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Arguments for and against the Pacific origin of the Caribbean Plate: discussion, finding for an inter-American origin

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ABSTRACT

Arguments in support of the Pacific origin for the Caribbean Plate are discussed along with others that point to an inter-American origin. Entry of a Pacific-derived plate would have involved unlikely, geometrically complex and highly diachronous events. They would have included changes in direction of subduction, changes in direction of plate migration, major (1000s of km) plate migration, major rotation of large parts of a volcanic arc, major rotations of the Maya and Chortis blocks and diachronous development of flysch/wildflysch deposits as the entering plate interacted with neighbouring elements. The internal structural conformity of the Caribbean Plate and of the Maya and Chortis blocks with regional geology of Middle America shows that no major migrations or rotations have occurred. Coeval, regional deposits of Albian shallow water limestones, Paleocene– Middle Eocene flysch/wildflysch deposits, Middle Eocene limestones, and a regional Late Eocene hiatus show an inter-American location, not a changing Pacific-Caribbean location. Neogene displacement of the Caribbean relative to North and South America amounts to no more than 300 km.

KEYWORDS **Caribbean Plate. Pacific vs. inter-American arguments. Inter-American origin.**

INTRODUCTION

Literature favours a Pacific origin for the Caribbean Plate; few papers argue for an inter-American origin. This paper, focused on the Caribbean plate region (Fig. 1), examines arguments published in support of the Pacific model and then considers others that point to the plate's inter-American origin.

Pacific Model summary

Pacific models (Fig. 2A) begin with palaeogeographic reconstructions showing the Maya (Yucatán) Block (Fig. 1) lying along the northern coast of South America, between North and South America, and the Chortis Block on the west side of Mexico (Ross and Scotese, 1988; Pindell et al., 2000). The "proto-Caribbean" oceanic province and the Gulf of Mexico formed in the Jurassic-Early Cretaceous as North America drifted away from Pangea and the Maya Block rotated 50° or more counterclockwise (Pindell et al., 2000; Pindell and Kennan, 2003). An east-facing island arc ("proto Antilles" or Caribbean Great Arc) trended northwest-southeast (Pindell et al., 1988; Tardy et al., 1994) or northeast-southwest (Rogers et al., submitted*c*) across the western end of the proto-Caribbean and alongside Mexico and northwest South America. The future Caribbean Plate lay southwest (Pindell and Barrett, 1990) or northwest (Rogers et al., submitted*c*) of the arc with a further, west-facing, island arc (in early papers, a "proto Costa Rica-Panamá arc") on its west flank. During the Cretaceous the plate thickened into a Large Igneous Province/Ocean Plateau. This occurred either as it migrated northeastward across the Galapagos Hotspot (early papers, e.g. Duncan and Hargraves, 1984; Bouysse, 1988), or above a rapidly melting mantle plume head (or both) (Hall et al., 1995; Kerr et al., 1997), or two plumes (Sala y Gómez and Galapagos) and then again by decompression melting (Révillon et al., 2000). At the time of writing the latest model (Kerr and Tarney, 2005) suggests that a Caribbean plateau formed near the Galapagos Hotspot while a Gorgona Plateau formed possibly at the Sala y Gómez hotspot.

The Caribbean Plate entered the gap between North and South America, overriding "proto-Caribbean" oceanic crust, after a reversal of subduction direction below the leading edge Caribbean Great Arc (Fig. 2A). The Chortis Block (Fig. 1), a complex of continental and arc origin (Rogers et al., submitted*a*, *b*) moved southeastward into its Central American location at the same time (Fig. 2A) and accreted (? – the mechanism is never explained) to the trailing edge of the Caribbean Plate (Rogers et al., submitted*c*). Arc activity along the northern and southern segments of the Great Arc ceased after collision with North and South America in the Paleocene-Middle Eocene (the collision is also known as the "Laramide Orogeny"; Antoine et al., 1974). This is seen as an early episode in the continuous, diachronous interaction of the Caribbean Plate with North and South America as it migrated from the Pacific. The Yucatán Basin opened as a Maastrichtian-Middle Eocene intra-arc or back-arc basin behind Cuba (Pindell, 2001) via slab rollback (in two different directions). Cuba collided with the Florida-Bahamas platform and accreted to the North American Plate along with the Yucatán Basin. The Caribbean – North American plate boundary jumped from north of Cuba to the Oriente–Swan Faults of the Cayman Trough. The Caribbean Plate then assumed an eastward migration direction between North and South America. Sinistral offset of 1100 to 1300 km occurred along the northern plate boundary since Cayman Trough opening began in the Eocene. Therefore dextral movement of similar magnitude occurred along the southern Caribbean plate boundary. The defunct northern and southern segments of the Great Arc became extended in an E-W direction, forming the Greater and Netherlands-Venezuelan Antilles. Remnant north-south trending segments of the arc formed the northern Lesser Antilles and the Aves Ridge. The latter arc segment jumped eastward in the Eocene to the southern Lesser Antilles, when the back-arc or inter-arc Grenada Basin formed (Bouysse, 1988; Pindell and Barrett, 1990; Bird et al., 1999). Volcanic-arc activity linked the continental Maya and Chortis blocks to South America via Costa Rica and Panamá.

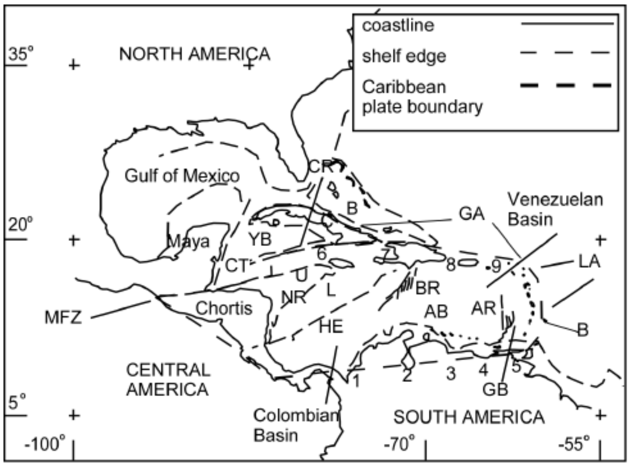


FIGURE 1 | **Middle America, geographic elements referred to in text. AB: Aruba-Blanquilla; AR: Aves Ridge; B: Bahamas; BR: Beata Ridge; C: Cuba; CR: Cayman Ridge; CT: Cayman Trough; GA: Greater Antilles; GB: Grenada Basin; HE: Hess Escarpment; LA: Lesser Antilles; NR: Nicaragua Rise (Upper, Lower); YB: Yucatán Basin. Numbers indicate pull-apart depressions along the southern and northern boundaries of the Caribbean Plate (1: Lower Magdalena; 2: Maracaibo; 3: Guarumen; 4: El Hatillo; 5: Gulf of Paria; 6: east Cayman Trough; 7: North Haiti; 8: Mona Passage; 9: Anegada Passage).**

Inter american model summary

The inter-American model (Fig. 2B) begins with a Pangean reconstruction (James, 2002b, 2003, fig. 5) that does not later involve large-scale rotations of elements such as the Maya and Chortis blocks (Fig. 1). It evolves via sinistral transtension between North and South America (Fig. 2B; James, 2002b, 2003a). The early Caribbean formed along with the Gulf of Mexico, the Yucatán Basin and the Cayman Trough when North America drifted northwest from Gondwana in the Jurassic-Early Cretaceous. Extended continental or transitional crust developed in the Bahamas Platform, Gulf of Mexico margins, distal parts of the Cayman Trough and the Nicaragua Rise. The sinistral, Caribbean–North American boundary was located along the early Cayman Trough and between the large continental fragments of Maya and Chortis. Thickening of ocean crust in areas of the present-day Venezuelan, Yucatán and Colombian basins occurred as a result of decompression melting, perhaps associated with triple junctions heralding spreading jumps to the Atlantic and Pacific, in the Aptian (James, 2002b, 2003a, 2005). Atlantic and Pacific spreading convergence with the Caribbean area resulted in outward facing island-arcs on the east and west of the Caribbean area, resulting in isolation of the Caribbean Plate. Divergence of spreading trajectories (North-South America) both in the Atlantic and the Pacific resulted in Caribbean Plate extension and further decompression-related extrusion, mainly at 90-88 Ma but continuing to 75 Ma. Continued westward movement of the North American Plate relative to the South American Plate (and the Caribbean) resulted in continued subduction in the Lesser Antilles. In the Paleogene flysch/wildflysch deposits, including very large olistoliths of Mesozoic continental margin sedimentary rocks, island-arc rocks, serpentinites and ophiolites formed along the plate margins. The event culminated violently in the Middle Eocene with development of a regional unconformity overlain by regional shallow-marine carbonates, recording regional uplift to wavebase and the photic zone. Subsequently, the plate remained stationary relative to the westward moving North and South American plates. Oligocene–Recent strike-slip along the northern and southern plate boundaries resulted in eastward-migrating pull-apart extension, thrusting and complementary foreland basin subsidence. Volcanic-arc activity along the western and eastern plate boundaries records continuing convergence between the Caribbean Plate and neighbouring oceanic plates.

