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The Peri-Caribbean Ophiolites and Implications for the Caribbean Plate Evolution

Ophiolitic terranes deformed and dismembered along both the northern and southern peri-Caribbean margins represent fundamental markers for the origin and evolution of the Caribbean Plate.

The main ophiolitic units 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 evolutionary stages of the Caribbean Plate is based on tentative paleogeographic restorations of the following elements: (1) continental margins of North and South America, and of minor blocks (Maya, Chortis, Guaniguanico, Venezuelan Cordillera de la Costa), (2) rifted continental margins, closely related to the main continental plates (Escambray in Cuba, Caucagua-El Tinaco and Tinaquillo in Venezuela), (3) oceanic realm, with MORB and MORB to OIB affinities, related to thickened crust coming from east to west, (4) intra-oceanic subduction zones and related volcanic arcs (and subduction complexes), with IAT and CA affinities, (5) sub-continental subduction zone producing melanges with rock blocks of MORB affinity (e.g., Franja Costera in Venezuela), and (6) intra-oceanic subduction zones producing Tonalitic Arc magmatism. The palinspastic restoration of the oldest geotectonic elements suggests a Middle Jurassic-Early Cretaceous location of their original paleo-domains in a westernmost, "near mid-America" position, almost at the western corners of the American plates.

The timeline of major Carribbean events (Fig.1) is characterised by different tectonic regimes (plume and spreading, accretionary, collisional), from the early proto-Caribbean stage of oceanization, through two eo-Caribbean accretionary stages of oceanic subductions, up to the collisional stage leading to the present Caribbean Plate. The

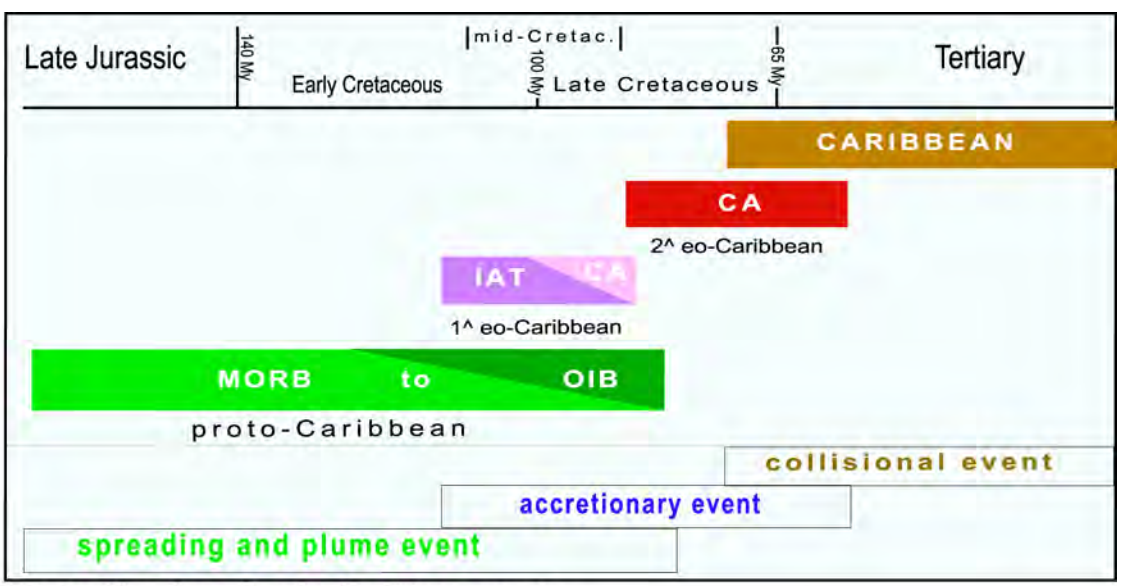

Fig.1 - Timeline of major Caribbean events.

model processing has been carried out taking into account some important constraints recognized in the last years, and the well known reconstructions of the Caribbean plate (i.e., Pindell and Barrett, 1990; Pindell,1994).The aim of this contribution is to highlight the main unresolved problem of the Caribbean tectonics, stressing them more than the acquired facts.

