Caribbean Journal of Earth Science, **36** (**2002**), 1-20.

The peri-Caribbean ophiolites: structure, tectono-magmatic significance and geodynamic implications

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ABSTRACT. **New geological and petrological data on ophiolitic complexes deformed and dismembered along the Caribbean Plate margins are presented in the framework of IGCP 433, in order to contribute to the debate on the origin and evolution of the Caribbean Plate. A "near Mid-America" original location of the Jurassic-Cretaceous Caribbean oceanic realm (proto-Caribbean phase) is suggested. Generation of oceanic crust can be initially referred to multiple spreading centres (LREE-depleted MORB, in Venezuela, Costa Rica, Cuba, Guatemala, Hispaniola), evolving, into a thickened oceanic plateau (REE-flat MORB locally associated with picrites, in Costa Rica, Hispaniola, Venezuela, Dutch and Venezuelan Islands). At the same time, both the South and North American continental margins were affected by rifting and within-plate tholeiitic magmatism (Venezuela and Cuba).**

From Early to Late Cretaceous (eo-Caribbean phases), one subcontinental subduction zone, with melange formation (recorded only in Venezuela), and two main stages of intraoceanic subduction may be recognised: 1) an initial NE- and SE-dipping sinking of unthickened proto-Caribbean lithosphere, recorded by deformed and HP/LT metamorphosed ophiolitic melanges and volcano-plutonic sequences with island-arc tholeiitic affinity (IAT) in Venezuela, calc-alkaline affinity (CA) in Cuba and both IAT and CA affinity in Guatemala and Puerto Rico; 2) followed by intraoceanic subduction, with reverse polarity, responsible for the first tectonic arrangement of the Caribbean margins, recorded by unmetamorphosed tonalitic intrusives, and related to the onset of the Aves-Lesser Antilles arc system and its eastward migration. In the Late Cretaceous, the undeformed interior of the Caribbean Plate, i.e. the Colombian and Venezuelan Basins, was restricted by subduction of the Pacific plate, building the Central American Isthmus. The Tertiary to Present eastward displacement of the Caribbean Plate led to the progressive dismembering of the deformed ophiolitic belts and their obduction at its margins. Presented at IGC-BRAZIL/2000

INTRODUCTION

The Caribbean Plate (Fig. 1) consists of a nearly undeformed central portion (Colombia and Venezuela Basins) bounded by active margins involving the interaction with the neighbouring Nazca, Cocos, North and South America, from the Mesozoic to present. The northern and southern Plate margins mainly consist of transpressive or strike-slip shear zones, while the western and eastern margins are represented by convergent systems and related magmatic arcs. These margins include Jurassic/Cretaceous ophiolitic complexes cropping out along suture zones or accreted terrains on the northern, southern and western sectors of the Caribbean Plate.

Systematic investigations carried out in the last few years on the most important peri-Caribbean ophiolitic units allow us to reconstruct their regional geometry, magma affinity and original tectonic setting. In particular new petrological and geochemical data are presented, and discussed in a general review, with the aim of defining the tectono-magmatic significance of the various igneous associations. This paper summarises the main results of the Italian-Latin American group, presented at the International Geological Congress of Brazil 2000, and is intended to contribute to the debate on the origin and evolution of the Caribbean Plate in the framework of the new IGCP 433.

REGIONAL GEOLOGICAL FRAMEWORK

The margins of the Caribbean Plate are represented by large deformed belts which result from several compressive episodes followed by tensional and/or

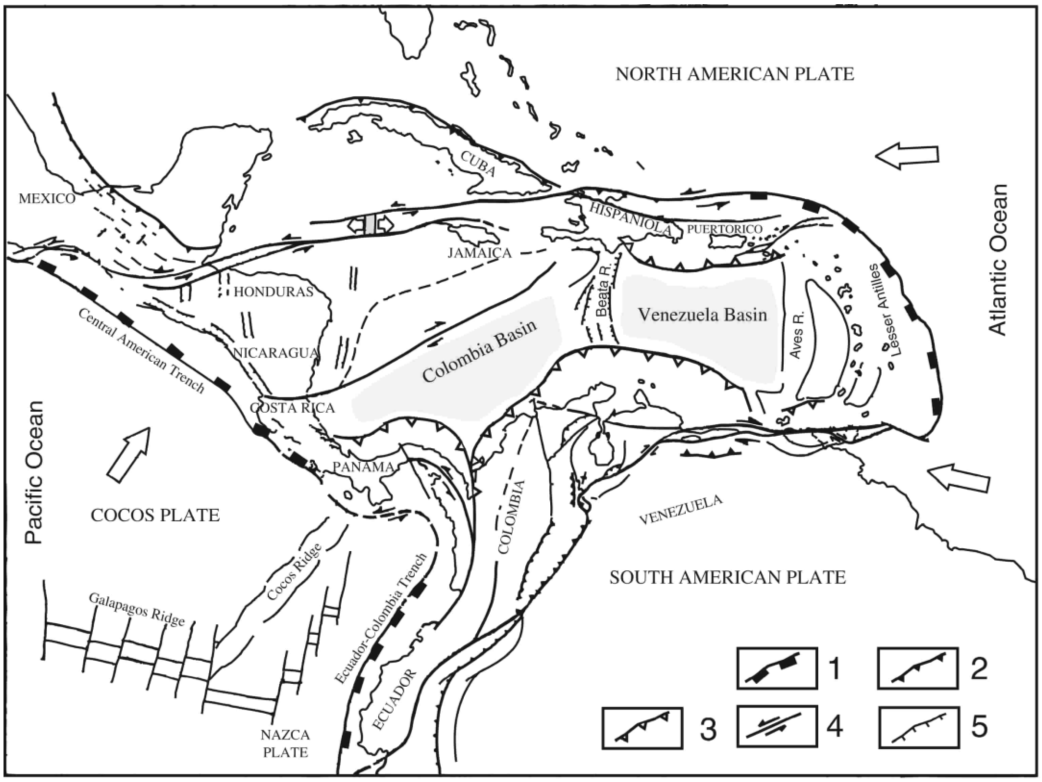


Figure 1. Structural sketch map of the Caribbean area (modified from Beccaluva *et al*., 1996). Arrows show the movement direction of the main plates. Symbols: 1, trenches and active subduction zones; 2, overthrust fronts; 3, Tertiary accretionary prisms; 4, strike-slip faults; 5, extensional faults.

strike-slip tectonics, starting in the Late Cretaceous. The Caribbean lithosphere has been deformed and piled up onto the Pacific and Atlantic oceanic crusts, giving rise to the western and eastern island arc systems of the Central American Isthmus and Lesser Antilles respectively, as well as onto the North and South American continental crusts, forming the suture zones of the Greater Antilles and Venezuela respectively (Fig. 1). The more internal Caribbean margins have been successively deformed and involved in a series of accretionary prisms (Venezuela, Colombia, Panama, Hispaniola, etc.) (Stephan *et al*., 1986). In both the northern and southern Caribbean margins, the main structural features have been controlled by a transpressional regime, leading in places to opposite vergences of the deformed belts (“flower structures”).

The present-day borders of the Caribbean Plate run along these deformed belts and are represented by suture zones or "accreted terranes" which include Jurassic-Cretaceous ophiolitic units. Sinistral and dextral strike-slip shears occur on the northern and southern margins, respectively (Fig. 1). As a consequence, certain portions of the deformed Caribbean lithosphere are now included in the crust of the adjacent plate margins, and should no longer be referred to the Caribbean domain s.s.

The most important geological features of the investigated sectors are reported below.

Guatemala

The present northwestern margin of the Caribbean Plate crops out along the Motagua Suture Zone in Guatemala, which links the meso-American trench with the Cayman Islands extensional system (Finch and Dengo, 1990; Beccaluva *et al*., 1995). It represents a sinistral shear-zone between the Maya and Chortis continental blocks, and includes E-W and ENE-WSW strike-slip fault systems (e.g., Polochic, Motagua, Cabañas, Jocatàn). Remarkable W-E trending uplift structures (Sierra Chuacus, Sierra de Las Minas, Montañas del Mico), pull-apart basins (Izabal Lake, Bananeras, etc.) and grabens elongated in a prevalent N-S direction (Guatemala, Chiquimila, etc.) are found within the shear zone of Motagua.

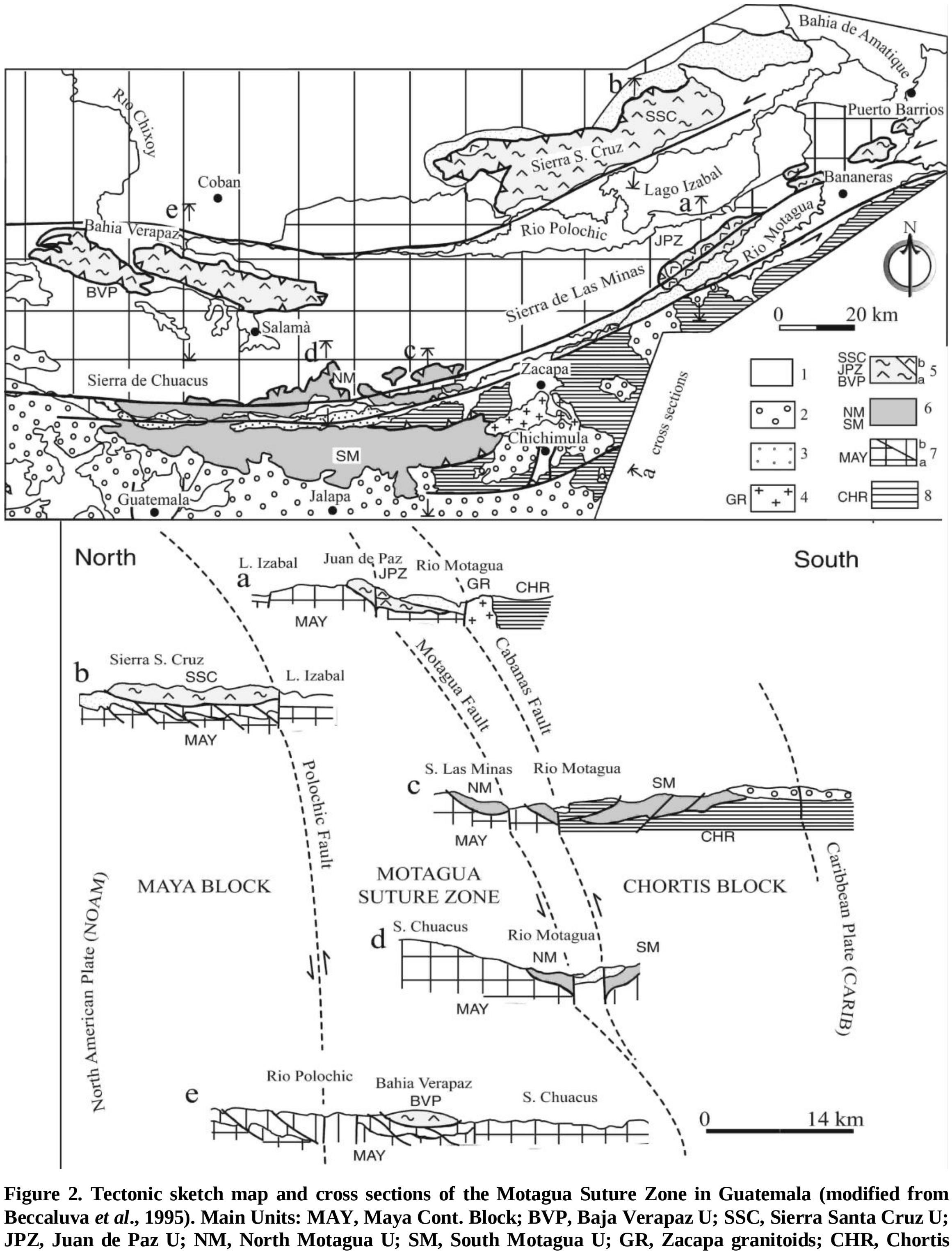


Figure 2. Tectonic sketch map and cross sections of the Motagua Suture Zone in Guatemala (modified from Beccaluva *et al*., 1995). Main Units: MAY, Maya Cont. Block; BVP, Baja Verapaz U; SSC, Sierra Santa Cruz U; JPZ, Juan de Paz U; NM, North Motagua U; SM, South Motagua U; GR, Zacapa granitoids; CHR, Chortis Cont. Block. Legend: 1, recent deposits; 2, Tertiary-Quaternary volcanics; 3, flysch and molassic deposits (Late Cretaceous-Eocene); 4, Arc tonalitic magmatism (Granitoids, GR) (Late Cretaceous-Eocene); 5, Volcano-plutonic arc sequences (Peridotites, gabbros and basalts, andesites, with IAT (5a) and CA (5b) affinity of supra-subduction complexes) with carbonatic-terrigenous sediments (Cretaceous); 6, MORB ophiolites (mantle peridotites, gabbros and basalts) with radiolarites to carbonatic-terrigenous sequences (Late Jurassic-Early Cretaceous); 7, continental basement (7a) and sedimentary covers (7b) of the Maya Block; 8, continental basement of the Chortis Block.