ARGUMENTS IN SUPPORT OF A PACIFIC ORIGIN FOR THE CARIBBEAN

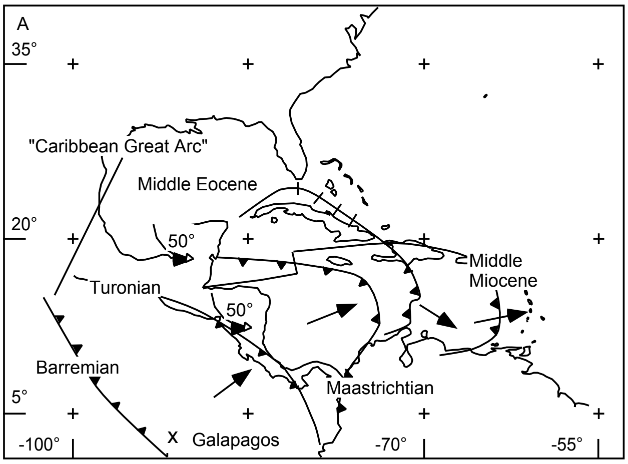
Pindell (1991, 1993, 2003) and Pindell and Barrett (1990) listed arguments supporting the Pacific model, concluding that the evidence was "overwhelmingly in favour" of a Pacific provenance. I paraphrase or directly quote these arguments in italics and follow with my discussion in plain text. Some arguments have been modified or abandoned and new arguments have evolved (Pindell, 2001; Pindell, 2003). For completeness I consider both old and new and attempt to show evolution of thought. Later, I present arguments for the inter-American origin of the Caribbean Plate.

Pindell and Barret (1990) and Pindell (1991, 1993) arguments: a discussion.

A1. *The Aves Ridge and the Lesser Antilles together present an upper Cretaceous-Recent (ca. 90 Ma) record of subduction of the Atlantic Plate beneath the eastern Caribbean. Minimum relative plate migration has been ca. 1000 km.*

Most papers (Freeland and Dietz, 1972; Meyerhoff and Meyerhoff, 1971; Bouysse, 1984, 1988; Maury et al., 1990; Bouysse et al., 1990; Pindell, 1991, 1993; Bird et al., 1999; Iturralde-Vinent and MacPhee, 1999) discuss the Aves Ridge (Fig. 1) in terms of a Late Cretaceous volcanic arc that became abandoned in the Eocene, either as subduction jumped to the southern Lesser Antilles or when the "back-arc" Grenada Basin formed. Pindell (1993) surmised that the Aves "arc" was east facing because of its convex-eastward shape and absence of an accretionary prism along its west flank. There is no evidence of an accretionary prism to the east, either, and there is no indication that the Grenada Basin deepened towards a subduction trench next to the Aves Ridge.

The Aves Ridge crosses the eastern Caribbean northward from the Venezuelan shelf margin towards the Virgin Islands. It originates in the south as a narrow, northeast trending ridge. Its eastern flank continues this trend to around 14°N whence it runs north, parallel to its



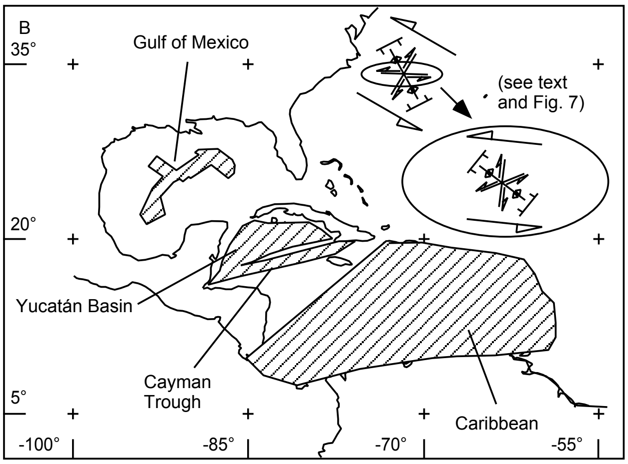


FIGURE 2 | **Pacific (A) and inter-American (B) concepts for the origin of the Caribbean Plate, shown against a modern map of the area. 1A illustrates migration of the Caribbean Plate leading-edge volcanic arc from the Pacific. The mechanism whereby the arc changes from a linear to a highly curved feature is never explained and is difficult to imagine. Arrows indicate published plate direction. They show an unlikely variation of plate migration. 1B shows formation of oceanic areas (Gulf of Mexico, Yucatán, Cayman Trough, Caribbean) between WNW, sinistrally diverging North and South America in the Jurassic-Early Cretaceous. The Caribbean Plate was rimmed by volcanic arcs of the Greater-Lesser-Aruba-Blanquilla Antilles and Central America. Ellipses indicate primary (drift) and secondary strain (see also Fig. 7).**

remarkably linear western flank. The eastern and western flanks seem to be fault controlled (Holcombe et al., 1990, fig. 12). North and east of 15° the topographic high broadens into a volcaniclastic fan, with northeast-southwest structural and magnetic grain (Bird et al., 1999), derived from the northern Lesser Antilles.

There is no proof that the Aves Ridge is a subduction arc. It has been directly sampled only by dredging and two DSDP holes (Fox et al, 1971; Nagle, 1972; Bouysse et al., 1985). The latter penetrated only Plio-Pleistocene sediments. Fox et al. (1971) described dredge samples of diabase, basalt and meta-basalt that gave dates of 60 Ma. Granodiorite also occurred amongst these samples, with K/Ar ages of lower Senonian, upper Senonian, and upper Paleocene. Fox et al. (1971) considered that this material possibly indicated the northern margin of South America. They noted that granodiorite compressional wave velocity was similar to obtained seismic refraction data. They proposed that the ridge was underlain by granitic rocks of late Mesozoic age and bore pedestals of volcanic origin (basaltic dredge samples).

The Ridge is separated from the Lesser Antilles arc by the so-called "inter-arc" or "back arc" Grenada Basin (Fig. 1). There are at least five models for the origin of this basin (Bird et al., 1999). They all invoke spreading ridges. Depending on which model, these range in orientation from east-west to north-south. In fact, there is no evidence for either spreading or ridges. Bouysse (1988) pointed out that magnetic anomalies in the basin are low in amplitude and have no clear pattern. The age of the basin is not known, it is estimated to be Paleogene on the bases of heat-flow measurements and depth to basement (Bouysse et al., 1990).

Bouysse (1988) remarked that the Grenada Basin formed through extensional tectonics that also structured the Aves Swell, which has a step-like eastern flank. He concluded that the southern basin was oceanic, while the northern area was probably rifted arc. He went on to say that all data suggest the existence during the late Mesozoic of a single arc system (the Mesozoic Caribbean Arc) that included the Greater, Lesser and the Netherlands-Venezuelan Antilles, as well as the Aves Ridge. He proposed that the Ridge became separated from the Lesser Antilles by the northward propagating back-arc, Grenada Basin. However, such a basin should narrow northwards and the Grenada Basin is symmetrical.

Fox et al. (1971) observed that the Aves Ridge appeared to be a thickened part of the 2-3 km thick 6.3 km/s layer of the Venezuela Basin. Bouysse (1988) recalled that Venezuelan and Colombian basin crust is three-layered, with the following velocity structure: 3.2-5.0 km/s, 6.0-6.3 km/s and 7.0-7.3 km/s. Grenada basin crust is also three layered, with velocities of: 5.3, 6.2 and 7.4 km/s. The similar patterns indicate similar origins for the crust east and west of the ridge.

In summary, the Aves Ridge and Grenada Basin both have undefined origins. They do not necessarily record subduction, arc jump or back-arc basin activity. In no way do they provide evidence of a Pacific origin of the Caribbean Plate.

A2. *The Cayman Trough oceanic component and reassembly of (extended) Cuba, Hispaniola, Puerto Rico and the Aves Ridge indicate at least 1000 km of sinistral movement between the Caribbean and North and South America (and hence the Atlantic Plate).*

For some, the Cayman Trough (Fig. 1) has assumed a pivotal position in discussions of Caribbean Plate history. Pindell and Barrett (1990) stated "A large amount of offset along the Cayman Trough (more than 800 km) is especially important in constraining models for the evolution of the Caribbean. The concept of the Caribbean Plate originating within the Pacific realm and entering the North-South American gap prior to the Eocene depends on this interpretation. If smaller estimates of offset are assumed, an inter-American formation of the Caribbean Plate (between North and South America) is required." They further argued that since little relative movement has occurred between North and South America since the Eocene, Cayman sinistral displacement along the northern Caribbean boundary implied a similar amount of dextral offset along the southern boundary.