Proto-Caribbean event

During the Jurassic, tensional and transtensional stress-fields related to the central Atlantic opening and induced by separation of the North (NOAM) and the South (SOAM) American Plates produced several spreading centers, offset by transform faults, developed in mid-American areas, leading to a proto?Caribbean oceanic realm between the Central Atlantic and Pacific Farallon Plate. Its accretion was initially related to multiple spreading centres (LREE-depleted MORB, in Venezuela, Costa Rica, Cuba, Guatemala, Hispaniola), evolving during the Cretaceous to a thickened oceanic plateau in its westernmost end (REE-flat MORB locally associated with picrites, in Costa Rica, Hispaniola, Venezuela, Dutch and Venezuelan Islands). Geological evidences from Guatemala, Cuba, Hispaniola, 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, through rifted continental margins with WPT magmatism recognized in both the northern and southern peri-Caribbean belts. How many ophiolitic units can be referred to the unthickned oceanic proto Caribbean crust is difficult to establish because several data suggest that some units should better fit an intra- or back-arc supra-subduction (SSZ) origin. In any case, the near American point of view already put forward by several authors (Giunta, 1993; Beccaluva et al., 1996; 1999; Meschede and Frisch, 1998; Giunta et al., 2002 a,b), is therefore favoured with respect to the classic hypothesis of the Caribbean Plate as a "Pacific promontory" (Duncan and Hargrave, 1984; Burke, 1988; Pindell and Barrett, 1990).

Collisional event

Actually, it must be taken into account that the Late Cretaceous-Present geodynamics of the Caribbean plate has been mainly driven by the eastward drift of the Caribbean plateau with respect to the NOAM and SOAM plates. The present Caribbean Plate is mainly represented by the Cretaceous plateau crust trapped in the Colombia and Venezuela basins by the intervening Pacific subduction, which built the Central American isthmus. As a result, both the northern and southern boundaries of the Caribbean correspond, since the Late Cretaceous, to two wide shear zones. During Late Cretaceous-Tertiary large-scale tear faulting favoured eastward dispersion and uplifting of the previous subduction-accretion systems. Similarities in the main evolutionary stages of both the margins are suggested. The strike-slip tectonic regime is still extensively 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: they are often composed of comparable geotectonic elements, even if different geometric associations between the first-order tectonic units are shown. They overthrust in a flower-like structure the foredeep basins developed onto the NOAM and SOAM continental margins respectively, and the slightly deformed oceanic plateau (e.g., Los Muertos and Venezuelan accretionary prisms), minor continental blocks (e.g., Chortis), or rifted continental margins (e.g., Escambray).Durimg the collisional events the main structural elements of the present Caribbean were essentially established in the Paleocene onwards. The northern and southern margins were in places represented by irregularly shaped suture zones, while subduction of the Pacific and Atlantic lithospheres, 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).

Accretionary event

In the Caribbean Plate deformed continental margins several ophiolitic units are found as relics of the mid to Late Cretaceous eo-Caribbean tectonic phases, indicating the occurrence of sub-continental subduction zones with melange formation and HP/LT metamorphism of ophiolitic rocks, and two main stages of intraoceanic subductions involving the proto-Caribbean oceanic lithosphere and/or supra-subduction complexes. These two stages are marked by the occurrence of (1) HP/LT metamorphic ophiolites and volcano-plutonic sequences with island-arc tholeiitic (IAT)