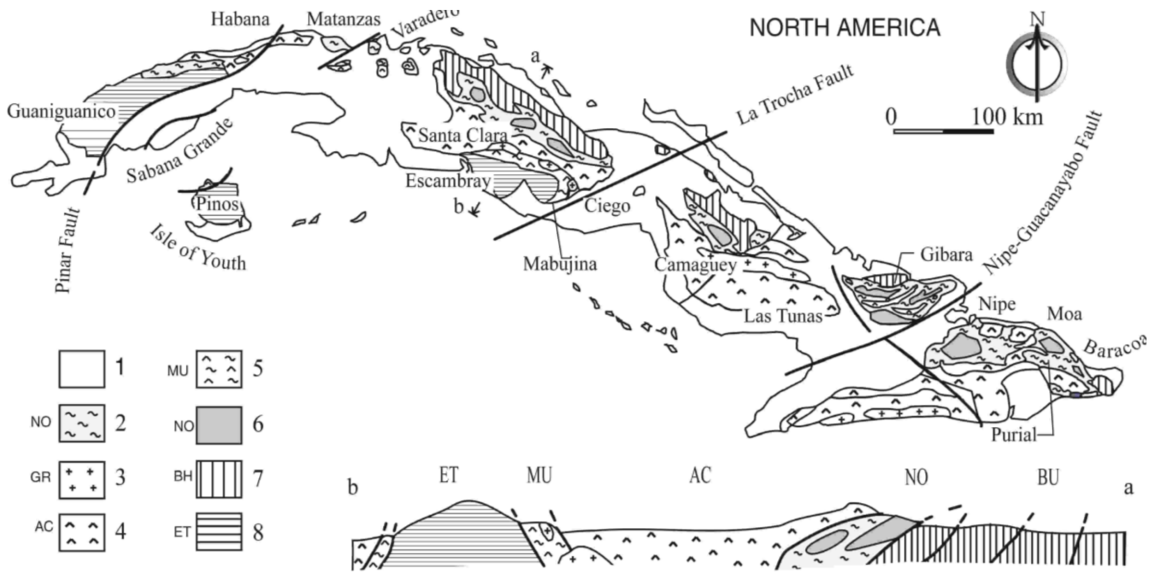


Figure 3. Tectonic sketch map and cross sections of Cuba (modified from Iturralde Vinent, 1994). Main Units: BH, Bahamas U; NO, Northern Ophiolites Melange; AC, Arc Cretaceous Us; MU, Mabujna U; ET, Escambray Us. Legend: 1, Tertiary-Quaternary deposits; 2, Melanges with variably terrigenous matrix (Late Cretaceous-Paleogene), including 5; 3, Tonalitic intrusive (Late Cretaceous-Eocene); 4, Arc Volcanics (CA affinity) with scattered reefal limestones (Cretaceous-Paleocene); 5, metamorphosed vulcano-plutonic arc sequences with CA affinity of supra-subduction complex (Cretaceous); 6, peridotites, cumulitic gabbros, basalts (MORB magmatism) and radiolarites (Late Jurassic-Early Cretaceous), involved in melanges; 7, sedimentary sequences (Jurassic-Cretaceous) of Bahamas continental margin; 8, metamorphic continental basement of Escambray.

The Motagua Suture Zone is a typical transpressional (or collisional) "flower structure", with northward and southward vergences of the following main ophiolitic units (Fig. 2):

1. The Sierra de Santa Cruz (SSC) and Baja Verapaz (BVP) Units clearly overthrust the Maya Block, the former onto the Late Cretaceous-Eocene carbonatic-terrigenous sequences of the Sepur Formation, the latter onto the Palaeozoic metamorphites of the Chuacus Group or the Mesozoic evaporitic-terrigenous-carbonatic deposits of the Todos Santos, Coban and Campur Formations;

2. The Juan de Paz Unit (JPZ) overthrust the Palaeozoic metamorphic basement of the Sierra de Las Minas and Montañas del Mico (Maya Block);

3. The South Motagua (SM) and North Motagua (NM) Units, outcropping in a narrow "flower structure", overthrust both the Palaeozoic continental basement (Las Ovejas and San Diego Formations) of the Chortis Block (SM) and the Palaeozoic metamorphic terranes of the Sierras de Chuacus and Las Minas of the Maya block (NM). These units are imbricated through variably dipping fault surfaces with "out of sequence" basement slices.

Lithologically, the SSC, BVP and JPZ Units are made up of generally serpentinized mantle harzburgites, layered gabbros, dolerites and scarce basalts. SSC is locally covered by small outcrops of terrigenous and volcanoclastic sequences including andesitic and dacitic fragments (Cretaceous Tzumuy Fm of Rosenfeld, 1981). The JPZ is covered by basic volcanoclastic and andesitic breccias, passing upward to carbonatic breccias and calcarenites, with sandstone and microconglomerates containing acid volcanic fragments (Late Cretaceous Cerro Tipon Fm of Muller, 1980).

The SM and NM consist of the so-called "El Tambor Group", made up of serpentinized peridotites and foliated gabbros, and followed by a thick basaltic pillow lava sequence, radiolarian cherts, metasiltites and metarenites with intercalations of basaltic flows. The top of the sequence is represented by phyllitic metasiltites alternating with marbles and dark levels of metacalcarenites (Late Cretaceous Cerro de La Virgen limestones). Along the Motagua River the JPZ, SM and NM Units are unconformably overlain by the Eocene continental molasses of the Subinal Fm.

Cuba

The northernmost portion of the Cretaceous Caribbean Plate margin crops out in Cuba near the southern edge of the North American Plate (Pardo, 1975; Iturralde Vinent, 1989, 1994). It is separated from the rest of the Greater Antilles (Jamaica, Hispaniola and Puerto Rico) by the Bartlett sinistral strike-slip structure, which represents today the northern boundary of the Caribbean Plate.

The Cuban folded belt, from west to east, is transected by subvertical, sinistral strike-slip structures (Pinar, La Trocha, Nipe Faults). As shown in Fig. 3, the whole complex is composed of two continental elements, respectively belonging to the Bahamas Platform (the northernmost) and the Guaniguanico-Piños-Escambray (ET) Terranes (the southernmost). These are both overthrust by the oceanic elements of the Northern Ophiolitic Melange (NO) and the Cretaceous Arc (AC) Units (Fonseca *et al*., 1990; Iturralde Vinent, 1994) and followed by the Paleogene Arc Units, which are exposed in eastern Cuba. The deformation front of the folded belt extends onto a Paleogene foredeep in a series of frontal slices with north vergence, associated with flyschoid sequences and olistostromes. Generally speaking:

1. The Bahamas Units (BH) are structurally the lowest in the folded system, and consist of at least four tectonic sheets: Cayo Coco, Remedios, Camajunì and Placetas, which represent the original edge of the North American continental margin. In the Placetas Unit, Late Jurassic tholeiitic lavas are also present. A Paleocene - Eocene foredeep basin overlies the Bahamas margin dating the collision of the Northern Ophiolites and Cretaceous Arc with the Bahamas crust.

2. The Northern Ophiolitic Melange (NO) Unit overthrusts the foreland basin and the Bahamas Units to the north and the northeast. The unit includes blocks of peridotites and cumulitic gabbros cut by dikes of diabases overlain by basaltic lavas, hyaloclastites, radiolarites and volcanoclastites of Hauterivian-Turonian age.

3. The Cretaceous Arc Units (AC) overlie the ophiolitic melange to the north and the Escambray Terranes to the south. They consist of lava flows, pyroclastites and volcanoclastic rocks, sometimes unconformably overlain by late Campanian-Maastrichtian carbonate and terrigenous sequences. Within the volcanic complex there are several rudist-bearing limestone horizons of Late Albian, Santonian and Early Campanian age.

4. The Mabujina subduction complex (MU), consisting of metavolcanics and metaplutonics with calc-alkaline magmatic affinity, underlies the Cretaceous Arc Units and overthrusts the Escambray continental terranes.

5. A plutonic complex intrudes the AC and the MU Units, with a variably thick cornubianitic aureola. The complex is made up of locally foliated granitoid and tonalitic bodies of Aptian-Campanian age.

6. The Escambray Terranes (ET), dating from the Late Jurassic to Late Cretaceous and considered the equivalent of the Guaniguanico and Los Piños terranes, tectonically underlies the Mabujina Unit, and crop out as a complex thrust system in a large dome-shaped structure. The sequence generally consists of Mesozoic terrigenous and carbonate deposits of the continental margin. Slices of metavolcanics, metagabbros and serpentinites have been reported in some localities, together with a metamorphic melange.

Hispaniola

Hispaniola represents a transpressional shear zone where portions of an oceanic plateau (Central Cordillera, Dominican Republic) are juxtaposed against Northern Cordillera ophiolites to the northeast and a portion of the oceanic plateau to the southwest (Massif de la Hotte-Salle-Bahoruco, Southern Peninsula of Haiti). The three main geological sectors of this flower structure are separated by large sinistral strike-slip faults (Septentrional, Enriquillo, Hispaniola, etc.) (Fig. 4).

The Northern Cordillera (NC) consists of an assemblage of tectonic units which constitute a heterogeneous ophiolitic terrane (Draper and Nagle, 1991; Draper *et al*., 1994). The NC is dismembered along WNW-ESE strike-slip faults in very complicated geometrical relationships. The main units are:

1. The Puerto Plata complex made up of variably-sized bodies of serpentinized peridotites, layered metagabbros, and pillowed metabasalts with scattered early Cretaceous radiolarites.

2. The Rio San Juan complex, composed of the following major units: a) the Gaspar Hernandez serpentinites; b) the Hicotea and Puerca Gorda schists; c) the Jagua Clara Melange, with several high pressure metamorphic blocks in an ultramafic matrix; d) the Cuaba Amphibolites, intruded by e) the Rio Boba gabbroic layered sequence.

