margin has been dominated since the middle Cretaceous by a right-oblique tectonic regime, which seems to have characterized the main evolutionary steps of all the Venezuelan units; i.e., their subduction, exhumation, rotation, thrusting, emplacement, and dismembering (Avé Lallemant and Guth, 1990; Pindell and Barrett, 1990; Meschede and Frisch, 1998; Smith et al., 1999; Giunta et al., 2002).

Nonetheless, two main geodynamic features remain unresolved in the reconstruction of the southern Caribbean Mesozoic evolution: (1) the original trend of the SOAM continental margin, as well as the exact significance of the continental margin groups of units of CdC-JG and TT-RI, which could have represented either part of the SOAM or independent microcontinents; and (2) the paleo-position and the polarity of the lithospheric sinking of the middle

Cretaceous subduction zone(s). As a consequence, the location (with respect to the Venezuelan belt units) of the transform kinematic linkage related to the dextral shear cannot be established exactly.

For these reasons, taking into account the previously discussed geologic constraints, three main middle Cretaceous geodynamic scenarios can be considered (Figure 5).

In **Model A** (Figure 5a), the main east-west-trending transform fault separating the two subduction zones, which were characterized by oppositely dipping directions, was located within the paleo-domains of the geotectonic elements from which the terranes successively developed.

To the north, a west-dipping intraoceanic subduction zone led to the development of IAT magmatism (e.g., VC and DH units in SI-t). Tectonic erosion of the edge of the overriding plate produced the sinking and related HP-LT metamorphism of parts of the arc (e.g., the VC unit). Alternatively, it can be hypothesized that the continuous convergence produced the involvement in the subduction zone of the continental margin of the SOAM northernmost areas, whose buoyancy withstood the subduction. Shortening at the edge of the overriding plate thus accommodated the convergent regime and resulted in deformation and HP-LT metamorphism of the VC unit in a west-dipping subduction zone.

To the south of the transform kinematic linkage, a low-angle, east-dipping, subcontinental subduction zone below the SOAM plate was connected with the development of an accretionary wedge where the oceanic lithosphere was deformed and metamorphosed under HP-LT conditions (FC units). In this framework, the CC-JG units are interpreted as part of a microcontinent that originated during the Jurassic–Early Cretaceous rifting phases, and the TT-RI units were probably representative of its thinned, rifted margin. These continental elements were subsequently involved in the east-dipping subduction and were metamorphosed under different P-T conditions, ranging from greenschist (e.g., TT and CC units) to eclogitic facies (e.g., RI and JG units), in response to the varying crustal levels of accretion. The continuous accretion of continental lithosphere resulted in shutoff of the subduction system, which induced collisional conditions during exhumation of the HP-LT units (e.g., CdC-t and MI-t).

In **Model B** (Figure 5b), all the geotectonic elements recognized in the Northern Venezuela belt were located originally at the north of the transform linkage. This reconstruction is characterized by the occurrence of only one, west-dipping, subduction and by development of both an accretionary wedge to the south and an intraoceanic island arc (VC and DH units in the SI-t) to the north. According to this model, both the CC-JG and the TT-LR units represented the northernmost part of the SOAM margin–a possible promontory, which was deeply subducted following the proto-Caribbean oceanic slab (e.g., FC and LH units). In the southern sector, convergence ceased when the unthinned part of this continental margin was involved in the subduction zone. In the northern sector, part of the VC unit (i.e., the barroisite subbelt) experienced early HP-LT metamorphism (96.3 ± 0.4 Ma: Smith et al., 1999) as a consequence of tectonic erosion of the overthrusting plate during intraoceanic subduction. The younger HP-LT peak conditions recorded in the other VC unit subbelts (79.8 ± 0.4 Ma: Smith et al., 1999) may be better explained by the subsequent involvement of continental crust in the subduction zone that produced westward shifting of the system and the consequent sinking of the external edge of the volcanic arc.

According to this model, the Late Cretaceous–Paleocene Piemontine Nappe represents the foredeep basin of the SOAM foreland.

In **Model C** (Figure 5c), the presence of only one, east-dipping, subduction zone is postulated, since all the geotectonic elements recognized in the southern margin of the Caribbean plate are located originally at the south of the transform linkage. In the northernmost area, an intraoceanic setting of the subduction is responsible for development of suprasubduction island-arc magmatism (e.g., the VC and DH units). By contrast, a subcontinental subduction zone developed in the southernmost area and was related to the accretion of an orogenic wedge where slices of the oceanic lithosphere were deformed and metamorphosed at different levels of accretion (e.g., FC and LH units). According to this scenario, the deformation and HP-LT metamorphism of both the continental-margin (e.g., JG and RI units) and island-arc (e.g., VC unit) units may be explained by large-scale tectonic erosion of the overridden plate that accommodated the convergence in response to the involvement in the subduction zone of a geodynamic stopper (probably represented by the thickened oceanic crust of the Caribbean plateau).