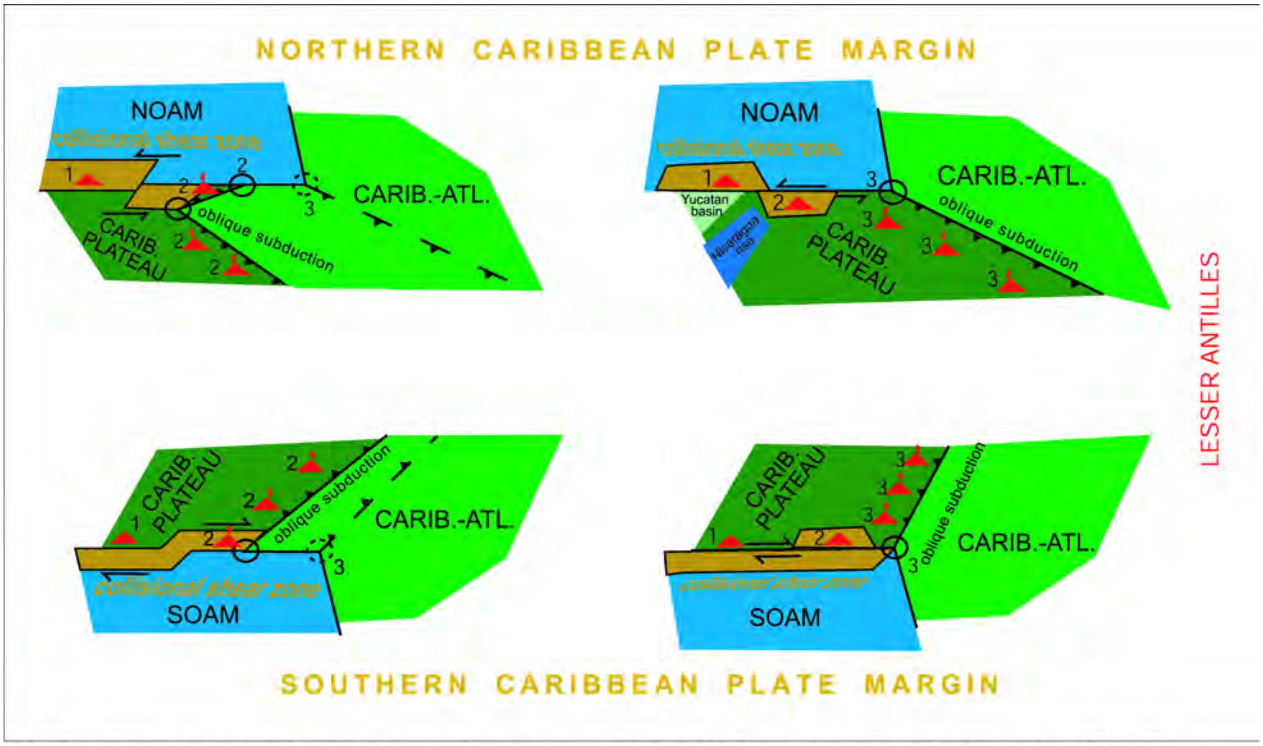

Fig.2 - Cartoon-model of the accretionary to collisional shear zones evolution related to the opposite triple-points shifting eastward, since the Late Cretaceous.

or calc-alkaline (CA) affinities; (2) unmetamorphosed tonalitic intrusions of CA affinity below the proto-Caribbean thickened oceanic plateau. The occurrence of this Cretaceous double arc magmatism is recorded in several terranes along the Caribbean margins: the first mid-Cretaceous which developed before 96 Ma, the second Late Cretaceous recorded from 86 Ma.

2° eo-Caribbean phase

Since the Late Cretaceous, the kinematics of the Caribbean plate is closely related to the eastward drifting of the proto-Caribbean oceanic plateau (Colombia and Venezuela Basins) that produced both a diachronous tonalitic magmatism (from 86 Ma) associated with a westward dipping oblique subduction of the proto-Caribbean-Atlantic ocean floor below the plateau, and an opposite dismembering of subduction complexes of different ages along an E-W trend (north and south Caribbean margins). This seems to be the consequence of the eastward shifting of both the northern and southern triple junctions (Fig.2), allowing to the progressive bending of the Aves- Lesser Antilles arc. Moreover, the Caribbean oceanic plateau was trapped by different rotation rates of the Chortis, Chorotega and Choco blocks during the construction of the western plate margin (Central American Isthmus).