3. The Samanà-Punta Balandra complex, consisting of a continuous sequence of foliated marbles with intercalations of mica schists, including boudins of metagabbros and metadolerites metamorphosed into blueschist and eclogite facies.

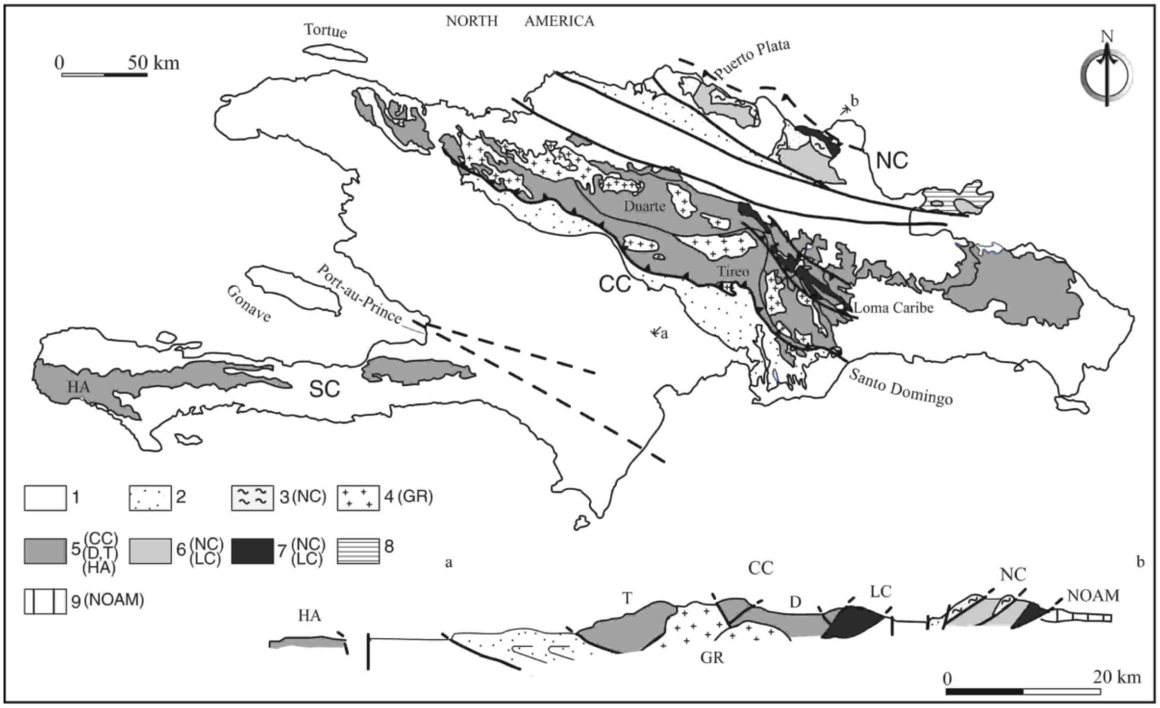


Figure 4. Tectonic sketch map and cross-section of Hispaniola (modified from Lewis and Draper, 1990). Main Units: NC, Northern Cordillera Us; CC, Central Cordillera Us; LC, Loma Caribe-Ortega U; D, T, Duarte and Tireo complex; GR, Tonalitic arc magmatism; SC, Southern Cordillera Us; HA, Massif de La Hotte-Salle-Bahoruco; NOAM, North American continental margin. Legend: 1, Tertiary-Quaternary deposits; 2, Terrigenous sequences (Late Cretaceous-Paleogene); 3, Melanges and olistostromes with variably terrigenous matrix (Late Cretaceous-Paleogene), including blocks of 6 and 7; 4, Gabbroid to granitoid intrusives (Tonalitic Arc magmatism, Late Cretaceous); 5, Metabasalts and metadolerites (D), and basic to acidic metavolcanics (T) (MORB to OIB affinity), with intercalations of radiolarites (Late Jurassic-Early Cretaceous and Late Cretaceous); 6, MORB ophiolites (mantle peridotites, metagabbros, metadolerites and metabasalts) with scattered radiolarites (Late Jurassic-Early Cretaceous), also included in 3; 7, Serpentinized mantle peridotites belonging to MORB ophiolites, also included in 3; 8, Foliated marbles and micaschists, with boudins of metagabbros and metadolerites with MORB affinity (Late Jurassic-Cretaceous); 9, North America Continental Plate.

The Central Cordillera (CC) terrane (Lewis and Draper, 1990), mainly constituted by the Duarte-Tireo complex, overthrust northeastward the Loma Caribe-Ortega (LC) Unit, which in turn overthrust the Maimon-Amina and Los Ranchos Units, the latter two separated by the Hatillo Thrust. Southwestward CC overthrust the Late Cretaceous-Paleogene terrigenous sequences of the Trois Rivieres belt.

From the above dismembered lithological units of the CC, a generalized stratigraphical sequence may be reconstructed from the base, as follows: serpentinized harzburgites (LC), covered by metadolerites and frequently pillowed metabasalts with intercalation of Late Jurassic-Early Cretaceous radiolarites (Duarte), passing upward to basalts, tuffs and volcanoclastites locally associated with Late Cretaceous radiolarites and siltstone (Tireo). The Amina-Maimon and Los Ranchos Units are respectively composed of dacitic metatuffs intercalated with metasediments, and of pillowed basalts and breccias with dacitic and rhyolitic composition, the latter underlying reefal limestones of the middle-late Cretaceous.

Several plutonic bodies of gabbroic and tonalitic composition are intruded into the Duarte-Tireo complex of the Central Cordillera.

The Massif de La Hotte-Salle-Bahoruco terrane (HA) of the Southern Peninsula in Haiti is mainly constituted by monotonous sequences of middle-late Cretaceous basalts and dolerites (with pelagic intercalations of limestones, cherts and siltstones), the most representative of which is the Dumisseau Fm.

Puerto Rico

According to Jolly *et al.* (1998), most of the island of Puerto Rico Island is made up of island arc volcanic "strata" (lavas, tuffs and volcanoclastic products) of Aptian to Eocene age. The volcanic complex, intruded by granitoid plutonites during the Late Cretaceous, may be subdivided in 3 main districts separated by sinistral NW-SE strike-slip faults.

Only the south western portion of the island is occupied by the Sierra Bermeja complex, which consists of a tectonic assemblage of serpentinized harzburgites, metabasalts and amphibolites (Las Palmas Unit), and scattered pelagic sediments with Cretaceous radiolarites (Mariquita Fm).

On the whole, the western sector of Puerto Rico is characterised by tectonic slices with variable vergence, separated by at least three NW-SE elongated peridotitic bodies (Monte del Estado, Rio Guanajbo, Sierra Bermeja).

Venezuela

The southern margin of the Caribbean Plate is represented by the Dutch and Venezuelan Islands and the Northern Cordilleras of Venezuela, so-called Sistema Montañoso del Caribe (Bellizzia, 1986).The southern margin of the Caribbean Plate links the northeastern segment of the Merida Andes to the Lesser Antilles volcanic island arc extending from the Barquisimeto depression, to the west, as far as the Trinidad-Tobago islands to the east. Southward it overthrusts the Guayana continental foreland of the South American Plate, while northward it is delimited by the north-vergent "accretionary prism" of Colombia and Venezuela along the Curaçao ridge (Stephan *et al.*, 1986).

The southern Caribbean Plate margin consists of a thrust belt (Fig. 5), made up of several imbricated tectonic units piled up with general south-vergences (Giunta *et al.*, 1997). These units are highly dismembered and affected by severe brittle and ductile/brittle deformations, related to a W-E dextral shear zone with strike-slip faults (e.g., San Sebastian, El Pilar, La Victoria) and associated with synthetic (e.g., Tacata, Charallave) and subordinate antithetic fault systems.

The Cordillera de La Costa (CC) uplift is made up of a pre-Mesozoic continental basement covered by Late Jurassic-Cretaceous carbonate-terrigenous sediments (with local volcanic intercalations) and separates two groups of tectonic sheets. In fact CC is overthrust by the ophiolitic melange of the Franja Costera (FC) Unit and part of the Caucagua -El Tinaco Units (TT) to the north, and the Caucagua-El Tinaco, Loma de Hierro (LH), Villa de Cura, (VC) and Dos Hermanas Units (DH) to the south:

1. The Franja Costera (FC) Unit, Cretaceous in age, consists of a volcano-sedimentary and carbonate-terrigenous sequence with boudins of serpentinized peridotites, metagabbros and metabasalts;

2. The Caucagua-El Tinaco Units (TT) consist of a pre-Mesozoic basement (El Tinaco complex) covered by a Cretaceous volcano-sedimentary sequence (Tucutunemo Fm), including the Los Naranjos basalts and Sabana Larga dolerites and gabbros; they are overlain by the Tinaquillo thrust sheets, which consist of serpentinized mantle lherzolites and meta-gabbros;

3. The Loma de Hierro (LH) Unit is made up of serpentinized mantle perodotites, layered gabbroic cumulates, and basaltic lavas and dolerites (Tiara Fm), discontinuously covered by Late Jurassic-Early Cretaceous radiolarites (Capas Rio Guare), and Cretaceous silicified metalimestones and siltites (Paracotos Fm);

4. The Villa de Cura (VC) Units consists of serpentinized mantle peridotites and wehrlite-clinopyroxenite cumulites (Chacao Complex), massive metabasalts (El Carmen), metatuffs and subordinate metalavas (El Chino-El Cano), as well as an Early?-Cretaceous metavolcano-sedimentary sequence, prevalently comprising rhyolites, siltstones and cherts (S. Isabel);

5. the Dos Hermanas (DH) Unit is represented by basaltic-andesitic lava breccias and volcanoclastics;

The last three units described above overthrust the Piemontine foredeep-terrigenous units to the south showing evidence of close tectono-sedimentary relationships with it since the Late Cretaceous-Early Tertiary;

6. The Venezuelan Islands (VI) Unit, offshore the northern Venezuelan coast, includes the basement of Dutch, Venezuelan and Tobago Islands, which is made up of basaltic and picritic lavas, dolerites and gabbros, intruded by Late Cretaceous tonalitic rocks, and rhyolitic dykes.

The relationships between the VI and the rest of the described orogen are very poorly known, probably consisting of discrete dextral strike-slip, high-angle faults.