The Late Cretaceous–Paleocene Piemontine Nappe may represent the landward-verging deformed basin of the inner forearc, which resulted
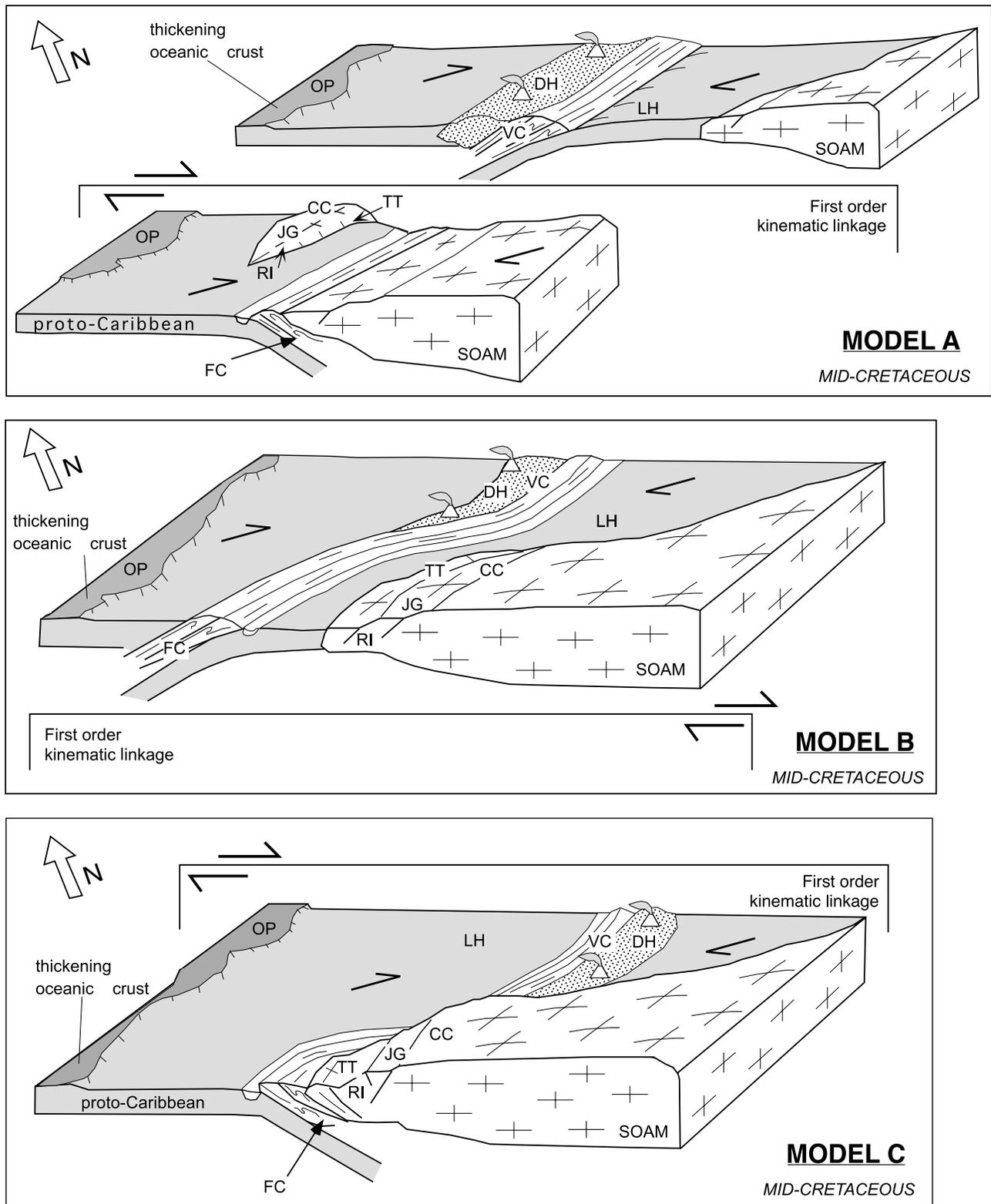
Figure 5. Possible geodynamic scenarios (Models A, B, and C) during the middle Cretaceous, showing the approximate locations of the main elements of the Caribbean southern margin. SOAM = South America Plate; JG and CC = continental margin of the Juan Griego and Cordillera de la Costa groups; RI and TT = subcontinental mantle and crust of rifted margins of La Rinconada and Caucagua–El Tinaco units characterized by WPT magmatism; FC and LH = MORB oceanic lithosphere of the Franja Costera group and Loma de Hierro unit; VC and DH = island arc showing IAT magmatism of the Villa de Cura and Dos Hermanas units; OP = thickening oceanic lithosphere (future Caribbean plateau). See text for details and more explanation of models A, B, and C.

from the collision between the SOAM and the Caribbean thickened oceanic plateau. Model C supports the reconstruction proposed by Beccaluva et al. (1999) and Giunta et al. (2002).