During this second eo-Caribbean stage, westward-dipping subduction of the oceanic lithosphere took place beneath both the oceanic plateau and the previous magmatic arcs, giving rise to (1) the widespread tonalitic arc magmatism of the northern and southern Caribbean plate margins (in Guatemala, Cuba, Hispaniola, Puerto Rico and Venezuela), (2) the HP/LT and amphibolitic metamorphic effects in both the ophiolitic units and continental margins (Cuba, Hispaniola and Puerto Rico), as well as (3) the onset of the Aves/Lesser Antilles magmatic arc system.

Transpressional tectonics along the northern and southern margins of the Caribbean plate caused the lateral dispersion and opposite rotation (sinistral vs. dextral, respectively) of the older structural elements. This resulted in significant differences between the two margins. Along the northern margin the younger (tonalitic) magmatic arc generally rests on the deformed belt, which includes both the older arc systems and the eastward migrating front of the new accretionary wedges. The Paleocene-Eocene volcanic arc in eastern Cuba (Sierra Maestra) may be related with a second-order shifting of a triple-point of junction southeastward , while the Late Cretaceous arc connected to the northwestern one already collided against the NOAM, becoming inactive. Along the southern margins the tonalitic magmatism is decoupled from the older arc, being intruded in both undeformed and deformed oceanic plateau and in part in the rifted continental margin units.

The present-day trending of the structural lineations suggests that displacement during early stage of the exhumation was high angle with respect to the subduction direction, as well as roughly parallel to the plate boundary between the Caribbean plate and both the NOAM and SOAM. Moreover , a complex decompression evolution is recorded in several HP/LT metamorphic units; the deformation phases, developed under P-T retrograde conditions during exhumation, demonstrate that the uplifting was characterized by a well developed ductile geometries.

The end of the eo?Caribbean accretionary phase is progressively older going westward marking the Late Cretaceous-Paleogene collision and/or obduction of the proto- and eo-Caribbean ophiolitic units against or onto the NOAM and SOAM continental margins, as suture zones in flake and wedge geometry. These structural features can be explained in a strike-slip tectonic regime which has largely ruled the geodynamics of the Caribbean boundaries, controlling their evolution since at least the beginning of exhumation of the HP-LT units in the mid-Late Cretaceous.

1° eo Caribbean phase

The mid-Late Cretaceous eo-Caribbean evolution requires different interpretations depending from a lot of unresolved problems. This period corresponds to the beginning of the compressional conditions in central America area characterized by sub-continental and/or intraoceanic subduction systems with associated IAT and CA arc magmatism.

Starting from the Early Cretaceous, the South Atlantic opening and related westward and northwestward motion of the American plates led to ocean-ocean and ocean-continent plate convergences ("eo?Caribbean" 1^ phase of Giunta, 1993), producing several SSZ and magmatic arcs. Remnants of these magmatic arcs and subduction complexes are represented to the north, by the Sierra Santa Cruz, Juan de Paz, and Baja Verapaz units in Guatemala, the Cretaceous Arc, Mabujina and Moa- Baracoa units in Cuba, as well as in Jamaica, and, to the south, by the Villa de Cura and Dos Hermanas units in Venezuela. Evidence of involvement of the proto-Caribbean oceanic lithosphere in subduction zones is also represented by the HP/LT metamorphosed units outcropping in the Caribbean margins, related to an ocean-ocean subduction or subordinately to an ocean-continent subduction. Moreover, portions of the previously rifted continental margins were also involved in the subduction zones, (e.g., La Rinconada Fm of the Caucagua-El Tinaco complex in Venezuela; Escambray in Cuba) reaching in places the eclogite facies.

A discussion on the main constraints leading the first eo-Caribbean accretionary event for the southern Caribbean margin is included in Giunta et al. (2002 b, and references therein). The oldest available radiometric age for the HP-LT metamorphic climax has been obtained at 96.3±0.4 Ma. Considering that some units (e.g. Villa de Cura in Venezuela) are generated in a supra-subduction setting, this radiometric age constrains the beginning of the subduction as older than this HP-LT event. The peak of the HP-LT metamorphism that affected some continental units (e.g. La Rinconada Fm of the Caucagua-El Tinaco complex in Venezuela) is probably younger than 114-105 Ma. 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 climax conditions (e.g., 79.8±0.4), as well as the oldest radiometric ages of the retrograde conditions (84.5±0.2 Ma). On the whole, mid-Cretaceous age for the early convergence in the Caribbean realm is suggested by the available data.