Costa Rica

The western margin of the Caribbean Plate was formed by the tectonic juxtaposition of three main blocks, the Chortis, Chorotega and Choco (Dengo, 1985), along the Central American Isthmus. Both Chorotega (present-day Costa Rica) and Choco represent deformed belts between the Cocos and Caribbean, and between the Nazca and Caribbean plate respectively, and are constituted by accreted

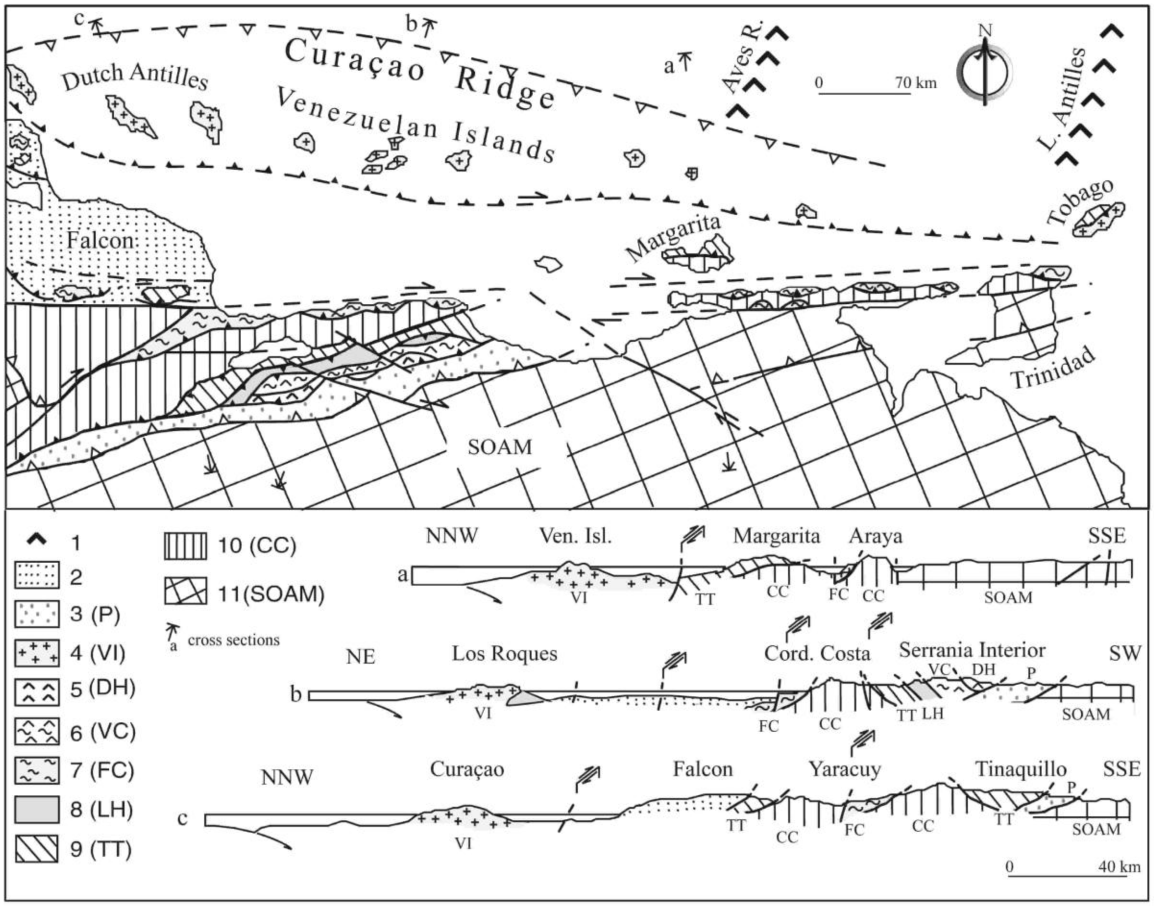


Figure 5. Tectonic sketch map and cross sections of the Sistema Montañoso del Caribe in Venezuela (modified from Giunta *et al*., 1997). Main Units: P, Piemontine foredeep Us; VI, Venezuela Islands U; DH, Dos Hermanas U; VC, Villa de Cura Us; FC, Franja Costera U; LH, Loma de Hierro U; TT, Caucagua-El Tinaco Us; CC, Cordillera de la Costa Us; SOAM, South America Continent. Legend: 1, Volcanic arcs of Aves and Lesser Antilles; 2, Tertiary terrigenous deposits; 3, terrigenous flysch-like sequences (Late Cretaceous-Paleogene); 4, Basaltic, doleritic and gabbroic basement with MORB affinity intruded by Tonalitic Arc magmatism (Late Cretaceous); 5, Arc volcanics (basaltic-andesitic lava breccias) with IAT affinity (Late Cretaceous); 6, metamorphosed vulcano-plutonic arc sequences (serpentinized peridotites, metabasalts, metatuffs and metavolcano-sedimentary sequence with rhyolites and cherts) with IAT affinity of Supra-subduction complex, (Early-Middle Cretaceous); 7, Volcano-sedimentary melanges with boudins of peridotites, metagabbros and metabasalts with MORB affinity (Early-Middle Cretaceous); 8, MORB ophiolites (serpentinized peridotites, basalts and dolerites) with scattered radiolarites, metalimestones and siltites (Late Jurassic-Cretaceous); 9, Continental cristalline basement (pre-Mesozoic) overlain by serpentinized mantle lherzolites and metagabbros (Tinaquillo), volcano-sedimentary sequence with basalts and dolerites (WPTh affinity) (Cretaceous); 10, Continental crystalline basement (pre-Mesozoic) covered by metacarbonate-terrigenous sequences (Late Jurassic-Cretaceous); 11, SOAM South America Continental Plate.

terranes largely overlain by recent arc magmatic products.

The Nicoya and Santa Elena complexes in Costa Rica (Fig. 6) are two of the most important ophiolitic occurrences in the western margin of the Caribbean Plate. They are delimited northward by a W-E shear zone between the Chorotega and Chortis blocks, which joins the Hess Escarpment eastward.

The Santa Elena complex (SE) mainly consists of a peridotitic body cut by a number of doleritic dykes, with subordinate breccias, overthrusting basaltic rocks in the westernmost part of the peninsula. The Nicoya complex on the other hand, is made up of an intrusive suite (gabbros, Fe-gabbros, Fe-diorites and plagiogranites) and basaltic rocks (basalts and dolerites), discontinuously covered by radiolarites. This complex was originally divided in two main units, Metapalo (ME) and Esperanza (ES) (Kuijpers, 1980; Azema *et al*., 1984). The ME is the older unit

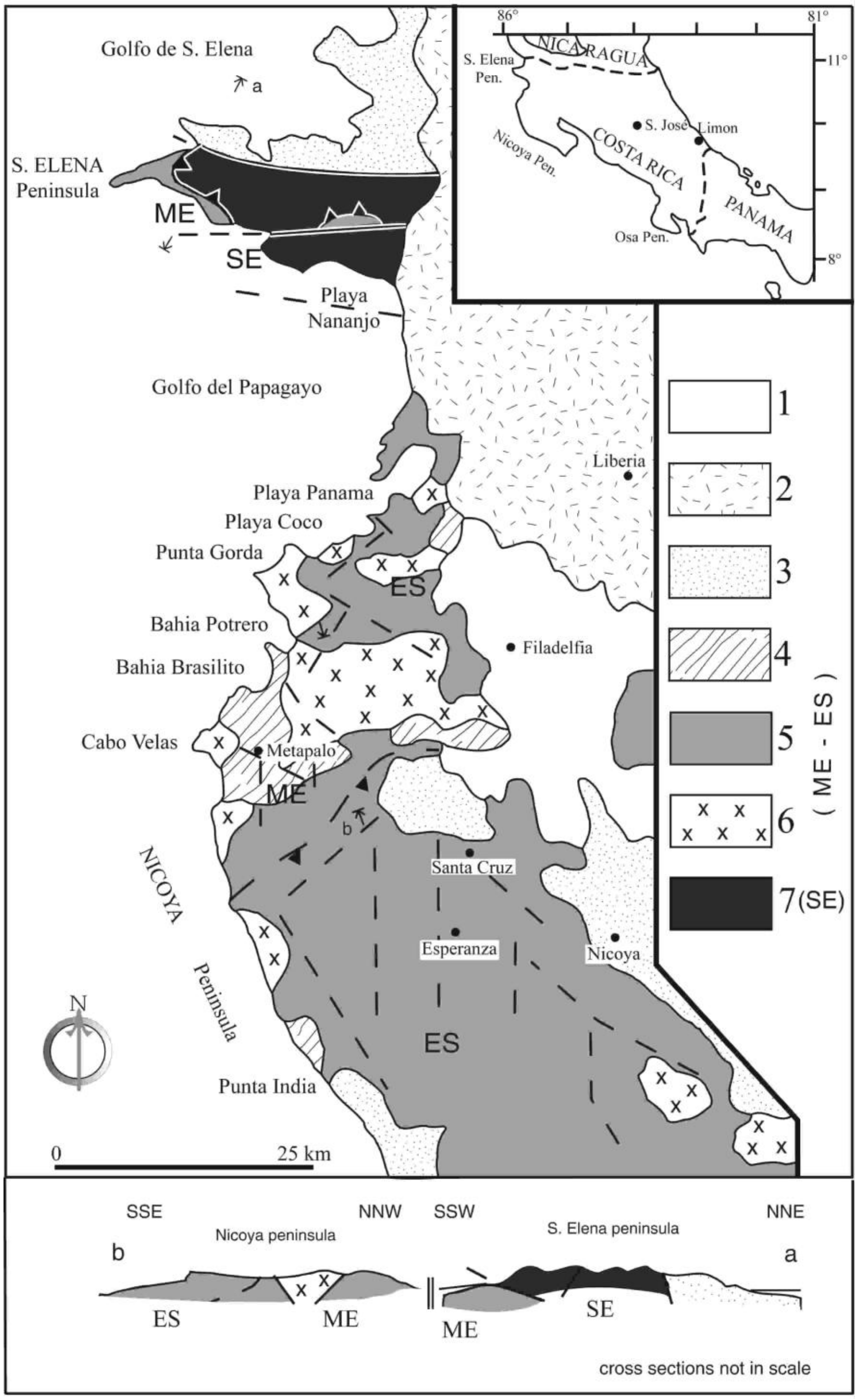


Figure 6. Tectonic sketch map and cross section of Costa Rica (modified from Beccaluva *et al*., 1999). Main Units: SE, Santa Elena U; ME, Metapalo U; ES, Esperanza U Legend: 1, Recent deposits; 2, Recent volcanics; 3, Terrigenous and carbonatic sequences (Late Cretaceous-Tertiary); 4, Radiolarites (Late Jurassic?-Early Cretaceous); 5, basalts and diabases with MORB affinity (Late Jurassic-Late Cretaceous); 6, gabbroic and scattered plagiogranitic intrusions with MORB affinity; 7, serpentnized mantle peridotites with doleritic dykes.

and consists of basalts with scarce gabbros (Potrero intrusives) and sills overlain by radiolarites of Late Jurassic? to Early Cretaceous age (Punta Conchal Fm), whereas the ES, dated mid to Late Cretaceous, consists of basalts and diabases with widespread gabbroic (Potrero) and plagiogranitic intrusions, with scattered radiolaritic cover (Sinton *et al*., 1998; Beccaluva *et al*., 1999). Several decollements may affect the complex, which however, preserves its original stratigraphic sequence. In places, the contact, between the Metapalo and Esperanza Units can be interpreted as high-angle faults. These two units are, in turn, unconformably overlain by the Campanian to Tertiary sedimentary sequences of Sabana Grande, El Viejo, Rivas, Las Palmas, Samara and Barraonda Fms, which are made up of turbiditic sandstones, andesite and carbonate rocks.