Since the Late Cretaceous, the three models converge to present a similar geodynamic reconstruction (Figure 6), in which the eastward motion of the Caribbean plateau, leading to the Aves–Lesser Antilles system, was the driving force in the evolution of the southern Caribbean margin. Exhumation of the HP-LT units took place from the Campanian, while the VC unit seems to have been completely exhumed by the latest Cretaceous. The initial phases of uplift were related to the early retrograde tectono-metamorphic events and resulted from a displacement in dextral shear zones, which probably occurred almost parallel to the plate boundary. This strike-slip regime also led to a progressive dismembering of the orogenic system and development of the different terranes, probably while exhumation of some previously subducted units was still active, and produced a northeastward shift of the MI-t with respect to the CdC-t and SI-t (Figure 6a). According to Giunta et al. (2002), the absence in the SI-t and CdC-t of Late Cretaceous (86–82 Ma) island-arc calc-alkaline magmatism, related to the west-dipping intraoceanic subduction of the proto-Caribbean/Atlantic lithosphere below the Caribbean plateau, indicates that these terranes already were independent geodynamically and disconnected from the subduction. In the early Palaeocene, the SI-t was probably emplaced onto the SOAM continental margin. On the other hand, the occurrence of calc-alkaline intrusions in the MI-t suggests that this terrane was shifted close to the future DV-t and above the subduction zone. The dextral strike-slip tectonics subsequently also involved the MI-t and DV-t, which progressively underwent rotation and east-west displacement, being juxtaposed next to the other terranes in the Northern Venezuelan belt (Figure 6b).

Starting from the Paleocene, the geometry of the orogenic belt has been controlled by the shear zone characterizing the Caribbean and SOAM transform plate boundary, producing a further east-west dismemberment of the belt to the present-day.

CONCLUSIONS

The available data allow different geodynamic reconstructions, each characterized by fundamental problems which remain unsolved. The outline of an unequivocal solution can derive only from improved information that will provide constraints for a more likely geodynamic reconstruction (deformations, metamorphism, radiometric ages, paleomagnetism, and other geologic data). Nonetheless, suitable constraints already can be derived from a comparison with the northern margin of the Caribbean plate (i.e., west-east alignment from Guatemala to the Greater Antilles), which represents the counterpart of the southern one described in this paper. The Late Cretaceous–Present geodynamics of the Caribbean plate have been driven mainly by the eastward drift of the Caribbean plateau with respect to the NOAM and SOAM plates. As a result, both the northern and southern boundaries of the Caribbean have corresponded, since the Late Cretaceous, to two wide shear zones.

Similarities in the main evolutionary stages of both margins are suggested. The strike-slip tectonic regime is still active (e.g., Motagua fault in Guatemala, El Pilar fault in Venezuela). In the present-day tectonic settings of the two marginal orogenic belts, ''displaced terranes'' are recognizable. Commonly, they are composed of comparable geotectonic elements, even if different geometric associations between the first-order tectonic units are shown. As in the southern Caribbean margin, the northern Caribbean margin shows a flowerlike structure; it overthrusts both the foredeep-like basins developed onto the NOAM continental margin to the north (e.g., in Guatemala and Cuba) and the slightly deformed oceanic plateau (e.g., southwest of Haiti and Los Muertos accretionary prism), minor continental blocks (e.g., Chortis), or rifted continental margins (e.g., Escambray) to the south.