The Cayman Trough is generally seen as a pull-apart within the sinistral north Caribbean plate boundary. Estimates of displacement related to the Trough range from 150 to 1400 Km (Hess and Maxwell, 1953; Kesler, 1971; White and Burke, 1980; Pindell and Dewey, 1982; Sykes et al., 1982; Wadge and Burke, 1983; Pindell and Barrett, 1990). Pindell and Barrett (1990) noted that 980 km of the Trough are characterized by depths typical of oceanic crust. They estimated an additional 70-100 km of extension related to block faulted zones (arc or continental material) at the western and eastern ends of the Trough. Possible correlation of Jurassic rift faults on the Maya and Chortis blocks indicates around 900 km of sinistral offset (James, 2002b, 2003a).

Bowin (1968) and Dillon and Vedder (1973) thought that the eastern part of the Trough began to form during Late Cretaceous or Paleocene time. Later papers emphasize Eocene opening. Rosencrantz et al. (1988) proposed that trough opening provided quantitative measures of relative plate motion along the northern Caribbean plate boundary zone and provided constraints on the relative movement of the Caribbean Plate as a whole with respect to surrounding plates. Estimates of the beginning age of trough opening (Eocene) were based upon depth-to-basement and heat flow studies. However, Rosencrantz et al. (1988) noted that ages from heat flow measurements were inconclusive and stated: "We suggest that the question of Cayman Trough heat flow be shelved until new and better measurements are obtained". Rosencrantz (1993) later suggested that Cayman Trough opening recorded local rather than regional plate movements and could not be used to track Caribbean-North American relative plate motion. The modification is entirely overlooked by literature that continually quotes the Rosencrantz et al. (1988) paper and quotes the Eocene age as if it were firmly established.

The only identified spreading ridge in the Caribbean area lies in the centre of the Trough. Rosencrantz (1993) and Leroy et al. (2000) recognized two main sets of magnetic anomalies in the trough. A younger set is associated with the spreading centre. It fits present-day plate movements and records these back to anomaly 6 (Early Miocene). An older, outboard set of anomalies does not fit current plate movements. Rosencrantz (1993) assigned the older set to the interval Early Oligocene-Middle Eocene. However, the older anomalies vary greatly in shape and amplitudes are low, prompting Leroy et al. (2000) to write: "Thus the characteristic magnetic anomaly shapes are hardly recognizable here, which makes the recognition of certain anomalies questionable". Stated simply, Cayman magnetic anomalies do not reveal when opening began.

The western continuation of Cayman sinistral offset crosses the Central American Isthmus. Here, the Maya and Chortis blocks are joined along the Acapulco-Guatemala or Malpaso, Motagua-Polochic Megashear (Fig. 1): a system of faults in Honduras, Guatemala and adjacent Mexico (Anderson and Schmidt, 1983; Guzmán-Speziale, 1989). Gordon and Ave Lallement (1995) used published fault offsets and estimations from fault zone widths to summarize offsets of 130 km on the Polochic Fault, up to 500 km along the Motagua Fault, 70 km along the Guayape Fault and 25 km along the Jocotán-Chamelecón Fault. The total 725 km of sinistral displacement does not account for the estimated 1100 km of Cayman offset. They proposed that distributed movement on cryptic strike-slip faults across the entire the Chortís block accounts for the remaining offset. They noted that faults are more commonly exposed in Cretaceous and older rocks than the Tertiary volcanic rocks, suggesting that most slip occurred before 30 Ma.

Sinistral movement along the Central American faults occurred from the Jurassic onwards, migrating southwards (Santa Cruz Fault, Jurassic, Malpaso Fault Late Cretaceous, Viniegra, 1971; Motagua Fault, mid Tertiary; Burkart, 1983). Burkart et al. (1987) restored Laramide structures sinistrally offset by 130 Km along the Polochic Fault of Guatemala (displacement began around 10 Ma). Iturralde-Vinent and MacPhee (1999) determined that 230 km of offset has occurred along the Oriente Fault of southern Cuba since the Miocene. The observations show that most of Cayman sinistral offset occurred prior to "Laramide" folding. In fact, most of the E-W relative displacement between North and South America (and the Caribbean Plate) developed during the Jurassic-Early Cretaceous along the northern Caribbean Plate boundary (Cayman Trough–Motagua–Polochic Fault system) (James, 2002b, 2003a).

Plutonic rocks that intrude the Jurassic-Cretaceous Xolapa complex in Mexico record crustal growth between 35 and 27 Ma (Oligocene), with decreasing age from west to east (Meschede and Frisch, 1998). This is a second phase of sinistral offset along the north Caribbean plate boundary, coeval with dextral offset along the southern boundary.

Three points follow from the above. First, the commonly quoted Eocene age of trough opening is not calibrated; it is only modelled. Second, most Cayman offset occurred during the Jurassic – Early Cretaceous (a second phase of sinistral movement -some 300 km only- began in the Oligocene, section B 13). Third, Cayman offset does not imply 1000 km of Cenozoic offset along the southern Caribbean Plate boundary (subduction below the Lesser Antilles since the Albian resulted from westward movement of North America relative to South America and the Caribbean, not eastward movement of the Caribbean Plate).

A final point concerns the nature of the Cayman Ridge and the walls of the Cayman Trough. They lie south of the Cuban segment of the Cretaceous island arc. According to Pacific models they followed the arc in from an oceanic setting. However, Dillon and Vedder (1973) observed that the acoustic basement of the Ridge consists of continental rocks. The western Cayman Ridge has crustal thicknesses of near-continental proportions and a low magnetic susceptibility, similar to the rift blocks of the margin of British Honduras. Perfit and Heezen (1978) developed a stratigraphy for the walls of the Cayman Trough. Clastic rocks include volcanic breccias, conglomerates, sandstone and argillites, red bed material, greywacke and arkose. The presence of continental material in the Cayman Ridge, the Nicaragua Rise and along the walls of the Cayman Trough rules out the Pacific origin of this area.

A3. *Seismicity and seismic tomography show a distinct west dipping Atlantic Benioff zone extending at least 1200 km beneath the eastern Caribbean.*

McCann and Pennington (1990) summarized seismicity studies in the Caribbean region. Intermediate-depth seismicity indicates penetration of American lithosphere to at least 200 km below the Lesser Antilles. Van der Hilst (1990) summarized that his tomographic studies imaged the Lesser Antilles subduction zone well below the seismic zones to a depth of 600 km. However, while discussing his methodology, results and interpretations he made several cautionary notes. Available seismic data in the area are highly heterogeneous. Most stations coincide with narrow zones along plate boundaries. Van der Hilst (1990) stated "… the results necessarily have a preliminary character and discussions and conclusions should be considered tentative." He described his interpretation "of inclined, slab-like velocity anomalies as transections through the blurred image of the Atlantic lithosphere subducted below the eastern Caribbean" as "a working hypothesis". Papers referring to Hilst's seismic tomography never acknowledge these cautions.

A4. *The Cretaceous stratigraphy of the Caribbean area is divisible into a Proto-Caribbean suite, comprising pre-Mesozoic basement with Jurassic rift sediments, Cretaceous shelf sediments and foredeep clastics (no volcanics) and a volcanic Caribbean suite. The two are presently juxtaposed across circum-Caribbean ophiolite belts but they must have formed in spatially separate locations.*

Continental and oceanic provinces invariably form in different locations. This does not require that the oceanic one formed in the Pacific.

A5. *As the Caribbean Plate moved into place diachronous flysch basins formed (Guatemala, Campanian; northern Cuba, Latest Cretaceous-Eocene; Maracaibo area, Eocene; Eastern Venezuela, Miocene).*

As long ago as 1938, Hess observed "Many geologists ... have a tendency ... to place a great deformation at the end of the Cretaceous. The great deformation came within the Tertiary, below the widespread Upper Eocene deposits and after certain Lower and Middle Eocene deposits".

I have emphasized that coeval flysch/wildflysch deposits formed across the northern margin of South America during the Paleocene-Middle Eocene history of the Caribbean (James, 1997). An expanded version of that paper (James, 2002a, table 1, fig. 1) records widespread occurrences of similar deposits in the Caribbean and neighbouring areas. They record a regional, coeval event and are not related to diachronous passage of a migrating Caribbean Plate (see also B7, below). Diachronous interaction between the plate and its northern and southern boundaries occurred only from the Oligocene-Recent (section B12). Pindell and Kennan (2002a) and Pindell (2003) (i.e., later models) attribute Paleogene flysch/wildflysch in Eastern Venezuela/Trinidad to subduction of Proto-Caribbean lithosphere beneath northeastern South America, prior to the arrival of the Caribbean Plate. They state that this caused "minor basement-involved deformation". In fact, the flysch/wildflysch regional event was extremely energetic (Stainforth, 1969).