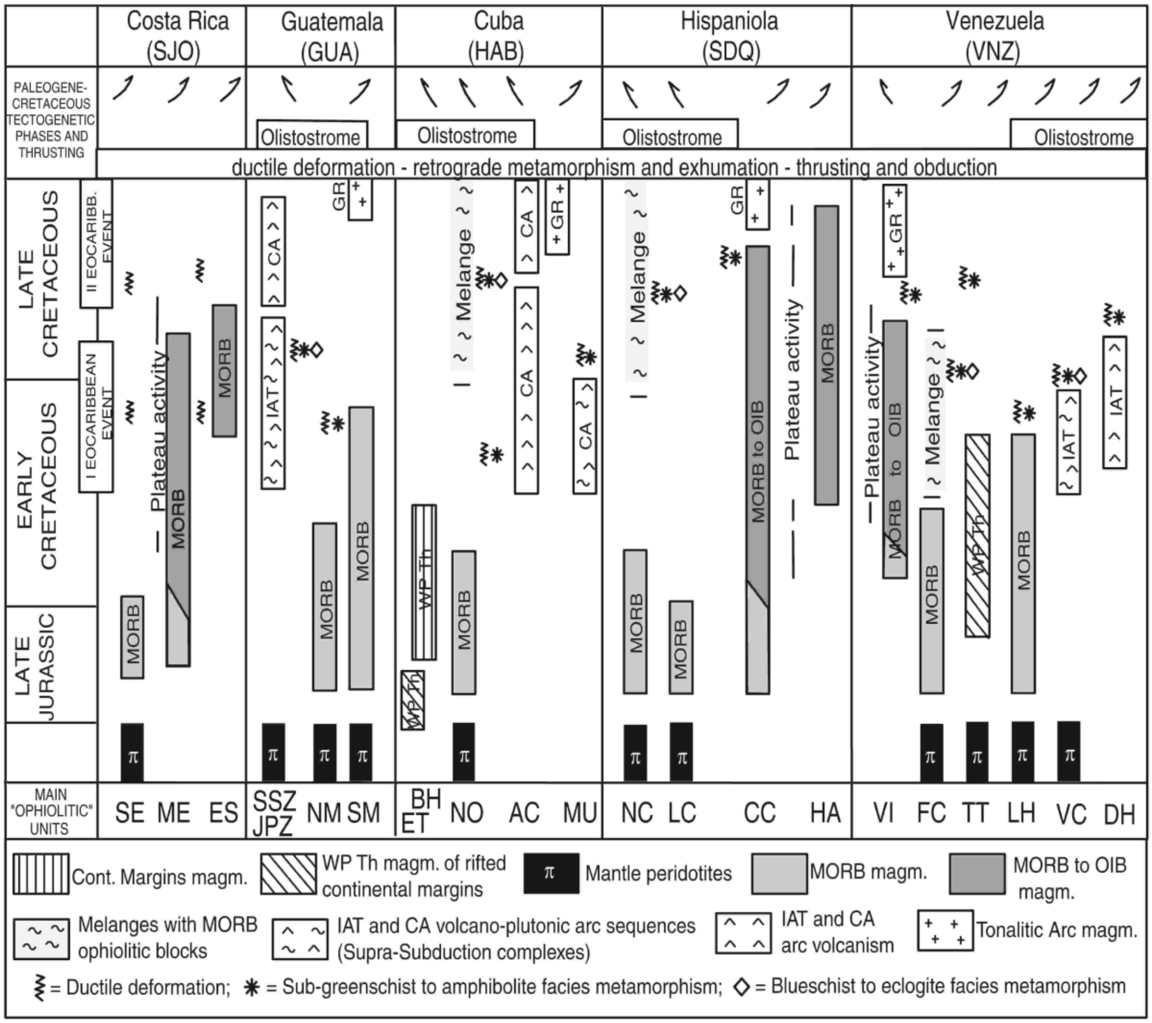


Figure 7. Tectono magmatic grid of the main peri-Caribbean igneous units (Modified from Giunta *et al*., 1998). Main Units: In Costarica (SJO): SE, Santa Elena complex; Nicoya complex: ME, Metapalo U; ES, Esperanza U; In Guatemala (GUA): SSZ, Sierra Santa Cruz U; JPZ, Juan de Paz U; NM, North Motagua U; SM, South Motagua U; In Cuba (HAB): BU, Bahamas U; ET, Escambray Terranes; NO, Northern Ophiolites Melange; AC, Cretaceous Arc U; MU, Mabujna U; In Hispaniola: NC, Northern Cordillera Us; LC, Loma Caribe U; CC, Central Cordillera Us; HA, Haiti; In Venezuela (VNZ): VI, Venezuelan Islands U; FC, Franja Costera U; TT, Caucagua-El Tinaco Us; LH, Loma de Hierro U; VC, Villa de Cura Us; DH, Dos Hermanas U

METAMORPHIC AND DEFORMATIONAL OUTLINES

The described tectonic units involved in the Caribbean Plate margins have been variably deformed and metamorphosed in relation to the tectonogenetic events which occurred in the Early-Middle Cretaceous, Late Cretaceous and Late Cretaceous-Eocene. Subsequently, since the Middle Tertiary the tectonic history has been dominated by brittle deformation. Ductile penetrative deformation is generally associated with metamorphic effects for each of the units indicated in Figure 7.

At the western margin of the Caribbean Plate in Costa Rica, the metamorphism is mainly zeolite to greenschist facies, presumably related to hydrothermal ocean floor metamorphism. Igneous textures are still preserved. At least three successive ductile deformative events are recorded mainly in radiolarites, with directions of the fold axes varying from NS to NNE-SSW (d1), from EW to NE-SW (d2), and NW-SE (d3) (Beccaluva *et al*., 1999).

In the tectonic units of both the Northern and Southern Caribbean Plate's margins metamorphism is generally associated with penetrative deformations (Beccaluva *et al*., 1995, 1996; Giunta *et al*., 1999), as following: prehnite-pumpellyite or sub-greenschists facies are present in both the AC in

Cuba and the DH in Venezuela; Greenschists/amphibolite facies metamorphism affects NM, SM and SSC in Guatemala; MU in Cuba, CC and NC in Hispaniola; TT and LH in Venezuela. The sedimentary cover of this last greenschist unit is deformed in two main ductile geometries; High Pressure/Low Temperature (HP/LT) metamorphic effects with development of blueschists and eclogite facies are recorded in the SM and in Guatemala, NO in Cuba, NC in Hispaniola, FC and VC in Venezuela.

All the above metamorphosed units are strongly deformed, especially in the less competent lithologies, where at least three ductile penetrative deformations can be recognized. Features of ductile deformation include development of foliation, isoclinal or tight folding with crenulation of the previous foliation, and cleavage, and tight to open folding of variably wavelength; upright limbs of the folds are generally preserved, while the overturned ones show shear zones up to the thrust fault generation. The latter geometry characterises the lithological surfaces along the main viscosity contrast. Several interference patterns may be recognised, as conjugate or sheath folds.

The metamorphism and deformation histories can be grouped in two main tectono-metamorphic events, the first is Middle-Late Cretaceous and the second is Late Cretaceous.

No significant metamorphism occured after the Late Cretaceous. Deformation since the Late Cretaceous is represented by ductile and ductile/brittle geometries, often related to the obduction and thrusting processes.

Owing to a scarcity of data, systematic and detailed studies on the relationships between ductile deformations and metamorphic paths are being conducted for a complete reconstruction of both the transport directions of each unit and the tectonic history of all the Caribbean margins.

TECTONO-MAGMATIC SIGNIFICANCE OF THE OPHIOLITIC UNITS

The tectono-magmatic significance of the investigated ophiolitic units is discussed in the following sections, based on petrological data from Beccaluva *et al*. (1995), (1996), (1999) and Giunta *et al*. (1997), (2001). Chondrite-normalized REE patterns, reported in Figures 8 and 9, effectively discriminate the various magma types generated in the Caribbean oceanic realm. The spatial-temporal distribution of the various igneous associations is correlated with the main tectonic events in Figure 7.

Mid-ocean ridge (MOR) is the most widespread magmatism in the area, being represented in several ophiolitic units in the northern, southern and western margins of the Caribbean Plate, as well as in the Colombian and Venezuelan Basins. Moreover, both the northern and southern continental margins were affected by rifting processes involving within-plate tholeiitic magmatism (WPTh), as recorded in the Cacagua-El Tinaco Units (TT) of Venezuela, Bahamas Units (BH) and Escambray (ET) of Cuba.

MOR basaltic and gabbroic rocks are characterised mainly by flat-REE (or slightly light-REE enriched) patterns in chondrite-normalised diagrams. This characteristic (Fig, 8A, B) is observed in the Late Jurassic-Late Cretaceous basalts, for example, the Nicoya complex (ME, ES) in Costa Rica; the NC (Puerto Plata, Punta Balandra and Jagua Clara melange) and the CC (Duarte, Tireo and Siete Cabezas, Los Ranchos) in Hispaniola; the Loma de Hierro (LH), part of the Franja Costera melange (FC) and Siquisique in Venezuela; the Curaçao volcanic sequence, Aruba lavas and Los Roques basement in the Dutch and Venezuelan Islands (VI).

Subordinate LREE-depleted basalts with typical Normal-MORB affinity (Fig. 8C) have been observed in the Northern Ophiolites (NO) in Cuba, the Loma Caribe (LC) and NC (Rio San Juan and Jagua Clara) in Hispaniola, part of the Franja Costera (FC) Unit in Venezuela, the Santa Elena (SE) complex in Costa Rica, the North (NM) and South Motagua (SM) Units in Guatemala, the Bermeja Complex in Puerto Rico, and Sites 146, 150, 153 (Venezuelan Basin) and 152 (Colombian Basin) (DSDP-Leg 15: Donnelly *et al*., 1973; Sinton *et al*., 1998). Also in the Blue Mountains of Jamaica an ophiolitic suite outcrop (Robinson, 1994).

On the whole, the spatial-temporal predominance of MOR basalts (MORB) with flat-REE patterns observed in most of the Caribbean igneous units, as well as their frequent association with picrites, strongly support an analogy with the tholeiitic magmatism of oceanic plateaus, such as those of the Western Pacific (Mahoney *et al*., 1993) where the oceanic crust is also exceptionally thickened. The anomalously thick crust of the Caribbean basins (from 12 to 20 km: Case *et al.*, 1990), is a further indication for an oceanic plateau structure (Burke, 1988; Storey *et al*., 1991; Hill, 1993; Kerr *et al.*, 1996a).