However, differences in the evolution of the northern and southern Caribbean margins also can be highlighted. For instance, in the northern marginal belt, the Late Cretaceous (about 85 Ma) calc-alkaline magmatism affected active accretionary complexes in which deformed and metamorphosed units of oceanic, continental, and island-arc origin already had been involved (e.g., in Guatemala, Cuba, Hispaniola, and Puerto Rico). By contrast, as previously described, in the southern margin the coeval calc-alkaline magmatism is recorded only in the DV-t and subordinately in the MI-t. This different occurrence suggests that during the Late Cretaceous, the early (middle Cretaceous) subduction complexes of the southern and northern Caribbean margins were variably located with respect to the trend of the west-dipping subduction that produced the calc-alkaline magmatism.
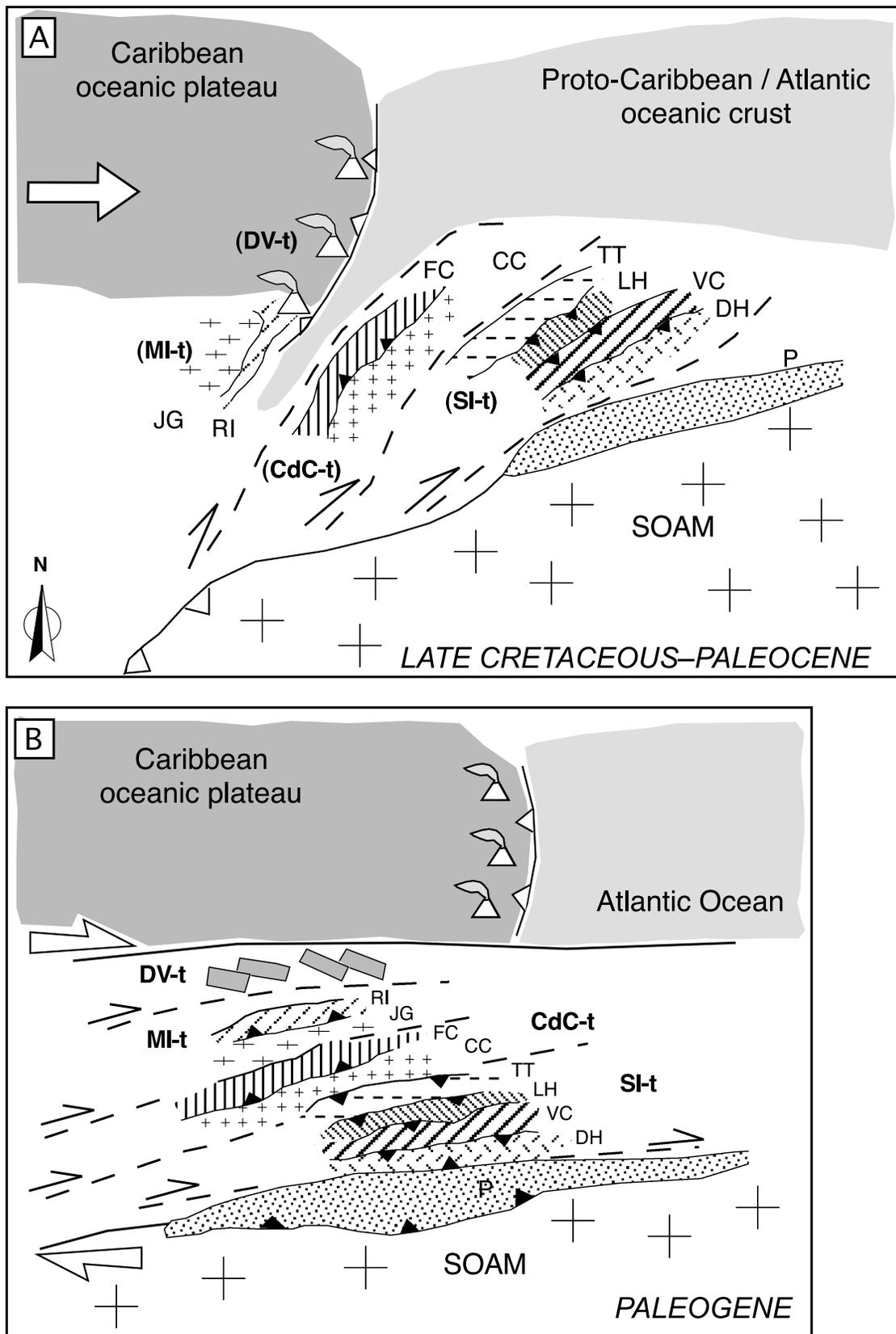
Figure 6. Sketches illustrating (A) the southern Caribbean plate margin reconstruction in the Late Cretaceous–Paleocene, and (B) during the Paleogene. RI = La Rinconada unit; JG = Juan Griego unit; LR = Los Robles unit; FC = Franja Costera group; CC = Cordillera de la Costa group; TT = Caucagua–El Tinaco unit; LH = Loma de Hierro unit; VC = Villa de Cura unit; DH = Dos Hermanas unit; P = Piemontine Nappe; SOAM = South American plate.

Despite these differences, authors generally agree with the hypothesis of common large-scale features of the Late Cretaceous–Tertiary geodynamic evolution of the northern and southern margins of the Caribbean plate. Major disagreements arise when a comparison between the middle Cretaceous geodynamics, which corresponds to the beginning of the convergence at the plate boundaries, is attempted. This is probably a result of the almost complete obliteration of structural and tectonic features by the subsequent deformational events, and the limited information available to provide further evolutionary constraints.

In conclusion, major advances in the reconstruction of the Caribbean geodynamics will be accomplished, given further increases of geologic data and integration on a regional scale of the large amount of detailed data presently available. This paper is an attempt to contribute to this accomplishment by adding to the knowledge of complex geodynamic evolution of the Caribbean area.

ACKNOWLEDGMENTS

REFERENCES CITED

Aubuoin, J., M. Baltuck, R. J. Arnott, J. Burgois, M. Filewiez, R. Helm, K. A. Kvenvolden, B. Lienert, T. McDonald, K. McDougall, Y. Ogawa, E. Taylor, and B. Winsborough, 1982, Leg 84 of the Deep Sea Drilling Project, subduction without accretion, Middle America Trench off Gautemala: Nature, v. 297, p. 458–460.

Audemard, F., and A. Singer, 1996, Active fault recognition in Northern Venezuela and its sismogenic characterization: Neotectonic and paleosismic approach: Geophisica International, v. 35, p. 245–255.

Avé Lallemant, H. G., 1997, Transpression, displacement partitioning, and exhumation in the eastern Caribbean/South America plate boundary zone: Tectonics, v. 16, p. 272–289.