A6. *The pre-Albian space between N. and S. America was too small to have housed a (probably) Jurassic Caribbean Plate.*

This observation is premised by two assumptions. First, that the Jurassic Caribbean area had the same dimensions as the present plate and second, that reconstruction of the pre-Albian area is correct. Diebold et al. (1999) presented seismic evidence that the Venezuela Basin comprises extensionally thinned oceanic crust, thickened by two phases of volcanic extrusion, the latest producing the smooth floor Horizon B". Bowland and Rosencrantz (1988) presented similar data from the Colombian Basin where a western plateau, locally capped by volcanic knolls, has a smooth character. The later of these thickening phases (Horizon B") has been sampled and dated at the latest Turonian (88-90 Ma; DSDP Leg 15 Sites). While the original Caribbean formed during the Jurassic, extension may have continued until the Late Cretaceous (James, 2005).

My reconstructions of plate movements indicate that the present day Caribbean Plate could have been accommodated sometime between the end of the Jurassic and the Late Cretaceous (James 2003a).

A7. *Truncated structural trends and a truncated Paleogene arc (Sierra Madre Occidental) of southwest Mexico (Oaxaca) are continued, across sinistral offset, in the Chortis Block of Central America. The latter rotated into a position south of, and sutured, to the Maya Block along with the Caribbean Plate in the Cenozoic.*

Donnelly et al. (1990) discussed the Maya (Yucatán) and Chortis blocks of northern Central America. They emphasized that most models of this region do not admit the small amount of data available to constrain possibilities. Pacific models show the Chortis Block originating in the central Gulf of Mexico, against the Yucatán Peninsula in the Gulf of Honduras, in its present position, along the southwest coast of Mexico, off the northwest coast of South America or in the Pacific Ocean. For Donnelly et al. (1990), the southwest Mexican model had most credibility because the basement and Mesozoic stratigraphy shows affinities between Chortis and Oaxaca. Work by Harlow et al. (2004) and Rogers et al. (submitted*c*) support geological affinities with southern Mexico but invoke complex history of rifting, spreading from and then accretion to Mexico, followed by southeast migration and 50° of counterclockwise block rotation before suturing to Maya. Rotation is negated by parallelism of Jurassic faults on Chortis with coeval faults in southeast North America and northern South America.

While Pindell and Dewey (1982) placed the Maya Block in the Gulf of Mexico and Pindell et al. (2000) showed the block lying along the north coast of South America, Donnelly et al. (1990.) noted that an Early Permian unconformity and Pennsylvanian-Permian volcanic rocks have no clear counterpart in either North or South America. As with Chortis, there are fault trends on Maya that negate block rotation (Fig. 2A). Richter (pers. comm., 2003) wrote "I believe that Cenomanian rocks of the northern part of the Chortis block (northeastern Honduras) have a facies relationship to the southern Mayan rocks and I believe it is unlikely that they came from the far northwest while the Mayan came from the protoGulf." There has merely been sinistral offset between the blocks, which are large continental remnants of extended Middle America (James, 2002b, 2003a).

Finally, Pacific models show the Caribbean Plate migrating northeastward into the Caribbean at same time (late Cretaceous) as the Chortis was migrating into place. It is geometrically impossible for the Chortis Block to have migrated southeastward and then eastward to enter the Central America region at the same time.

A8. *Shelfal faunal provinces in the Mexican-Caribbean region were separate until the Campanian when they merged as a result of tectonic juxtaposition, presumably during relative eastward migration of the Caribbean Plate between the Americas (a bottleneck between Colombia and Yucatán).*

The concept here is that the Great Arc formed a topographic link between continental Central and South America as it entered the Caribbean region.

Bowland and Rosencrantz (1988) noted that horizontal shortening of the Nicoya Complex (Costa Rica) occurred in the late Santonian or Early Campanian as a result of east-west oriented regional stress. Lundberg (1983) discussed the Campanian sedimentary complex above the complex. Radiolarian-rich mudstones are followed by foraminifer-rich calcareous mudstones, suggesting a rise through the CCD. Donnelly et al. (1990) noted that ophiolite obduction occurred regionally in the latest Campanian or Maastrichtian. Echevarría-Rodríguez et al. (1991) concluded that NNE directed shortening occurred from at least the Campanian in Cuba. Iturralde-Vinent et al. (1996) presented K/Ar data showing a Campanian-Maastrichtian peak of ages in Cuban terranes indicating regional collision of the arc with North America. Khudoley and Meyerhoff (1971) noted an angular unconformity between the Cenomanian or Turonian and the overlying Campanian or Maastrichtian throughout the Greater Antilles. Beets et al. (1984) concluded that collision of the Aruba-Blanquilla arc with South America occurred in the Coniacian-Campanian.

Clearly, uplift, shallowing, collision and accretion occurred on a regional scale, not just at the western end of the Caribbean where the leading edge Mesozoic arc is supposed to have been entering the area. Furthermore, "the Great Arc" could not bridge the Mexico-Colombia gap and collide with North (Cuba) and South (Venezuela) America at the same time.

A9. *Montgomery et al. (1994) identified cold water Late Jurassic radiolaria that can only have come from the Pacific.*

Montgomery et al. (1994) noted that the radiolarian genera *Praeparvicingula* and *Parvicingula* signify minimum paleolatitudes of 22-30° north or south of the equator. Their presence in two Jurassic Caribbean fragments (basement complex; La Désirade, now 16.5°N; Bermeja Complex, Puerto Rico, now 18°N) was evidence of significant translation of these components. A third Jurassic fragment (Duarte Complex, Hispaniola, now 19°N) had an equatorial origin, shared also by the Bermeja Complex. The oldest material (Pliensbachian) occurs on Puerto Rico. It is stated to have formed in open-ocean environment before oceanic crust existed between North and South America. Montgomery et al. (1994) concluded that radiolarian palæogeography is totally incompatible with any fixist Caribbean model.

All these radiolaria occur on islands on the northeastern margin of the Caribbean, adjacent to Central Atlantic Jurassic crust. Second, older oceanic crust in the Gulf of Mexico - Yucatán Basin - Cayman Trough - Caribbean never has been sampled in place and remains undated; its age is only modelled. Davison et al. (2003) emphasized that the oldest oceanic crust in the Atlantic is Triassic-Jurassic. It now lies along the eastern seaboard of North America. Bajocian (Crawford et al., 1985) or Triassic-Liassic (Davison et al., 2003) salt occurs in the Takutu Graben, Guayana, Triassic palynomorphs have been found in Gulf of Mexico salt and salt occurs below Triassic shales in Chiapas (Morris et al., 1995).

Stainforth (1969) noted that deep (3000 to 8000 m) early Mesozoic trenches existed in Venezuela and postulated Triassic to early Cretaceous separation of North and South America. According to Viniegra (1971) the Mexican and Gulf of Mexico salt basins probably came into existence during the Triassic. Salvador (1987) suggested that the thickest Louann Salt accumulated in a major graben trending E-northeast across the Gulf, on trend with the Late Triassic-early Jurassic grabens of South Carolina, Georgia and the Florida Panhandle. Its initiation would mark the beginning of the formation of the Gulf of Mexico Basin. Bartolini and Larson (2001) estimated that the oldest Central Atlantic oceanic crust is not much younger than 200 ± 4 Ma and that supercontinent separation began in the Pliensbachian-Toarcian (190-180 Ma). Iturralde-Vinent (2001, 2002) noted that similarities among several groups of Jurassic animals in western Tethys and the southwestern Pacific suggest marine connection since the Sinemurian. Ager (1986) noted that the bivalve *Weyla* must have passed through Central America on the way to Europe (Damborenea and Manceñido, 1979) by the Pliensbachian.

These discussions show that significant separation had occurred between the Americas by the early Jurassic when there was a marine connection between the Atlantic and Pacific oceans. Oceanic crust could have begun forming between the Americas as long ago as the Triassic. The material studied by Montgomery et al. (1994) could indicate that oceanic crust existed between the Americas in the early Jurassic. Their data are compatible with the inter-American Caribbean model.

Pindell (2000, 2001, 2002, 2003) arguments:

Meetings in Rio de Janeiro and Stuttgart (2000), Havana and Leicester (2001) and Guatemala (2002) discussed the Caribbean Plate origin debate. Summaries on Internet Web pages provide updates on arguments supporting the Pacific model. Pindell et al. (2002, 2003) also provide an update. Again, the arguments are summarized or directly quoted in italics and discussed in plain text.