In this setting, the basaltic parental magmas may have been generated at oceanic spreading centres by a high degree partial melting of undepleted sources in a mantle plume (Saunders *et al*., 1996; Sinton *et al*., 1998, Beccaluva *et al.*, 1999). Significantly,

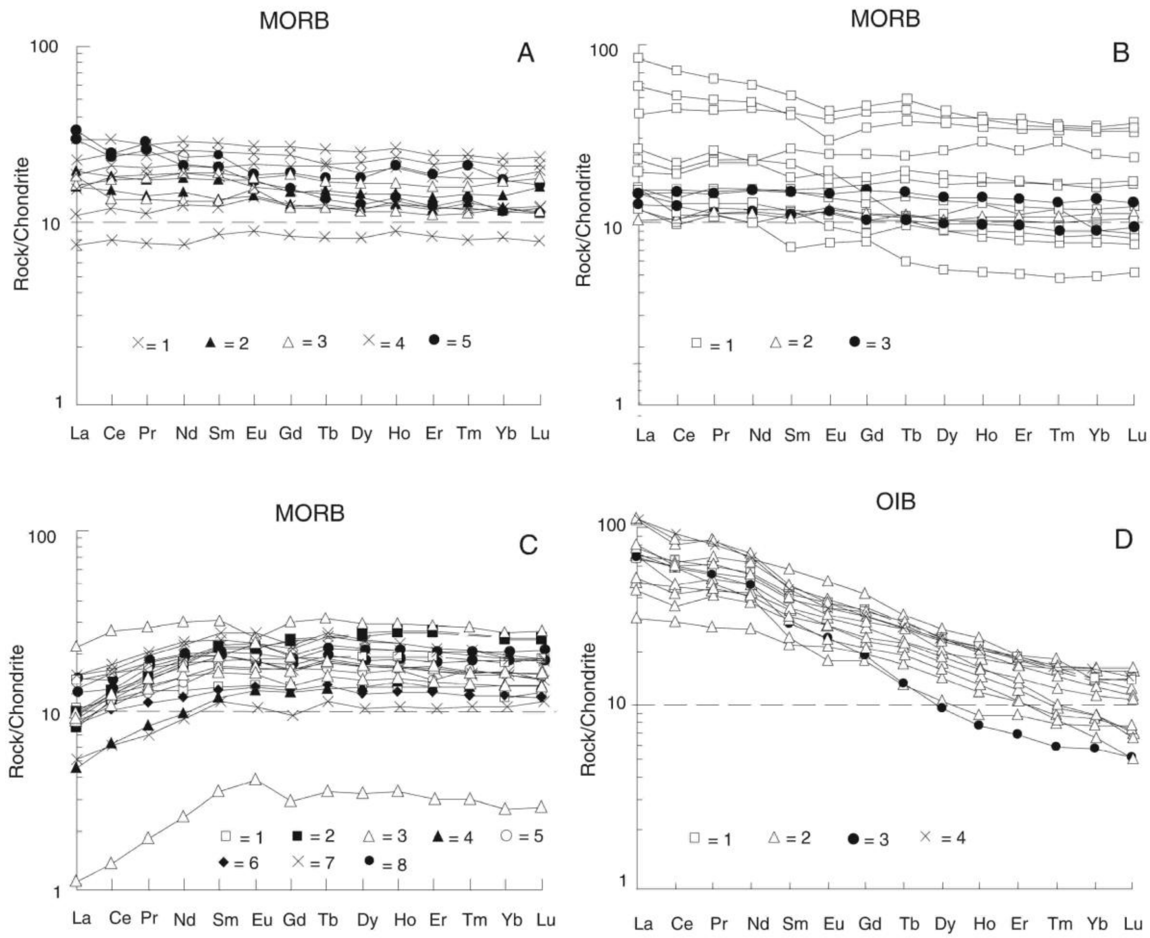


Figure 8. Chondrite-normalized REE patterns of Caribbean basaltic and gabbroic rocks. A: 1, Nicoya, Costa Rica; 2, Loma De Hierro, Venezuela; 3, Franja Costera, Venezuela; 4, Siquisique, Venezuela; 5, Puerto Plata, Dominican Republic. B: 1, Duarte, Tireo and Siete Cabezas, Dominican Republic; 2, Los Roques, Venezuelan Islands; 3, Curacao, Dutch Antilles. C: 1, Venezuelan Basin; 2, Colombian Basin (after Sinton *et al*., 1998); 3, Loma Caribe and Rio San Juan, Dominican Republic; 4, Franja Costera, Venezuela; 5, Santa Elena, Costa Rica; 6, Northern Ophiolites, Cuba; 7, North and South Motagua Faults, Guatemala; 8, Bermeja Complex, Puerto Rico. D: 1, Beata Ridge (after Sinton *et al*., 1998); 2, Duarte e Tireo, Dominican Republic; 3, dikes, Cuaracao; 4, South Motagua Fault, Guatemala. Normalizing factors after Sun and McDonough (1989).

these magmas are characterised by flat REE patterns, although LREE-depleted or enriched patterns may also occur in relation to the heterogeneity of their mantle sources (Mahoney *et al*., 1993; Kerr *et al*., 1997; Fitton *et al*., 1997). Accordingly, the generation of high MgO magmas, such as komatiites and picrites, with flat REE patterns, requires comparatively greater partial melting of compositionally analogous MORB sources (Beets *et al*., 1982) that have undergone adiabatic upwelling in the plume region (McKenzie and Bickle, 1988; Kerr *et al*., 1996b). The magmatism may therefore indicate thermal anomalies, arising from hot plume-heads in the upper mantle plume region near or at previous spreading centres (Sen *et al*., 1988).

On a regional scale, crustal growth probably developed over a long time (Fig. 7). Production of oceanic crust started at several spreading centers with formation of normally-thick oceanic crust (e.g., ES and part of ME in Costa Rica, NM and SM in Guatemala, NO in Cuba, NC, LC and the basement of CC in Hispaniola, the basement of VI, FC and LH in Venezuela), which only later may have evolved in places to ridge segments with excess magmatism (ME and ES in Costa Rica, CC and HA in Hispaniola, VI in Venezuela), as proposed for the "Icelandic-type" plateau model by Saunders *et al.* (1996). Vertical overthickening of the pre-existing oceanic crust may also have resulted from repeated eruptions (and intrusions) of new basaltic and picritic magmas.

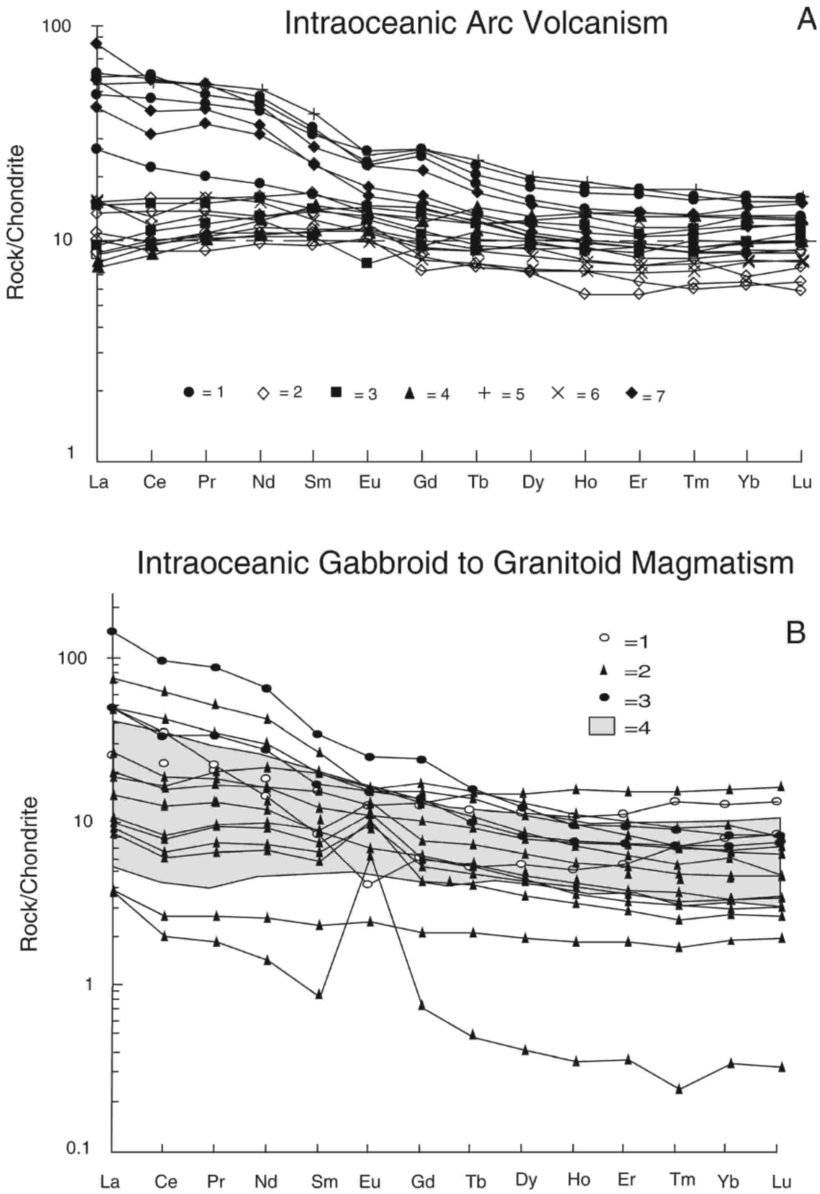


Figure 9. A: Chondrite-normalized REE patterns of tholeiitic and calcalkaline volcanics from the arc magmatism of Venezuela, Guatemala, Cuba and Puerto Rico. 1, calcalkaline basalts, basaltic andesites, and rhyodacites from the Mabujina and Cretaceous Arc Units in Cuba; 2, 3, tholeiitic basalts and andesites from Villa de Cura and Dos Hermanas Arc Units, respectively (Venezuela); 4, 5, tholeiitic and calcalkaline basalts, respectively, from Juan de Paz and Sierra de Santa Cruz Arc Units in Guatemala; 6, 7, tholeiitic and calcalkaline basaltic to andesitic volcanics, respectively, from the Arc Complex in Puerto Rico. B: Chondrite-normalized REE patterns of tonalitic intrusives from the Dutch and Venezuelan Islands, Dominican Republic and Puerto Rico. 1, quartz-diorites and granites from Los Roques (Venezuelan Islands); 2, gabbroid to granitoid intrusives from Dominican Republic; 3, granitoid intrusives from Puerto Rico; 4, gabbro-tonalite intrusives from Aruba (Dutch Islands), after White *et al*. (1999). Normalizing factors after Sun and McDonough (1989).

Tholeiitic and transitional basaltic lavas and dikes with OIB affinity are represented in the Caribbean area in minor amount. These magmatic products, characterised by LREE-enriched and positively fractionated HREE patterns (Fig. 8D), occur in the basaltic lavas of the CC (Duarte and Tireo complexes) in Hispaniola, the VI (Curaçao dikes) in Southern Caribbean, in places in the South Motagua (SM) Units in Guatemala, and Site 151 (DSDP - Leg 15) in the Beata Ridge (Sinton *et al*., 1998). Differentiation is characterized by pronounced Fe-Ti-enrichment and is strictly comparable with the tholeiitic/transitional lava suites of ocean islands (OIB), such as those of Iceland and Galapagos central volcanoes (Furman *et al*., 1992; Geist *et al*., 1995). Accordingly, the mantle sources of these magmas must have been enriched in incompatible elements with respect to the MORB sources. This basaltic magmatism therefore represents within-oceanic plate activity, further contributing to the thickening of the Caribbean oceanic plateau.

Island arc magmatism is recorded in several ophiolitic units at the northern and southern margins of the Caribbean Plate, starting from the Early Cretaceous (Fig. 7). This implies that intraoceanic subduction took place while plateau formation by MORB magmatism was still active. Arc magmatic events are represented along the northern Caribbean margin by (1) tholeiitic (IAT) and calc-alkaline (CA) volcanics from Juan de Paz (JPZ) and Sierra Santa Cruz (SSC) in Guatemala, (2) calc-alkaline suite of the Cretaceous Arc (AC) and Mabujina Units (MU) in Cuba, (3) tholeiitic and calc-alkaline volcanics in the arc complex of Puerto Rico, and, according to Robinson (1994; and references therein), (4) calcalkaline volcanics in the Blue Mountains of Jamaica.

At the southern margin, island arc tholeiitic suites are represented by the Villa de Cura (VC) and Dos Hermanas (DH) Units in the northern cordilleras of Venezuela. Here, volcanics are sometimes associated with wehrlitic-pyroxenitic cumulates and underlying mantle harzburgites of the arc basement, as in the Chacao complex (Beccaluva *et al*., 1996). Arc lavas ranging in composition from basalts to rhyodacites display flat (tholeiitic) to LREE-enriched (calc-alkaline) patterns (Fig. 9A), and enrichment in Low Field Strength Element (LFSE), coupled with depletion in High Field Strength Element (HFSE) compared to MORB. The basic parental magmas of these suites are, therefore, to be considered as the result of high-degree remelting of depleted mantle sources, which underwent subduction-related fluid enrichment.