Avé Lallemant, H. G., and R. Guth, 1990, Role of extensional tectonics in exhumation of eclogites and blueschists in an oblique subduction setting: Northeast Venezuela: Geology, v. 18, p. 950–953.

Avé Lallemant, H. G., and V. B. Sisson, 1993, Caribbean-South America plate interactions: Constraints from the Cordillera de la Costa Belt, Venezuela, in J. L. Pindell, ed., Mesozoic and early Cenozoic development of the Gulf of Mexico and Caribbean region: Transactions, Gulf Coast Section Society for Sedimentary Geology (SEPM) Foundation 13th Annual Research Conference, Houston, Texas, p. 1–9.

Bartock, P. E., O. Renz, and G. E. G. Westermann, 1985, The Siquisique Ophiolites, northern Lara State, Venezuela: A discussion on their Middle Jurassic ammonites and tectonic implications: Geological Society of America Bulletin, v. 96, p. 1050–1055.

Beccaluva, L., M. Coltorti, G. Giunta, M. Iturralde-Vinent, E. Navarro, F. Siena, and F. Urbani, 1996, Cross sections through the ophiolitic units of the southern and northern margins of the Caribbean plate in Venezuela (Northern Cordilleras) and central Cuba: Ofioliti, v. 21, p. 85–103.

Beccaluva, L., A. L. Chinchilla, M. Coltorti, G. Giunta, F. Siena, and C. Vaccaro, 1999, The S. Elena-Nicoya Ophiolitic Complex in Costa Rica, and its geodynamic implications for the Caribbean Plate evolution: European Journal of Mineralogy, v. 11, p. 1091–1107.

Beck, C., 1978, Polyphase Tertiary tectonics of the interior range in the central part of the western Caribbean chain, Guarico State, northern Venezuela: Geologie en Mijnbouw, v. 57, p. 99–104.

Beck, C., 1986, Caribbean colliding, Andean drifting and the Mesozoic-Cenozoic geodynamic evolution of the Caribbean, in Memoria: 6th Congreso Géologico Venezolano, Caracas: Sociedad Venezolana de Geòlogos, v. 10, p. 163–182.

Beets, D. J., W. V. Maresch, G. T. Klaver, A. Mottana, R. Boccchio, F. F. Beunk, and H. P. Monen, 1984, Magmatic rock series and high-pressure metamorphism as constraints on the tectonic history of the southern Caribbean, in W. E. Bonini, R. B. Hargraves, and R. Shagam, eds., The Caribbean-South America Plate boundary and regional tectonics: Geological Society of America Memoir, v. 162, p. 95–130.

Bellizzia, A., 1986, Sistema Montañoso del Caribe, una cordillera alóctona en la parte norte de América del Sur, in Memoria: 6th Congreso Géologico Venezolano, Caracas: Sociedad Venezolana de Geòlogos, v. 10, p. 6657–6836.

Bellizzia, A., and G. Dengo, 1990, The Caribbean mountain system, northern South America; A summary, in G. Dengo and J. E. Case, eds., The Caribbean Region, The Geology of North America, v. H: Boulder, Colorado, Geological Society of America, p. 167–176.

Bocchio R., L. De Capitani, G. Liborio, W. V. Maresch, and A. Mottana, 1990, The eclogite-bearing series of Isla Margarita, Venezuela: Geochemistry of metabasic

lithologies in the La Rinconada and Juan Griego Groups: Lithos, v. 25, p. 55–69.

Bocchio, R., L. De Capitani, G. Liborio, W. V. Maresch, and A. Mottana,1996, Equilibration conditions of eclogite lenses from Isla Margarita, Venezuela: Implication for the tectonic evolution of the metasedimentary Juan Griego Group: Lithos, v. 37, p. 39–59.

Bowland, C., and E. Rosencrantz, 1988, Upper crustal structure of the western Colombian basin, Caribbean Sea: Geological Society of America Bulletin, v. 100, p. 534–546.

Burke, K., 1988, Tectonic evolution of the Caribbean: Annual Reviews in Earth and Planetary Sciences, v. 16, p. 201–230.

Burke, K., P. J. Fox, and A. M. C. Sengor, 1978, Bouyant ocean floor and the evolution of the Caribbean: Journal of Geophysical Research, v. 83, p. 3949–3954.

Burke, K., C. Cooper, J. F. Dewey, P. Mann, and J. L. Pindell, 1984, Caribbean tectonics and relative plate motions, *in* W. Bonini, R. B. Hargraves, and R. Shagam, eds., The Caribbean-South America plate boundary and regional tectonics: Geological Society of America, v. 162, p. 31–63.

Burmester, R. F., M. E. Beck, R. C. Speed, and A. W. Snoke, 1996, A preliminary paleomagnetic pole for middle Cretaceous rocks from Tobago: Further evidences for large clockwise rotations in the Caribbean-South America plate boundary zone: Earth and Planetary Science Letters, v. 139, p. 79–90.