A10. *Models deriving the Caribbean from the Pacific explain regional Caribbean geology far better than models deriving the Caribbean Plate from between the Americas. "Circumstantial evidence overwhelmingly favours a Pacific origin for Caribbean oceanic lithosphere ….".*

There are two primary lines of evidence:

A10.1. The Greater Antilles Arc (Great Arc) is older than the Central American Arc, which is predicted by Pacific but not by Intra-American models;

A10.2. Caribbean tectonic interaction and control of stratigraphic development in northern Colombia and southern Yucatán began in the Campanian, which requires a more southwestward (Pacific) position of the Caribbean Plate until that time.

The Greater Antilles Arc is not older than the Central American Arc. Calvo and Bolz (1994) concluded that subduction occurred in the Central American arc since at least the Albian (the Loma Chumico volcanic arc sedimentary section, Upper Nicoya Complex, contains radiolarites, radiolarian claystone). Holcombe et al. (1990) noted that earliest arc activity occurred in the Late Jurassic in Honduras.

The Stuttgart meeting summary (www.ig.utexas.edu/CaribPlate/CaribPlate.html) records a debate on this subject, noting that geochemical and geological investigations by Hoernle and Astorga in the Nicoya Complex did not confirm the Calvo and Bolz findings. This does not mean that Calvo and Bolz were wrong. Calvo and Bolz emphasize (pers. comm., 2003) that the oldest pyroclastic deposits in northwestern Costa Rica are intercalated with hemipelagic sediments containing the late Albian ammonite *Neokentroceras* sp. (Azema et al., 1979). In southwestern Nicaragua, the oldest hemipelagic sediments containing tephra deposits carry the late Albian-Cenomanian planktonic foraminifer *Rotalipora appenninica* (RENZ) (Calvo and Bolz, 1994).

Further record of Aptian/Albian arc activity in Central America is provided by Lew (1985) while DeWever et al. (1985) record Liassic-Dogger radiolaria in volcano-sedimentary formations on the Santa Elena Peninsula.

Frisch et al. (1992) reported palaeomagnetic data from the Loma Chumico Formation indicating an equatorial latitude of formation, consistent with and inter-American (Central American) location, and suggested that subduction might have begun already in the Jurassic.

A11. *The latest models claim to have refined earlier Pacific-derived Caribbean evolutionary models to new levels of kinematic and palinspastic precision and conclude:*

A11.1.*The Galapagos Hotspot has nothing to do with Caribbean evolution;*

A11.2. *The Panamá-Costa Rica arc formed at Equatorial paleolatitudes.*

These two points concede to data and arguments presented by Frisch et al. (1992), Meschede (1998a, b) and Meschede and Frisch (1998) showing that Caribbean crustal thickening occurred in a near-American position rather than at the Galápagos hot spot (see A10). The

Stuttgart meting summary noted two fundamental positions regarding the role of the Galápagos hotspot in the geology of the Caribbean. One holds that it had nothing to do with proto-Caribbean crust or the Caribbean Plate (Meschede, 1998; Pindell, 2001), because it was always positioned to the west. The Caribbean Plate arrived from the south (from the north according to Rogers et al., submitted*c*), travelling up the west coast of South America inboard of the "Hotspot".

The other interpretation holds that the Galápagos hotspot produced the Caribbean plateau basalts (Hoernle et al., 2002). Thickening of the Caribbean Plate first occurred at 130 – 120 Ma (Diebold et al., 1999) but Galápagos hotspot activity is known only as far back as the Oligocene (Lonsdale and Klitgord, 1978; Christie et al., 1992).

Finally, it is difficult to accept that the Caribbean Plateau, Cocos, Malpelo, Coiba and Carnegie Ridges all formed above the Galapagos area, yet this idea persists (Hoernle et al., 2002).

A11.3. *High-P/low-T metamorphic assemblages in the Caribbean pertain to Aptian-Early Albian onset of W-dipping subduction beneath Great Caribbean Arc after Aptian arc polarity reversal, which then allowed the crust of the Caribbean Plate to enter the Proto-Caribbean realm during Upper Cretaceous-Cenozoic;*

A11.4. *The central Cuban Arc comprises mainly forearc elements of the Great Arc, and Sierra Maestra is more representative of the Great Arc itself;*

A11.5. *Campanian cessation of magmatism in central Cuba pertains to shallowing of subduction angle as Great Arc approached southern Yucatán, and* central Cuban forearc remained *ahead of the magmatic axis as the Yucatán intra-arc basin opened in the Maastrichtian-early Paleogene;*

A11.6. *The Yucatán intra-arc basin formed in two phases. Maastrichtian and Paleocene northwest-southeast extension was driven by slab rollback of Jurassic Proto-Caribbean lithosphere along eastern Yucatán, and Early and Middle Eocene NNE migration of central Cuba was driven by rollback of Proto-Caribbean crust toward the Bahamas, facilitated by N-ward propagation of a NNE-trending east-Yucatán tear fault, during which western and northern Cuban terranes were accreted to the front of the central Cuban forearc;*

A11.7. *Middle Eocene collision of all Cuban terranes with the Bahamas, and rapid uplift of the orogen as the Proto-Caribbean slab detached from the south-dipping Benioff Zone.*

These points (direct quotes from the Caribbean Web page report on the Leicester meeting) attempt to explain reported geology via increasingly complex modelling. There is no evidence of "slab rollback" of proto-Caribbean lithosphere to the northwest and northeast during the opening of the Yucatán Basin. At least six models for the development of this basin appear in the literature (Lara, 1993). Rosencrantz (1990) concluded that the oldest crust in the eastern Yucatán Basin is at least Late Cretaceous and could be Aptian-Albian or even Late Jurassic in age. Lewis (1990) observed that similar continental deposits indicate proximity of Cuba (Guaniguanico, western Cuba) to Guatamala and Yucatán in the early Jurassic but by Oxfordian time little continental material was arriving in the Cuban area (spreading was underway, producing separation of these areas). The Yucatán Basin probably formed during Jurassic separation of North and South America (James, 2002b, 2003, 2005b), along with the Gulf of Mexico and the Cayman Trough and may have expanded in the late Cretaceous-early Paleogene.

A11.8. *Eocene onset of Cayman Trough pull-apart allowed for the well-known subsequent migration of Caribbean Plate to its present position relative to the Americas, and the late? Oligocene onset of separation of Hispaniolan arc assemblages from Oriente, Cuba.*

As discussed in section A2, Cayman Trough opening is not calibrated to the Eocene. Only heat-flow and depth-to-basement models indicate this age. To state that something is "well-known" when it is only modelled is misleading. More importantly, most of the sinistral offset of the Trough probably developed much earlier (James, 2002b, 2003). Oligocene separation of Hispaniola and Cuba is part of the ongoing eastward movement of the Caribbean Plate relative to the Americas. Oligocene to recent fill of pull-apart basins along both the north and southern boundaries of the Caribbean Plate record its age (Lewis and Draper, 1990; section B13).

A12. *Pacific models imply strong Cretaceous interaction of the Caribbean Plate with the northern Andes. Intra-American models do not explain dramatic contrasts between the northern Andes (Ecuador, Colombia) and central Andes (central Peru to Bolivia) in Cretaceous orogenesis and magmatism. (Kennan and Pindell, 2003).*

The inter-American Caribbean model does not have to account for the geology of western South America.

Variations in Andean geology result from differences in rate and angle of Pacific/South America convergence, age and density of subducting crust and the influence of long-lived continental structures (Gansser, 1973; Jordan et al., 1983; Corvalan, 1989). A pronounced change in Andean strike occurs at the 5°S Huancabamba Deflection (an east-west transverse structure associated with the

Carnegie Ridge-Galápagos Islands in the west and the Amazon River trend in the east). To the north, oblique convergence between the Pacific and South America is partitioned into dextral strike-slip and Benioff slip. It resulted in accretion of flysch, chert and ophiolites in the late Jurassic or early Cretaceous and in the late Cretaceous – early Paleocene (McCourt et al., 1984; Dalziel and Forsythe, 1985; Aspden and McCourt, 1986; Jaillard et al., 1990; Aspden and Litherland, 1992; Litherland and Aspden, 1992). South of the deflection, in the Central Andes, orthogonal convergence results in the classic Andean margin (trench, magmatic arc, great uplift, foreland fold and thrust belt) without terrane accretion (Jordan and Gardeweg, 1989). South of the Bariloche Transversal (40°S, where the Chile Rise impacts South America) in southern Chile/Argentina, oblique convergence again resulted in ophiolite accretion in the Southern Andes (Corvalan, 1989). This mirrors the Northern Andes. Clearly, the Caribbean Plate had nothing to do with this area. It had nothing to do with developments in the northern Andes either.