Several geological evidences indicate the contemporaneous presence of two subduction settings developed in an intra-oceanic convergence the first and in a sub-continental setting the latter. HP-LT assemblages (blueschist and eclogitic) in both oceanic and continental lithospheres require a geodynamic model where these both oceanic and continental lithospheres have been deeply involved in the subduction zones. The development of HP-LT conditions in MORB-type units is commonly related to the subduction of dense oceanic lithosphere, in either sub-continental or intra-oceanic settings. The metamorphism of units that represent remnants of continental margin requires more complex subduction mechanisms (e.g., continental collision, tectonic erosion) that include underthrusting of more or

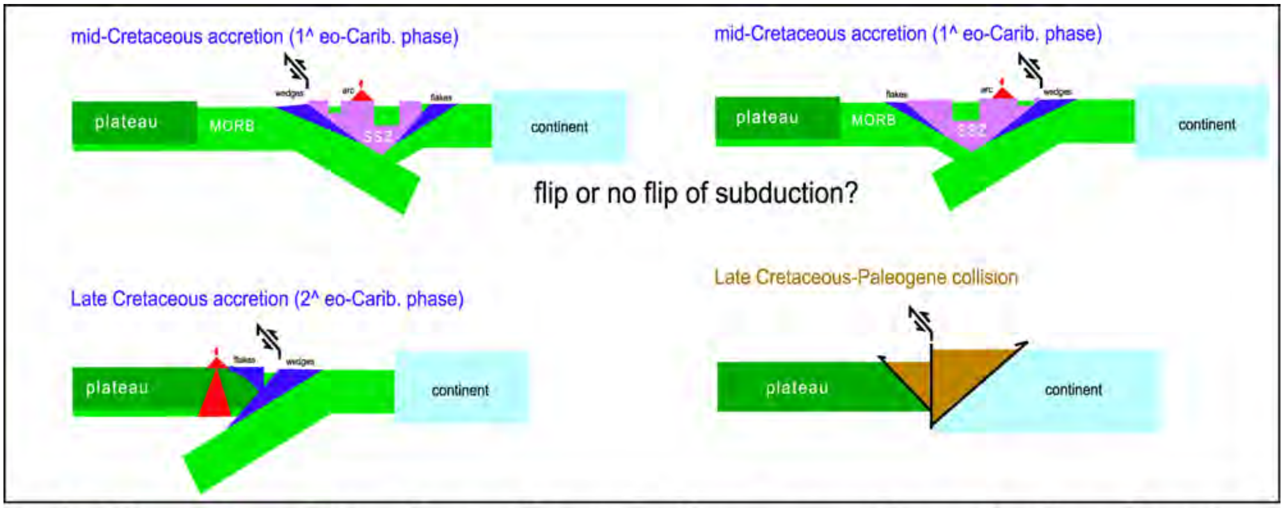

Fig.3 - Cross-section cartoons showing the main problems on accrectionary to collisional events: (1) subduction directions, (2) Supra Subduction Zone evolutions, (3) strike-slip fault locations.

less thinned continental crust. Moreover, the atypical evolution of the early volcanic arc should be resolved (tectonic erosion?), because some arc units (in Cuba and Venezuela) were deeply subducted and early affected by blueschist facies metamorphism. The supra subduction zone complexes generally obduce, floating and escaping from involvement in the deep part of the subduction slab; only a amphibolitic sole often develops in a narrow zone below the obducing, relatively hot slab.

This oldest intra-oceanic convergence can be supposed to affect the eastern sector of the proto-Caribbean domain, where the thinner portions of the oceanic lithosphere were in more favourable conditions to be subducted, while at the same time the western sector 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.