Case, J. E., W. D. MacDonald, and P. J. Fox, 1990, Caribbean crustal provinces: Seismic and gravity evidence, *in* G. Dengo and J. E. Case, eds., The Caribbean region, The Geology of North America, v. H: Boulder, Colorado, Geological Society of America, p. 15–36.

Coney, P. J., D. L. Jones, and J. W. H. Monger, 1980, Cordilleran suspect terranes: Nature, v. 270, p. 329–333.

Dengo, G., 1985, Mid-America: Tectonic setting for the Pacific margin from southern Mexico to northwest Colombia, *in* A. E. M. Nairn, F. G. Stehli, and S. Uyeda, eds., The Oceanic Basins and Margins, v. 7, The Pacific Ocean: New York, Plenum Press, p. 123–180.

Donnelly, T. W., 1975, The geological evolution of the Caribbean and Gulf of Mexico: Some critical problems and areas, *in* A. E. M. Nairn and F. G. Stehli, eds., The Oceanic Basins and Margins, v. 3, The Gulf of Mexico and the Caribbean: New York, Plenum Press, p. 663–690.

Donnelly, T. W., and J. J. W. Rogers, 1978, The distribution of igneous rocks throughout the Caribbean: Geology en Mijnbouw, v. 57, p. 151–162.

Donnelly, T. W., and J. J. W. Rogers, 1980, Igneous series in island arcs: The northeastern Caribbean compared with worldwide island arc assemblages: Bulletin of Volcanology, v. 43, p. 347–382.

Donnelly, T. W., D. Beets, M. J. Carr, T. Jackson, G. Klaver, J. Lewis, R. Maury, H. Schellenkens, A. L. Smith, G. Wedge, and D. Westercamp, 1990, History and tectonic setting of Caribbean magmatism, *in* G. Dengo and J. E. Case, eds., The Caribbean region, The Geology of North America, v. H: Boulder, Colorado, Geological Society of America, p. 339–374.

Duncan, R. A., and R. B. Hargraves, 1984, Plate tectonic evolution of the Caribbean region in the mantle reference frame, *in* W. E. Bonini, R. B., Hargraves, and R. Shagam, eds., The Caribbean-South America plate boundary and regional tectonics: Geological Society of America Memoir, v. 162, p. 81–93.

Edgar, N. T., J. I. Ewing, and J. Hennion, 1971, Seismic refraction and reflection in the Caribbean Sea: Bulletin of the American Society of Petrology and Geology, v. 55, p. 833–870.

Ernst, W. G., 1988, Tectonic history of subduction zones inferred from retrograde blueschist P-T paths: Geology, v. 16, p. 1081–1084.

Frisch, W., M. Meschede, and M. Sick, 1992, Origin of the Central American ophiolites: Evidences from paleomagnetic results: Geological Society of America Bulletin, v. 104, no. 10, p. 1301–1314.

Girard, D., C. Beck, J. F. Stephan, R. Blanchet, and R. C. Maury, 1982, Pétrologie, géochimie et signification géodynamique de quelques formations volcaniques crétacées péri-Caraibes : Bulletin Societé Géologique de France, v. 24, p. 535–544.

Giunta, G., 1993, Los margenes mesozoicos de la Placa Caribe: Problematicas sobre nucleacion y evolucion, Memoria: 6th Congreso Colombiano de Geologia, Medellin: Societad Geologica Colombiana, v. 3, no. 8, p. 1–14.

Giunta, G., L. Beccaluva, M. Coltorti, and F. Siena, 1997, Ophiolitic units of the Southern margin of the Caribbean Plate in Venezuela: An appraisal of their petrogenesis and original tectonic setting: 8th Memorias Congreso Geologico Venezolano, Porlamar: Sociedad Venezolana de Geologos, v. 1, p. 331–337.

Giunta, G., L. Beccaluva, M. Coltorti, and F. Siena, 1998, Tectono-magmatic significance of the peri-caribbean ophiolitic units and geodynamic implications, *in* Proceedings of 15th Caribbean Geological Conference: Kingston, Jamaica, West Indies University, p. 1–21.

Giunta, G., L. Beccaluva, M. Coltorti, F. Siena, D. Mortellaro, and D. Cutrupia, 2002, The peri-Caribbean ophiolites: Structure, tectono-magmatic significance and geodynamic implications: Caribbean Journal of Earth Sciences, v. 36, p. 1–20.

Giunta, G., L. Beccaluva, M. Coltorti, F. Siena, and C. Vaccaro, 2002, The southern margin of the Caribbean plate in Venezuela: Tectono-magmatic setting of the ophiolitic units and kinematic evolution: Lithos, v. 63, p. 19–40.

Holcombe, T. L., J. W. Ladd, G. Westbrook, N. T. Edgar, and C. L. Bowland, 1990, Caribbean margine geology; ridges and basins of the plate interior, *in* G. Dengo and J. E. Case, eds., The Caribbean Region, The Geology of North America, v. H: Boulder, Colorado, Geological Society of America, p. 231–260.

Iturralde-Vinent, M., 1994, Cuban geology: A new plate

tectonic synthesis, Journal of Petroleum Geology, v. 17, p. 38–70.