ARGUMENTS AGAINST THE PACIFIC MODEL

B1. *Geometric impossibility of entry of the Mesozoic island arc into the Caribbean area.*

According to the Pacific model, the Greater, the Lesser Antilles and/or Aves Ridge and the Netherlands-Venezuelan Antilles are the remains of an approximately northwest or northeast trending, linear Mesozoic island-arc that entered the Caribbean (undergoing a subduction polarity reversal in the process, Fig. 2A; Pindell, 1993, 2001; Rogers et al., submitted*c*) in the late Cretaceous. Summation of the present day components of this arc (islands and submarine extensions; intervening pull-apart removed) amounts to around 3000 km. This is about the distance from the northwest coast of Colombia to the Texas coast in the Gulf of Mexico. The Netherlands-Venezuelan Antilles used to be the western continuation of the Villa de Cura-Margarita-Testigos-Lesser Antilles (see section B13), making the original total length around 4000 km. The Colombia-Yucatán gap through which the arc is supposed to have passed measures about 1400 km.

Once in the Caribbean area the northern and southern arms of the arc are supposed to have rotated 90°, anticlockwise and clockwise (Fig. 2A), respectively, to become the E-W trending Greater and Netherlands-Venezuelan Antilles, leaving only 850 km of north-trending arc in the Lesser Antilles. How this happened is never is explained.

Such rotation is geometrically impossible. The rotating arc sections would either have to be decoupled from and slipped back over a narrowing Caribbean Plate or the plate would have show intense internal folding. The former would require plate-ward facing subduction below the rotating arc (Pacific model illustrations of this episode show the arc facing outwards; Pindell et al., 1988; Ross and Scotese, 1988). In addition the fate of the subducted crust as it continued to move east is difficult to imagine. The latter is not evident; on the contrary, the plate is highly extended (Diebold et al., 1999; Driscoll and Diebold, 1999).

B2. *Geometric impossibility of entry of the Caribbean Plate between the Americas.*

Diagrams illustrating the entry of the Caribbean Plate between the Americas show northeast movement in the late Cretaceous- Palaeocene, followed by eastward movement (Pindell and Dewey, 1982) and strong northwest-southeast convergence with South America since the Eocene (Fig. 2A; Pindell and Barrett, 1990; Pindell, 1993). Pindell et al. (1998, fig. 11) showed the pole of Caribbean rotation moving south-southeast from 0.5°N, 78.5°W (Middle Eocene), to 20°S, 76°W (Late Oligocene) to 68°S, 54° E (Late Middle Miocene). Figures 11 and 12 of the same paper show E45°S convergence (450 km north-south) between the Caribbean and northeastern South America between 59 and 10 Ma, followed by a further, 57° change of relative plate migration direction to azimuth E12°N.

The postulated migrations imply a 90° change in direction of plate movement (Fig. 2A). In detail, diagrams show the 3 000 km long plate progressively taking up the change of direction upon entry into the inter-American location. The trailing edge of the plate retains its northwest trend and northeast migration while the leading edge is moving east. This is not possible without major internal plate deformation (northwest trending extension followed by compression?). I show later (see section B14) that the plate is characterized by extension along northeast trending faults.

B3. *Geometric impossibility of Chortis rotation.*

Diagrams illustrating the entry of the Caribbean Plate between the Americas show the Chortis Block migrating southeastwards at the same time as the trailing edge of the plate is migrating northeastwards (Pindell, 1993; Rogers et al., submitted*c*). This is not possible.

Moreover, a Jurassic rift crosses Honduras (see section B14) (Mills et al., 1967; Gordon, 1993; Rogers et al., submitted*a*). It parallels regional Jurassic extensional strain between North and South America (James, 2002b, 2003a, 2005b) and argues against rotation of the block. When the faulted eastern margin of the Maya Block is lined up with the San Andreas Lineament east of Chortis, Jurassic grabens on the blocks also line up, indicating around 900 km of sinistral offset (early Cayman offset, section A2). Regional considerations (James, 2002b, 2003) show that this resulted from westward motion of North America (Maya included), not eastward movement of Chortis. Chortis has always been at the western end of the Caribbean region.

B4. *Continental margin sequences of Cuba show that the island was in the Caribbean during the Jurassic and end Cretaceous units show proximity of volcanic arc and continental margin.*

Cobiella-Reguera (2000) emphasized the similarity of stratigraphy and magmatism in the upper part of Jurassic continental margin sequences on Cuba (the Guaniguanico mountains, the Maisí area of eastern Cuba and the Southern Metamorphic Belt -Isle of Youth and Escambray- in the south, and the evaporite-bearing section of north-central Cuba). The two sections show a simple Jurassic paleogeography deepening southwards from the Bahamian shelf. The latest Maastrichtian Via Blanca Formation contains fragments of arc igneous rocks (Takayama et al., 2000). Cretaceous megaturbidites (Cacarajícara, Amaro and Peñalver Fms.) indicate that the volcanic arc (terrane) was close to the North American continental margin at the end of the Cretaceous (Cobiella-Reguera, 2000), long before the postulated arrival of Pacific crust.

B5. *Coeval continental margin sequences and ophiolites of western Cuba suggest original proximity of these rocks.*

Radiolarian cherts of Cuba occur in both deep-water, continental-margin rocks and in ophiolites (Aiello et al., 2004). In the continental margin sequence of Rosario (Guaniguanico Terrane, western Cuba), the radiolarian cherts of the Santa Teresa Fm overlie Lower Cretaceous basinal limestones (Artemisa Fm) or sandstones (Polier Fm). Radiolaria indicate deposition between the Aptian and the Cenomanian (Pszczolkowski, 1999). The ophiolite nappe of western Cuba also contains radiolarian cherts. Radiolarian ages range between the Albian and the Cenomanian (Iturralde-Vinent, 1994, 1998). The ophiolite cherts are almost coeval with the continental margin cherts of the Santa Teresa Formation. The sections clearly are related.

B6. *Albian shallow-water limestones above an unconformity characterize both Caribbean and neighbouring continental areas (Fig. 3), indicating a shared history.*

Mattson (1984) noted a regional Albian unconformity in the Caribbean. It is recorded in Cuba, Hispaniola and Puerto Rico as a time of metamorphism, deformation and intrusion. A coeval break exists along the southern plate boundary in the Caribbean Mountains, Santa Marta Massif and on the Colombia-Caribbean coast. Lebron and Perfit (1993) noted that in central Puerto Rico and eastern Hispaniola lower, Primitive Island Arc rocks are separated from upper calc-alkaline rocks by an unconformity. The unconformity is overlain by shallow-water, Aptian-Albian limestone indicating that uplift had occurred.

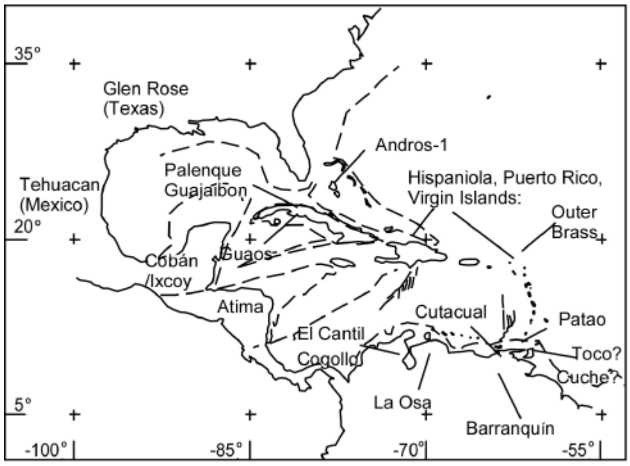


FIGURE 3 | **Regional distribution of Albian shallow-water limestones in the Caribbean region. They occur above a regional unconformity and indicate a shared geologic history between continental and island-arc elements and indicate that the Caribbean Plate was inter-American at this time.**

Donnelly (1989) summarized that early Cretaceous section around the Caribbean consists mostly of thin units of diverse lithologies, dominated by carbonates. The lower limit in most areas is Albian, characterized by thick limestones. Donnelly (1989) discussed Albian-Campanian platform limestones on the Maya Block (Cobán/Ixcoy, Campur Formations).

Tardy et al. (1994) described the rocks of the Guerrero suspect terrane of western Mexico and discussed these in relation to Caribbean rocks. Whatever the basement, oceanic or continental, on which the arc rocks were built, they are capped by ubiquitous Albian limestones with reef faunas similar to those on the North American craton. Meyerhoff and Hatten (1974) reported that the Andros-1 well (Bahamas) bottomed in Albian backreef carbonates. Shallow water Albian limestones occur in Cuba both in the North American passive margin section of north Cuba (Palenque and Guajaibon Fms.) and in the volcanic arc terrane in the south (Guaos Fm.) (Iturralde-Vinent 1998). Albian limestones occur across northern South America: in Venezuela the Cogollo Group in the west and the El Cantil Fm in the east (James, 2000). Lewis (2002) discussed Albian unconformities in the Dominican Republic (overlain by Hatillo Fm. limestone), Cuba (overlain by Provincial limestone) and Puerto Rico (overlain by Barrancas and Río Matón limestones).