A Late Cretaceous second arc magmatism, mainly tonalitic (GR) in composition, is found as scattered, unmetamorphosed intrusive bodies in the deformed and metamorphosed MORB and arc units. In the southern Caribbean margin the tonalitic rocks in Aruba are dated at 85-82 Ma (White *et al*., 1999). Quartz-dioritic/granitic intrusives of Los Roques (Fig. 9B) occur in the Dutch and Venezuelan Islands (VI). In the northern Caribbean margin Late Cretaceous arc magmatism is represented by the plutonic suites intruding the Duarte (D) and Tireo (T) complexes (CC) in Hispaniola, the Arc Units (MU and AC) in Cuba, and the Cretaceous island arc in Jamaica (Robinson, 1994). This second arc magmatism implies new intra-oceanic subduction, with reverse polarity of cooler and thinner portions of the oceanic crust, beneath the thickened plateau structure (Giunta *et al*., 1998).

GEODYNAMIC IMPLICATIONS

The main ophiolitic units involved and dismembered along the peri-Caribbean margins can be grouped into some first order kinematic elements, taking into account their structural setting and tectono-magmatic significance. The spatial-temporal definition of the main evolutionary stages of the Caribbean Plate is based on tentative paleogeographic restorations of the following elements: a) continental margins of North and South America, and of minor blocks (Maya, Chortis, Guaniguanico-Escambray, Venezuelan Cordillera de la Costa), b) rifted continental margins, closely related to the main continental plates (e.g. Caucagua-El Tinaco and Tinaquillo in Venezuela), c) oceanic realm, with MORB and MORB to OIB affinities, related to thickened crust coming from east to west, d) intra-oceanic subduction zones and related volcanic arcs (and subduction complexes), with IAT and CA affinities, e) sub-continental subduction zone producing melanges with rock blocks of MORB affinity (e.g., Franja Costera in Venezuela), and f) intra-oceanic subduction zones producing Tonalitic Arc magmatism.

In the following sections a reconstruction (Fig. 10) is presented from the early proto-Caribbean stage of oceanization, through two eo-Caribbean stages characterised by plateau accretion and oceanic subductions, up to the Tertiary setting of the Caribbean Plate. The model processing has been carried out taking into account the well known reconstructions of the Caribbean plate (i.e., Pindell and Barrett, 1990; Pindell,1994).

The proto-Caribbean phase

During the Jurassic, tensional and transtensional stress-fields related to the central Atlantic opening and induced by separation of the North and the South American Plates, resulted in a new paleotectonic arrangement. Several spreading centers, offset by transform faults, developed in mid-American position, leading to a proto-Caribbean oceanic realm between the Central Atlantic and Pacific Farallon Plate (Fig. 10A).

Geological evidences from Cuba, Guatemala, and Venezuela strongly suggest a spatial continuity of this oceanic domain with the Bahamas, Maya and Chortis continental margins to the north, and the Guayana shield to the south.

Oceanic crust generation was accompanied by rifting tectonics at both the northern and southern continental margins, as indicated by the occurrence of within-plate tholeiitic magmatism in the Caucagua-El Tinaco Units (TT, Venezuela) and the Bahamas Units (BH, Cuba). Remnants of the early proto-Caribbean oceanic lithosphere are represented by the MORB ophiolitic units of Costa Rica (SE), Guatemala (NM and SM), Cuba (NO), Hispaniola (NC and LC), Puerto Rico, and Venezuela (FC and LH). The proto-Caribbean oceanic domain probably underwent crustal thickening mainly in its western portion, progressively evolving, until the Late Cretaceous, to a plateau structure. This is supported by the petrological characteristics of the basaltic and picritic magmatism (with MORB affinity) recorded by the ophiolitic complexes in Costa Rica (ME and

ES), Hispaniola (CC, HA), Dutch Antilles and Venezuela (VI). OIB magmatic events, that is, volcanic seamounts, scattered throughout the Caribbean area and particularly abundant in the Central Cordillera (CC) of Hispaniola, may have contributed to crustal accretion.

In this context, the thickening of the oceanic crust may have been caused by a production of oceanic crust through at least two mechanisms (Saunders *et al*., 1996): 1) multiple spreading centres evolving to ridge segments with excess magmatism above a mantle plume area; 2) vertical over-thickening of the pre-existing oceanic crust by repeated eruptions and intrusions of new basaltic and picritic magmas, resulting from hot plume-heads locally rising from the mantle plume region.

Consequently, both thin and thickened (plateau) portions of the Jurassic-Cretaceous oceanic crust have to be considered as belonging to the same proto-Caribbean domain, originally formed in a "near mid-American" position (Dengo, 1985; Giunta, 1993; Iturralde-Vinent, 1996a, 1996b; Beccaluva *et al*., 1996, Giunta *et al*., 1998; Meschede and Frisch, 1998). This model is, therefore, to be considered an interpretation alternative to the classic hypothesis of the Caribbean Plate as a "Pacific promontory" inserted between the two Americas (Pindell and Barrett, 1990; Pindell, 1994).

The eo-Caribbean phases

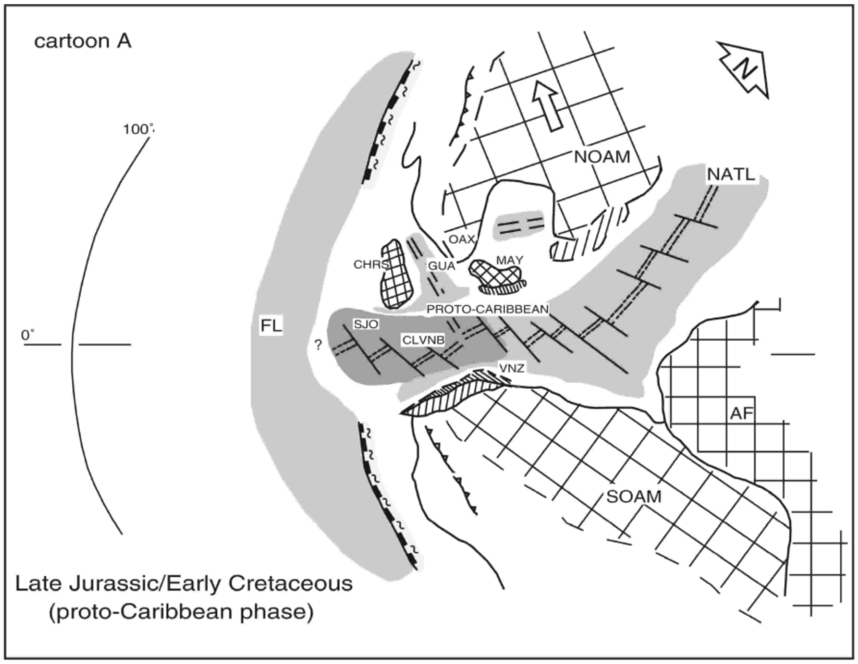
Starting from the Early Cretaceous, the South Atlantic opening and related northwestward motion of the South American Plate led to ocean-ocean and ocean-continent plate convergences ("eo-Caribbean" phase, Giunta, 1993), producing several magmatic arcs (Fig. 10B). Remnants of these magmatic arcs and subduction complexes are represented to the north, by the Sierra Santa Cruz (SSC), Juan de Paz (JPZ), and Baja Verapaz (BVP) Units in Guatemala, the Cretaceous Arc (AC) and Mabujina (MU) Units in Cuba, as well as in Jamaica, and, to the south, by the Villa de Cura (VC) and Dos Hermanas (DH) Units in Venezuela. Evidence of involvement of the proto-Caribbean oceanic lithosphere in subduction zones is also represented by the HP/LT metamorphosed units of the Villa de Cura (VC) and Franja Costera (FC) of the southern Caribbean Plate margin in Venezuela, related to an ocean-ocean subduction the first, and to an ocean-continent subduction the latter. Moreover, portions of the previously rifted continental margins were also involved in the subduction zones, reaching the eclogite facies (e.g., La Rinconada Fm of the TT Unit in Venezuela, Bocchio *et al*., 1996).

This intra-oceanic convergence affected the eastern sector of the proto-Caribbean domain, where the thinner portions of the oceanic lithosphere were in more favourable conditions to be subducted, with eastward dipping, in opposition to the general movement of the North and South America plates. At the same time the western sector of the proto-Caribbean domain was undergoing progressive crustal thickening, ultimately leading (Late Cretaceous) to a well defined oceanic plateau structure. This view is significantly different from the model proposed by Pindell and Barrett (1990) and Pindell (1994) where in Barremian-Albian times subduction was located in an area corresponding to the present Central American Isthmus.

In the Late Cretaceous subduction ceased when the marginal portions of the oceanic plateau (CC in Hispaniola and VI in Venezuela) reached the plate boundary. This was presumably due to buoyancy of this thickened and still hot lithosphere. Nevertheless, the persistent northwestward drifting of the South and North American Plates forced subduction to new sites, but, with reverse polarity (Draper *et al*., 1994; Giunta *et al*., 1998; Kerr *et al*., 1999; Giunta *et al*., 2001).

During this second eo-Caribbean stage (Fig. 10C), westward-dipping subduction of the oceanic lithosphere took place beneath both the oceanic plateau and the previous magmatic arcs, giving rise to the widespread tonalitic arc magmatism of the northern and southern Caribbean Plate margins (GR in Guatemala, Cuba, Hispaniola, Puerto Rico and Venezuela), the HP/LT metamorphic effects in the NO (Cuba), NC (Hispaniola) and Puerto Rico, as well as the onset of the Aves/Lesser Antilles magmatic arc system.

The distribution of the tonalitic magmatism, in time and space, implies that the eastward bending of the Aves/Lesser Antilles arc system has been progressively enhanced by the oblique convergence at the northern and southern tips of the arc. Accordingly, the present position is related to the eastward motion of the Colombian and Venezuelan Basins, relative to the two American Plates. Transpressional tectonics along the northern and southern margins of the Caribbean Plate caused the dismemberment and opposite rotation (sinistral vs. dextral, respectively) of older structural elements. This resulted in significant differences between the two margins. Along the northern margin the younger (tonalitic) magmatic arc rests on the deformed belt, which includes both the older arc systems and the eastward migrating front of the new