Jackson, T., and E. Donovan, 1994, Tobago, *in* S. Donovan and T. Jackson, eds., Caribbean geology: An introduction: Kingston, Jamaica, West Indies University, p. 193–207.

Jackson, T., and E. Robinson, 1994, The Netherlands and Venezuelan Antilles, *in* S. Donovan and T. Jackson, eds., Caribbean geology: An introduction: Kingston, Jamaica, West Indies University, p. 249–263.

Kerr, A. C., J. Tarney, G. F. Marriner, G. T. Klaver, A. D. Sounders, and M. F. Thirlwall, 1996, The geochemistry and petrogenesis of the late-Cretaceous picrites and basalts of Curaçao, Netherlands Antilles: A remnant of an oceanic plateau: Contributions to Mineralogy and Petrology, v. 124, p. 29–43.

Lewis, J. F., and G. Draper, 1990, Geology and tectonic evolution of the Northern Caribbean margin, *in* G. Dengo and J. E. Case, eds., The Caribbean Region, The Geology of North America, v. H: Boulder, Colorado, Geological Society of America, p. 77–110.

Loubet, M., R. Montigny, B. Chahati, N. Duarte, B. Lambert, C. Martin, and R. Thuizat, 1985, Goechemical and geochronological constraints on the geodynamic development of the Caribbean chain of Venezuela, *in* A. Mascle, ed., Symposium on Caribbean geodynamics: Paris, Edition Technip, p. 553–566.

Maresch, W. V., 1974, Plate tectonic origin of the Caribbean Mountain system of northern South America: Discussion and proposal: Geological Society of America Bulletin, v. 85, p. 669–682.

Maresch, W. V., 1975, The geology of northeastern Margarita Island, Venezuela: A contribution to the study of Caribbean plate margins: Geologische Ründshau, v. 64, p. 846–883.

Maresch, W. V., and K. Abraham, 1980, Petrography, mineralogy, and metamorphic evolution of an eclogite from the Island of Margarita, Venezuela: Journal of Petrology, v. 22, p. 337–362.

Maresch, W. V., B. Stockhert, A. Baumann, C. Kaiser, R. Kluge, G. Kruckhans-Lueder, M. R. Brix, and S. Thomson, 2000, Crustal history and plate tectonic development in the Southern Caribbean: Zeitschrift für Angewandte geologie, v. 1, p. 283–289.

Meschede, M., and W. Frisch, 1998, A plate-tectonic model for Mesozoic and Early Cenozoic evolution of the Caribbean plate: Tectonophysics, v. 296, p. 269–291.

Mottana, A., R. Bocchio, G. Liborio, L. Morten, and W. V. Maresch, 1984, The eclogite-bearing metabasaltic sequence of Isla Margarita, Venezuela: A geochemical study: Chemical Geology, v. 50, p. 351–368.

Morris, A. E. L., I. Tarney, H. A. Meyerhoff, and A. A. Meyerhoff, 1990, Tectonic evolution of the Caribbean region; Alternative hypothesis, *in* G. Dengo and J. E. Case, eds., The Caribbean Region, The Geology of North America, v. H: Boulder, Colorado, Geological Society of America, p. 433–457.

Navarro, E., 1974, Petrogenesis of the ophiolitic rocks of isla de Margarita, Venezuela: Ph.D dissertation, University of Kentucky, Lexington, University Microfilms, n. BFJ75-18501, p. 1–222.

Navarro, E., 1983, Petrologia y petrogenesis de las rocas metavolcanicas del gruppo Villa de Cura: GEOS Venezuela, Escuela de Geologìa y Minas, Universidad Central de Venezuela, Caracas, v. 28, p. 170–317.

Navarro, E., 1997, Complejo ofiolitico de Margarita y su relaciòn con la tectonica de Placas del Caribe, in Guia de la excursion n°4, 8th Congreso Geologico Venezolano, Porlamar: Sociedad Venezolana de Geòlogos, Special Publication, p. 1–11.

Ostos, M., 1990, Evolucion tectonica del margen Sur-Central del Caribe, basados en datos geoquìmicos: GEOS, Escuela de Geologìa y Minas, Universidad Central de Venezuela, Caracas, v. 30, p. 1–294.

Ostos, M., and E. Navarro, 1986, Faja de Villa de Cura. Realmenta un complejo de arco de isla aloctono? *in* Memoria, 6th Congreso Géologico Venezolano, Caracas: Sociedad Venezolana de Geòlogos, v. 10, p. 6615–6638

Piburn, M. D., 1967, Metamorphism and structure of the Villa de Cura Group, northern Venezuela: Ph.D. dissertation: Princeton University, Princeton, New Jersey, 148 p.

Pimentel, B. N., H. Gaudette, and W. Olsewsky, 1985, Nuecas dataciones en el basamento de la Cadena Caraibe, *in* Memoria, 6th Congreso Géologico Venezolano, Caracas: Sociedad Venezolana de Geòlogos, v. 2, p. 1979–1994.