The unconformity/shallow-water limestone couplet formed at a time when transgression was beginning (Villamil et al., 1999). It records tectonic uplift and erosion followed by carbonate formation. It affected the Caribbean and adjacent continental areas and shows a shared history.

B7. *Paleocene – Middle Eocene flysch/wildflysch deposits are regionally developed in the Caribbean area (Figs. 4 and 5).*

Flysch and wildflysch deposits occur in south Central America (Rivas, Las Palmas and Brito Fms); between the Maya and Chortis blocks (Sepur Fm) in the Guaniguanico Cordillera (Manacas Fm) and in north central Cuba (Vegas and Vega Alta Fms (Iturralde-Vinent, 1998), on Jamaica (Richmond Fm, Wagwater) and Puerto Rico (San German Fm), in northwest Colombia (Luruaco Fm; Maco Conglomerate, Aleman, 1997, pers. comm.), in western and central Venezuela (Matatere, Río Guache, Guárico, Paracotos Fms, in Trinidad (Pointe-a-Pierre, Chaudiere and Lizard Springs Fms), offshore Venezuela on Bonaire (Rincón Fm) and Margarita (Punta Mosquito/Carnero Fms) and in Golfo Triste wells, on Grenada (Tufton Hall Fm) and on Barbados (Scotland Group; James, 1997, 2002a, 2005a).

They also occur in Peru (Talara Formation; Dorreen, 1951), Ecuador (Clay Pebble Bed, Marchant, 1956; San Eduardo Formation, Daly, 1989), southeast Mexico (Ocozocuautla Formation, Dengo, 1968), in the Parras and Chicontepec basins of north-northeast Mexico (Tardy et al., 1974).

The circum-Caribbean deposits include Cretaceous and older continental rocks, along with volcanic-arc and ophiolitic material derived from the Caribbean Plate. They show regional and coeval interaction between the Caribbean Plate and adjacent areas of North and South America (James, 2002a, 2003, 2005a). Wildflysch deposits contain blocks many kilometres in dimension and are associated with very large nappes that sourced the material (for review, see James, 2002, 2005a). They record a violent event that is clearly distinct from the later (Oligocene – Recent), diachronous transpression along the northern and southern Caribbean Plate boundaries. Pacific models persistently fail to distinguish these two separate histories (A5).

B8. *Lithologic continuity between autochthonous deep Caribbean and Venezuelan allochthonous units show that the Caribbean Plate was in place during the Paleocene-Middle Eocene event.*

At Site 146/149 aphanitic limestones and claystones of Campanian age are followed by siliceous limestones and black cherts with Maastrichtian claystones followed and then Paleocene laminated claystones interbedded with siliceous limestones. The same sequence occurs in the Río Chávez Formation, a klippe, and in the Mucaria Formation of the Piemontine Nappe in northern Venezuela (Vivas and Macsotay, 2002). The abyssal sediments remained in their original position, while the Mucaria and Río Chávez formations were imbricated and thrust above the South American passive margin. This occurred during the Paleocene-Middle Eocene event noted in the preceding paragraph.

B9. *Middle Eocene limestones occur around the Caribbean (Fig. 6), recording coeval uplift.*

Following the flysch/wildflysch deposits (B7) Middle Eocene, shallow-water limestones are widespread in the Caribbean area. In Central America they are known from Costa Rica at five localities (Bolz and Calvo, 2002): Parritilla (southern Valle Central), Damas (Parrita), Punta Catedral (Quepos promontory), Penón de Arío (Nicoya Peninsula), and Quebrada Piedra Azul (Burica Peninsula). In Panamá they occur in the Chiriquí (David Limestone) basins (Escalante, 1990). Escalante (1990) described widespread limestone at the top of the turbiditic Brito Fm in the Nicoya Complex. It traces through the Nicoya Peninsula (Junquillal and Punta Cuevas Limestones), the Central Pacific provinces (Damas Limestone) and the Térraba Basin (El Cajón and Fila de Cal Limestones) to the Chiriquí (David Lime-

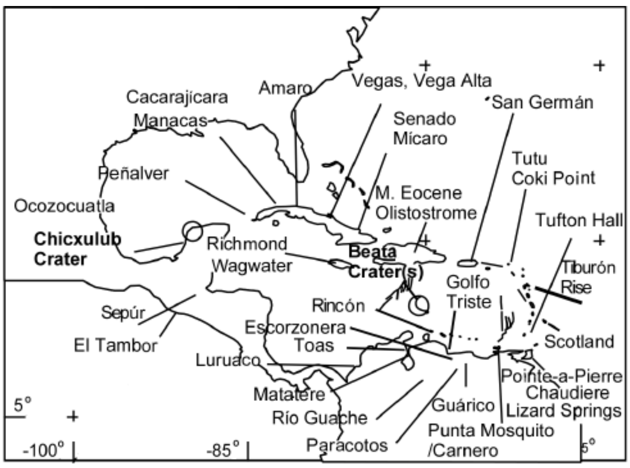


FIGURE 4 | **Regional distribution of Palaeocene-Middle Eocene flysch/wildflysch deposits. They record energetic (even violent) regional interaction of the Caribbean Plate with neighbouring elements. The future Aruba-Blanquilla island chain was emplaced onto northern S America along with the Villa de Cura nappe (see Fig. 5A). Quartz sands of the Scotland Group (Barbados) were abruptly deposited, on the Atlantic Plate, more than 300 km offshore northern South America. Their progress was halted by the Tiburón Rise. The Group contains clasts derived from northeast South America. The latter two points show that these sands accumulated in their present location, not further west as posited by Pacific models. The Peñalver and Amaro Formations of Cuba are thought to be K/T impact megabreccias.**

stone) and Tuira-Chucunaque (Corcona Limestone) basins of Panamá. Middle Eocene reef limestone (Río Tonosí Formation) overlies upper Cretaceous basalt in southwest Panamá (Kolarsky et al., 1995).

In the Greater Antilles Middle Eocene limestones occur on Jamaica (White Limestone, Robinson, 1967; James and Mitchell, 2002), Cuba (Boiteau et al., 1972; Iturralde-Vinent, 1994, 1998), Haiti (Pubellier et al., 2000), St. Barts (St. Bartholomew Fm, Christman, 1953; Tomblin, 1975), Tortola and Virgin Gorda (Tortola and Necker Formations include several limestones, Lewis and Draper, 1990).

In the Lesser Antilles, the northeastern branch of low-lying Lesser Antillean islands is called the Limestone Caribees because of extensive middle Eocene-Pleistocene calcareous cover (Maury et al., 1990). Tomblin (1970) noted the presence of siliceous limestones with Middle – Early Eocene foraminifera on Mayreau and of upper Eocene, reefal limestones on Carriacou.

Hunter (1995) described a line of late Middle Eocene algal/foraminiferal limestones from the Central American Isthmus, Colombia (Cienega de Oro or Tolu) to Venezuela (Tinajitas), capping highly deformed flysch and other deep-water sediments. They are best developed on the frontal thrusts. They occur on Aruba (Helmers and Beets, 1977), Curaçao (Beets, 1977) and in the Cariaco Basin (exploration drilling).

Middle Eocene limestone also occurs within the Caribbean Plate on the Aves Ridge (Fox et al., 1971; Nagle, 1972; Bouysse et al., 1990), Saba Bank (Pinet et al., 1985), the Beata Ridge (Fox et al., 1971) and the Nicaragua Rise (Alivia et al., 1984; Rogers et al., submitted*a*).

The limestones record the culmination of Paleocene-Middle Eocene convergence when uplifts reached the photic zone (Kugler, 1953; Hunter, 1995; Escalante, 1990; Sageman and Speed, 2003). Such a chronologically well-defined event throughout the Caribbean area shows regional interaction with adjacent plates of North and South America.

Several authors have referred to this synchronous tectonic event in northern South America. Bell (1972) recognized a Middle Eocene orogeny, involving crustal shortening, overthrusting, uplift and strike-slip faulting in Venezuela and Trinidad. Guedez (1985) noted late Middle Eocene uplift of the Monay-Carora area. Chigne and Hernández (1990) stated that Andean uplift in Venezuela began in the Middle Eocene. Audemard (1991, 1993) reported seismic evidence of uplift of the Perijá in the Eocene. Maresch et al. (1993) and Kluge et al. (1995) reported (K/Ar) radiometric data indicating uplift of Margarita Island at 50 – 55 Ma. Apatite fission track data indicate Middle Eocene deformation in the Serranía del Interior of eastern Venezuela (Aleman, 2001, pers. comm.).