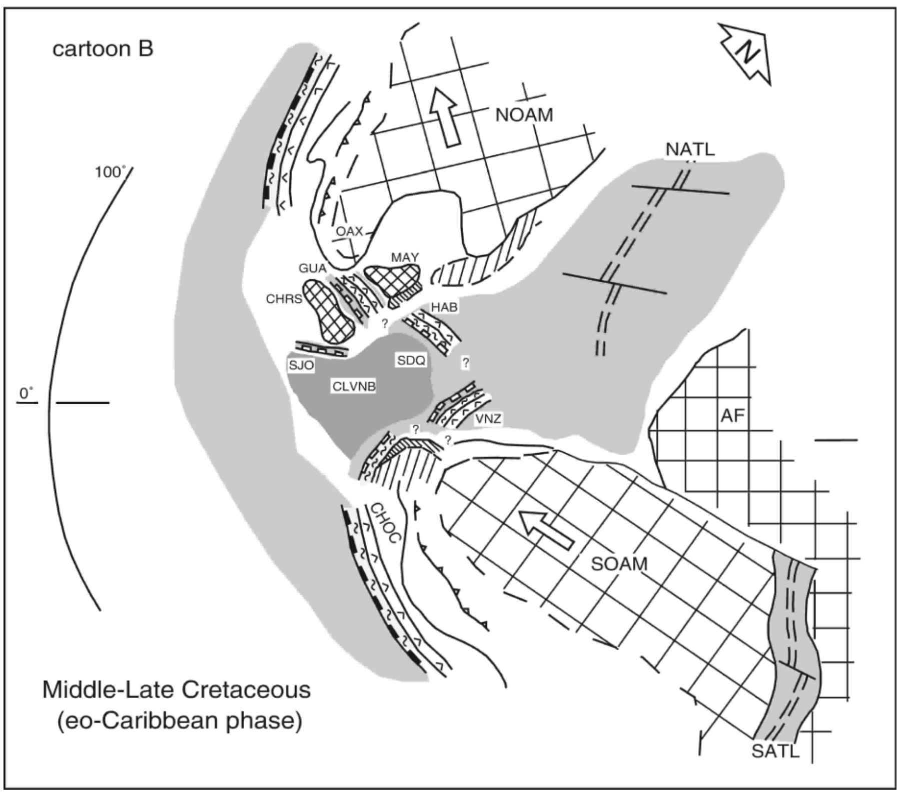
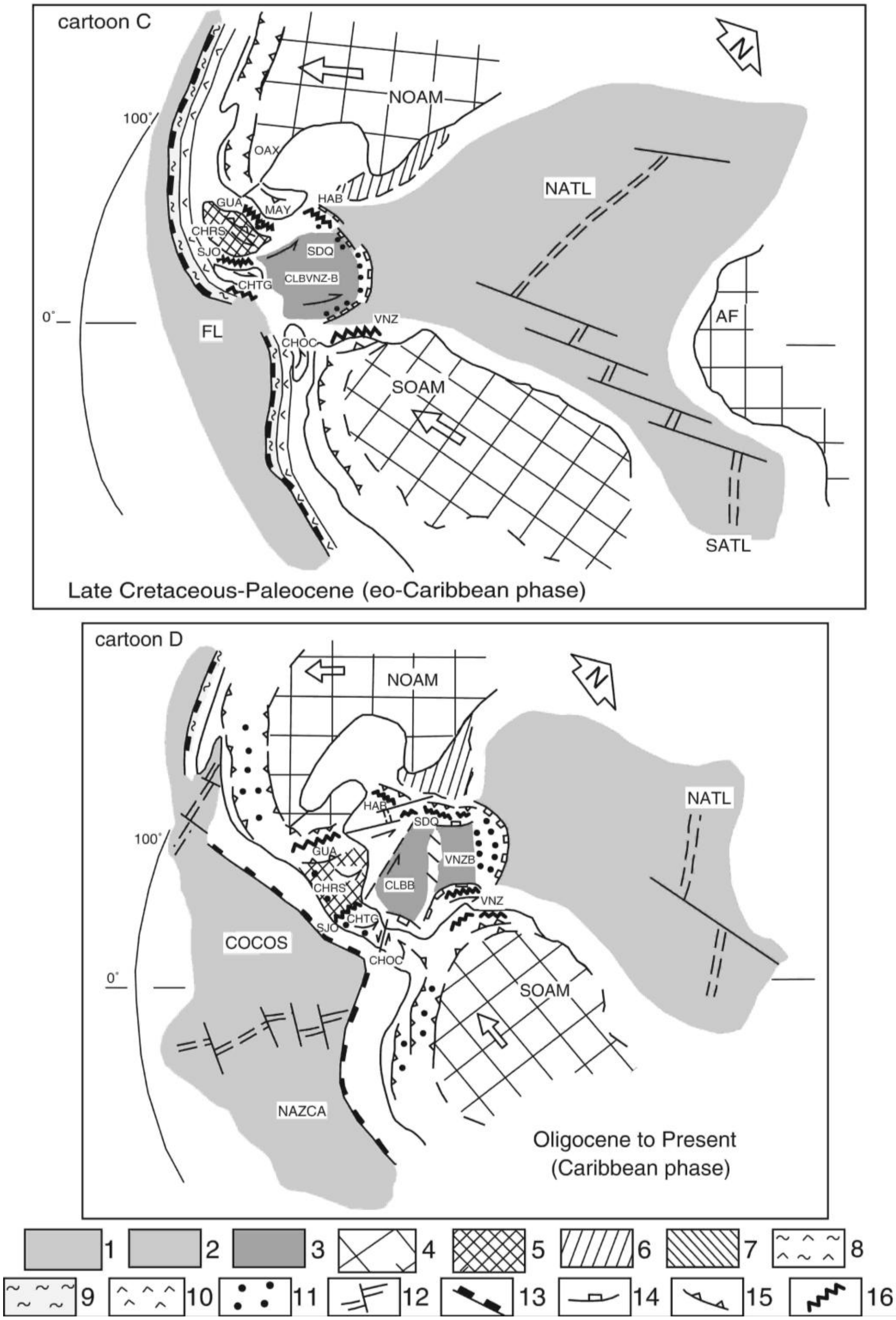


Figure 10. Kinematic evolutionary model of the Caribbean Plate, from Late Jurassic to Tertiary. Legend: 1, Oceanic crust of the Farallon Plate; 2, Proto-Caribbean and Atlantic oceanic crusts (SE in Costa Rica, NM and SM in Guatemala, NO in Cuba, NC and LC in Hispaniola, FC and LH in Venezuela); 3, Proto-Caribbean oceanic area undergoing crustal thickening (ME and ES in Costa Rica, CC and HA in Hispaniola, VI in Venezuela); 4, Major continental plates (NOAM, SOAM, AF); 5, Minor continental blocks (MAY, CHRS); 6, Continental margins (BH in North America, CC in Venezuela); 7, Rifted continental margins, with WPTh magmatism (Escambray Terranes and BH in Cuba, TT in Venezuela); 8, Metamorphosed volcano-plutonic arc sequences with IAT and CA affinities (Supra-subduction complexes: SSC and JPZ in Guatemala, MU in Cuba, VC in Venezuela); 9, melanges including ophiolitic blocks with MORB affinity (NO in Cuba, NC in Hispaniola,



FC in Venezuela); 10, Arc volcanism with IAT and CA affinities (SSC and JPZ in Guatemala, AC in Cuba, DH in Venezuela); 11, Tonalitic Arc magmatism (SM in Guatemala, AC and MU in Cuba, CC in Hispaniola, VI in Venezuela); 12, Oceanic spreading centers; 13, Subductions of the Farallon-Pacific oceanic litosphere; 14, Intraoceanic and subcontinental subductions in the Caribbean area; 15, Main overthrust fronts; 16, Deformed thrust belts, including suture zones, accretionary prisms and olistostromes. Abbreviations: FL, Farallon; NOAM, North America; SOAM, South America; AF, Africa; NATL, North Atlantic; SATL, South Atlantic; OAX, Oaxaca; MAY, Maya; CHRS, Chortis; CHTG, Chorotega; CHOC, Choco; SJO, Costa Rica; GUA, Guatemala; SDQ, Hispaniola; HAB, Cuba; VNZ, Venezuela; CLVNB, Colombia-Venezuela Basins; CLBB, Colombia Basin; VNZB, Venezuela Basin.

accretionary wedges. Along the southern margins the tonalitic magmatism is decoupled from the older arc, being intruded in both undeformed and deformed oceanic plateau. The end of the eo-Caribbean phase is marked by the Late Cretaceous-Paleogene obduction of the proto- and eo-Caribbean ophiolitic units onto the peri-Caribbean deformed margins, as suture zones in flake and wedge geometry.

As far as the western Caribbean Plate margin is concerned, its tectonic evolution appears to be closely related to the kinematics of the Maya, Chortis, Chorotega, and Choco blocks. From the Late Cretaceous, the Chortis continental block moved eastward with an anticlockwise rotation with respect to the Maya block. This lead to the development of the Motagua suture zone of Guatemala. The movement, in turn, induced a Pacific intraoceanic convergence southward of the Chortis block, building the Chorotega block. The latter, which corresponds to present-day Costa Rica, started to form by the accretion of oceanic thrust sheets, inserted between the Maya-Chortis and Choco-South America continental blocks. The subsequent approach of the North and South America plates during their general westward drift caused a more anticlockwise rotation of both the Chorotega and Choco blocks with respect to the Chortis block and the Andean system, progressively juxtaposing all the blocks in a mosaic along the Mid American Trench. As a consequence, the inner and undeformed portions of the Caribbean Plate, that is, the Colombian and Venezuelan Basins, were trapped by the intervening Central American subduction system (Beccaluva *et al*., 1999).

The Caribbean phase

The main structural elements of the present Caribbean were essentially established in the Paleocene onwards (Fig. 10D). The northern and southern margins were in places represented by irregularly shaped suture zones, while subduction of the Pacific and Atlantic lithosphere, and production of related volcanic arcs, continued to develop in the western and eastern (Lesser Antilles) margins respectively. Fore- or back-arc and piggy-back basins, on the deforming plate borders, were filled by clastic sediments and volcanoclastics. On the northern and southern continental margins, thrust belt-foredeep systems began to develop, involving previously deformed belts along north- or south-verging fronts (Sepur Basin in Mexico-Guatemala; Foreland Basin in Cuba; Piemontine Basin in Venezuela). Along these margins oblique subduction beneath the eo-Caribbean elements were probably still active, resulting in transpressional tectonics and concomitant dismembering of the tectonic units in W-E directions (Greater Antilles, Venezuela).

From the Middle Tertiary, continued westward drifting of the two Americas resulted in further encroachment on the Caribbean Plate, giving rise to transpressional stress-fields at the northern and southern margins. This led to a geometry of the plate borders substantially similar to the present configuration, where sinistral or dextral shear zones, with compressive or distensive strike-slip components, allowed a gradual dismembering and scattering of the eo-Caribbean units along the tectonic belts (e.g., Motagua Fault Zone in Guatemala, Cayman Ridge System, Puerto Rico Trench, and Oca, Bocono, S. Sebastian, La Victoria, El Pilar Fault Zones in Colombia and Venezuela).

Along the western border of the plate, the NW-SE compressional stress field along the deformed borders of the mid-American Trench produced an adjustment of the Chorotega and Choco blocks, with different rotations through strike-slip fault zones (e.g., the Hess Escarpment and Panama Canal).

The continued convergence between the two Americas produced a further convergence along the plate borders, with generation of accretionary prism-like systems, which progressively involved crustal portions of the Colombian and Venezuelan Basins (Los Muertos in Hispaniola, Venezuela-Colombia and Panama accretionary prisms). The Dumisseau Fm (HA) in Haiti may represent the northeastern portion of the Colombian Basin oceanic plateau, which was inserted between the Hess Escarpment and Beata Ridge, and deformed against the Hispaniola thrust-belt and Los Muertos accretionary prism, due to the continuing anticlockwise rotation of the Nicaraguan Rise and Colombian Basin. The eastern plate margin continued to migrate eastward, overriding the Atlantic lithosphere, developing the Lesser Antilles arc-backarc system and related Barbados accretionary prism.

Acknowledgements. *The authors thank the colleagues of the IGCP 433 project for the discussion on the Caribbean Tectonics, and the anonymous reviewers for the improvement of the manuscript. The researches have been carried out with the financial support of the MURST-Cofin 2000 "Caribbean Plate" project (resp.: L.Beccaluva and G.Giunta), and the CNR-Bilateral project (resp.: G.Giunta)*

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Revised manuscript received 1st December 2002, accepted 10th December 2002.

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Caribbean Plate