Pindell, J., 1993, Regional synopsis of Gulf of Mexico and Caribbean evolution, *in* J. L. Pindell and B. F. Perkins, eds., Mesozoic and early Cenoizoic development of the Gulf of Mexico and Caribbean region: A context for hydrocarbon exploration: Gulf Coast Section Society for Sedimentary Geology (SEPM) Foundation 13th Annual Research Conference, Houston, Texas, p. 251–274.

Pindell, J. L., and S. F. Barrett, 1990, Geological evolution of the Caribbean region: A plate-tectonic perspective, *in* G. Dengo and J. E. Case, eds., The Caribbean Region, The Geology of North America, v. H: Boulder, Colorado, Geological Society of America, p. 339–374.

Pindell, J. L., S. C. Cande, W. C. Pitman III, D. B. Rowley, J. F. Dewey, J. Labrecque, and W. Haxby, 1988, A plate-kinematic framework for models of Caribbean evolution: Tectonophysics, v. 155, p. 121–138.

Ross, M. I., and C. R. Scotese, 1988, A hieratical tectonic model of the Gulf of Mexico and Caribbean Region: Tectonophysics, v. 155, p. 139–168.

Seyler, M., J. L. Paquette, G. Ceuleneer, J. R. Kienast, and M. Loubet, 1998, Magmatic underplating, metamorphic evolution and ductile shearing in a Mesozoic lower-crustal-upper mantle unit (Tinaquillo, Venezuela) of the Caribbean Plate: Journal of Geology, v. 106, p. 35–58.

Shagam, R., 1960, Geology of the central Aragua State, Venezuela: Geological Society of America Bulletin, v. 71, p. 249–302.

Sinton, C. W., R. A. Duncan, M. Storey, J. Lewis, and J. J. Estrada, 1998, An oceanic flood basalt province within the Caribbean Plate: Earth and Planetary Sciences Letters, v. 155, p. 221–235.

Sisson, V. B., I. Evren Ertan, and H. G. Avé Lallemant, 1997, High-pressure (−2000 MPa) kyanite- and glaucophane-bearing pelitic schist and eclogite from Cordillera de la Costa Belt, Venezuela: Journal of Petrology, v. 38, p. 65–83.

Skerlec, G. M., and R. B. Hargraves, 1980, Tectonic significance of paleomagnetic data from the Northern Venezuela: Journal of Geophysical Research, v. 85, p. 5303–5315.

Smith, C. A., V. B. Sisson, H. G. Avé Lallemant, and P. Copeland, 1999, Two contrasting pressure-temperature paths in the Villa de Cura blueschist belt, Venezuela: Possible evidence for Late Cretaceous initiation of subduction in the Caribbean: Geological Society of America Bulletin, v. 111, p. 831–848.

Snoke, A., D. Rowe, D. Yule, and G. Wadge, 2001, Petrologic and structural history of Tobago, West Indies: A fragment of the accreted Mesozoic oceanic arc of the southern Caribbean: Geological Society of America Special Paper 354, 354 p.

Stephan, J. F., R. Blanchet, and B. Mercier de Lepinay, 1986, Northern and Southern Caribbean Festoons (Panama, Colombia, Venezuela, Hispaniola, Puerto Rico) interpreted as subductions induced by the East West shortening of the Pericaribbean continental frame, *in* F. C. Wezel, ed., The origin of arcs, Development in geotectonics, v. 21: Amsterdam, Elsevier Science, p. 35–51.

Stephan, J. F., B. Mercier de Lepinay, E. Calais, M. Tardy, C. Beck, J. C. Carfantan, J. L. Olivet, J. M. Vila, P. Bouysse, A. Mauffret, J. Bourgois, J. M. Thery, J. Tournon, R. Blanchet, and J. Dercourt, 1990, Paleogeodynamic maps of the Caribbean: 14 steps from Lias to present: Bullettin de la Societé Géologique de France, v. 8, p. 915–919.

Stockhert, B., et al., 1993, Tectonic history of Isla Margarita, Venezuela – A record of a piece of crust close to an active plate margin: Zentralblatt für Geologie und Paläontologie, v. 1, p. 485–498.

Stockhert, B., W. V. Maresch, M. Brix, C. Kaiser, A. Toetz, R. Kluge, and G. Kruckhans-Lueder, 1995, Crustal history of Margarita Island (Venezuela) in detail: Constraint on the Caribbean plate-tectonic scenario: Geology, v. 23, p. 787–790.

Sykes, L. R., W. R. McCann, and A. L. Kafka, 1982, Motion of the Caribbean plate during the last 7 million years and implications for earlier Cenozoic movements: Journal of Geophysical Research, v. 87, p. 10656–10676.

White, R .V., J. Tarney, A. C. Kerr, A. D. Saunders, P. D. Kempton, M. S. Pringle, and G. T. Klaver, 1999, Modification of an oceanic plateau, Aruba, Dutch Caribbean: Implication for the generation of continental crust: Lithos, v. 46, p. 43–68.