The main problems to be resolved concern: (1) the mid-Cretaceous location and the subduction drifting directions of either ocean-ocean or ocean-continent convergences, and subordinately, (2) the ocean floor or back-arc pertinence of the MOR-type ophiolitic units, (3) both the volcanic arc complexes and thinned continental crusts involvement in subduction zones.

In a tentative to best fit all the recognized constraints, at least three models can be proposed, depending on some strike-slip faults playing as cinematic releases between different geodynamic environments in the proto-Caribbean area.

These three models differ from the strike-slip fault locations, deviding subduction areas with either opposite dipping directions or very complicated paleogeographical morphology, taking into account that the Caribbean evolution, since mid-Cretaceous, has been dominated by a strongly-oblique tectonic regime, which seems to have characterized subduction, exumation, emplacement and dismembering processes (see also Giunta et al., 2002 b). In the first model, more or less east-west trending transform faults separating subduction zones with different dipping directions (westward the intraoceanic convergence, eastward the subcontinental one), are supposed located inside the oceanic domain, with the presence of microcontinents. In the second model all the oceanic domain could be located between the main transform releases; this reconstruction requires the occurrence of both a west- dipping subduction and very complicated continental margins morphology (as continental promontories). In the third model, the occurrence of a widespread east-dipping subduction is postulated; the location of the transform faults allowed the contemporaneous intraoceanic and subcontinental subductions.

The whole geological data confirm that the eo-Caribbean accretionary phase ends in the Late Cretaceous, when the unthickned oceanic realm was involved in subduction below the thicker oceanic plateau, with a likely westward sinking of the lithospheric slab. This implies a flip of the intraoceanic subduction direction in the third model, or a continuous westward subduction in both the first and second models (Fig. 3).

The proposed kinematic evolution seems to be speculative, because based much more on unresolved problems than on recognized facts, as (1) the Early Cretaceous paleogeography and morphology of the margins of the North and South American continents and minor blocks; (2) the sinking direction of the previously subducted oceanic slabs; (3) the locations of and relationships between the intraoceanic and sub-continental subduction zones. Taking these points into account and on the basis of the new geological constraints, we consider several alternative tectonic models, each of which needs kinematic releases (strike-slip faults) allowing either the simultaneous activation of intraoceanic and sub-continental collisions, or the progressive insertion by tectonic erosion of the rifted continental portions in the subduction complexes. In a whole transpressional regime the different subduction zones can be inferred to dip either eastward with a later flip westward below the oceanic plateau, or continuously westward.

References

Beccaluva L., Chinchilla Chaves A.L., Coltorti M., Giunta G., Siena F., Vaccaro C., 1999 - The St. Helena-Nicoya Ophiolitic Complex in Costa Rica and its geodynamic implications for the Caribbean Plate Evolution. Eur. J. Mineral., 11, 1091-1107.

Beccaluva L., Coltorti M., Giunta G., Iturralde Vinent M., Navarro E., Siena F., Urbani F., 1996- Cross sections through the ophiolitic units of th Southern and Northern Margins of the Caribbean Plate, in Venezuela (Northern Cordilleras) and Central Cuba. "Ofioliti",21 (2), 85-103.

Burke K., 1988 - Tectonic evolution of the Caribbean. Annual Rev. Earth and Planet. Sci., 16, 201-230.

Duncan R.A., and Hargraves R.B., 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, 162, 81-93.

Giunta G., 1993 - Los margenes mesozoicos de la Placa Caribe: Problematicas sobre nucleacion y evolucion. 6° Congreso Colombiano de Geologia Mem., III, 729-747.

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

Giunta G., Marroni M., Padoa E., Pandolfi L., 2002 b - Geological constraints for the Geodynamic evolution of the southern margin of the Caribbean Plate. AAPG-Sp.Vol. (in press).

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

Pindell J.L., 1994 - Evolution of the Gulf of Mexico and the Caribbean. In Donovan, S.K., Jackson, T.A. (Eds.), Caribbean Geology: An Introduction, U.W.I. Publ. Ass. Kingston, 13-39.

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