B10. *A regional Late Eocene hiatus characterizes many circum-Caribbean sections.*

Bandy and Casey (1973) noted that a hiatus covers most of the Late Eocene-Early Oligocene interval in eastern Panamá, with deep-water sedimentation occurring again in the Middle Oligocene. Barbosa et al. (1997) described how broad continental areas formed in the arc in the Middle-Late Eocene in Costa Rica. Calais and Mercier de Lepinay (1995) noted tectonic unconformities on land and at sea in the Late Eocene of Cuba and Hispaniola. Ave Lallement and Gordon (1999) reported isotopic data indicating exhumation of metamorphic rocks on Roatan Island, Honduras, in the Late Eocene – Early

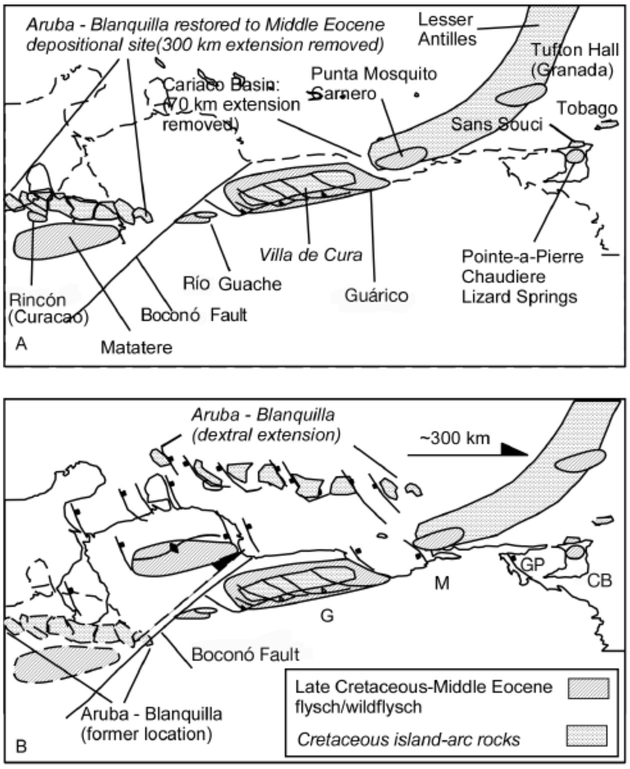


FIGURE 5 | **A) Detail of the Middle Eocene flysch/wildflysch deposits emplaced onto northern South America in the Middle Eocene. The Aruba-Blanquilla complex is shown as the western extension of the Villa de Cura-Margarita-Lesser Antilles volcanic-arc. B) shows the same area after northeast translation of the Bolivar-Bonaire blocks, driven by the converging Pacific Nazca Plate. The Bonaire Block has transgressed the dextral Caribbean-South America plate boundary. It became internally deformed by pull-apart extension since the Oligocene. Summation of this extension indicates 300 km of dextral plate movement. G: Guárico Basin; M: Maturín Basin; GP: Gulf of Paria; CB: Columbus Basin are foreland basins that progressively developed from west to east, from the Oligocene to Recent.**

Oligocene. Hunter (1974) noted that in northern South America only the Cerro Mision Formation of Falcón and the San Fernando Formation of Trinidad yield conclusive evidence of Late Eocene age. As with sections B 7 and 9, regional history indicates that the Caribbean Plate was in place at this time.

B11. *The Scotland Group of Barbados; not a far-traveled deposit.*

The Barbados accretionary prism includes the Middle Eocene Scotland Group (Fig. 4; James, 2002b, 2003, 2005a). This almost pure quartzite, containing blue quartz, correlates with the Lower – Middle Eocene Mirador and Misoa Fms of Colombia and Venezuela.

Early Pacific Caribbean models showed the migrating plate picking up the Scotland sands from a site north of the Maracaibo Basin (Dickey, 1980; Beck et al, 1990; Pindell, 1993). Pindell et al. (1998) changed this model, showing the sands accumulating in the Lesser Antilles trench when it lay north of the Araya Peninsula during the Oligocene. However, the sands are interbedded with hemipelagic units containing Middle and Late Eocene radiolaria (Cuevas and Maurasse, 1995). DSDP Site 672, on the Atlantic Plate to the east, encountered correlative Middle and Upper Eocene sands (Mascle et al., 1986). Deposition occurred in the Middle Eocene, at the same time as regional flysch/wildflysch deposition (B7).

Peter and Westbrook, (1976) and Westbrook et al. (1984) noted that basement ridges in the Atlantic cause ponding of Orinoco fan sediments. The Barbados Ridge dies out at the Tiburón Rise (Dolan et al., 1990). Dolan et al. (1990) reported the presence of Middle Eocene-Oligocene (Middle Eocene peak) "coarse" (very fine silt to medium and-rare-coarse sand) sediment on top of the Tiburón Rise (ODP Leg 110). Mineralogy suggests a South American source. Such sediments are absent from Site 543, just 19 km to the north, confirming that the material arrived from the south and that sediment flow was blocked to north by the Rise.

FIGURE 6 | **Regional distribution of Middle Eocene shallow-water limestones in the Caribbean region. They indicate regional geological uplift at the culmination of Paleocene-Middle Eocene convergence. Like the deposits of Fig. 4, they indicate an inter-American location of the Caribbean Plate at the time of deposition.**

Exotic rocks on Barbados indicate that the Scotland Group came from the eastern part of northern South. America. Kugler (1953) and Tomblin (1970) identified rocks like the Naparima Hill (the unit occurs in Trinidad and areas to the east), while Meyerhoff and Meyerhoff (1971) mentioned the presence of large exotic blocks of Albian limestone bearing faunas identical to those of Trinidad and eastern Venezuela (Vaughan and Wells, 1945; Douglass, 1961). Senn (1944) described the sands as sharp and angular, angular to edge-rounded, rarely well rounded. They clearly arrived at such a distant location via very rapid transport (see Section B7).

The relationship between the Scotland sands and the Tiburón Rise, on the Atlantic Plate, and the presence of rocks derived from northeast South America show that they accumulated in place.

B12. *Seismic data show that the Lesser Antilles is a long-lived arc.*

Middle Eocene sands encountered on the Tiburón Rise at DSDP 672, on top of the Tiburón Rise correlate with reflections on a proprietary seismic line over the eastern slope of the Lesser Antilles. Distinctive Middle Eocene reflections tie back to middle Eocene section in the well Caracolito-1x on the Venezuelan continental margin. The Middle Eocene-Jurassic ocean basement section pinches out against the flank of the Lesser Antilles and shows that the arc is long-lived.

B13. *Dextral displacement of only 300 km has occurred between the Caribbean and South America since the Oligocene (Figs. 5A and 5B).*

Edgar et al. (1971) reported that the Netherlands West Indies are underlain by a 5.4 km/s layer and surrounded by thick, high-velocity sediments. The islands do not form a continuous ridge but are individual, aligned highs of 5.4 km/s material separated by thick sedimentary fill. The islands' structural periodicity is identical to that of the Internal Ranges of Venezuela and records their common tectonic heritage (James, 2000).

Beets et al. (1984) and Donnelly et al. (1990) noted the similarity in chemistry of the Bonaire and Curaçao volcanics and the Villa de Cura Group. Igneous rocks of the Netherlands Antilles consist of 3-5 km thick, Middle Albian to Coniacian arc lavas and a Santonian tonalite-gabbro batholith. The Villa de Cura group is a 4-5 km thick sequence of "Caribbean Plateau basalts", island-arc volcanic and volcaniclastic rocks. Both sets of rocks are associated with flysch/wildflysch (B7). Figure 5A shows that the island chain originally was the westward continuation of the Villa de Cura nappe, emplaced along northern Venezuela during Paleocene-Middle Eocene convergence (James, 2003, 2005a). The eastern continuation is the Tobago Terrane (Snoke, 1990), which links the Villa de Cura nappe, via Margarita and Los Testigos, with the Lesser Antilles.

Following the regional Paleocene-Middle Eocene convergence event northwestern South America (the Bolivar Block, James, 2000, 2005b) moved northeast along faults that parallel Colombia's Eastern Cordillera and Venezuela's Mérida Andes. The northern part of the Block (the Maracaibo-Bonaire Block, James, 2000) delaminated and crossed the Caribbean-South American plate boundary (literature commonly and incorrectly refers to this overthrusting as subduction of the Caribbean below northwest South America, but the Caribbean Plate is moving east, not south). From the Oligocene onwards, E-W dextral relative motion characterized the plate boundary. As a result, major pull-apart basins bounded by northwest-southeast oblique slip, tensional faults formed in the Maracaibo-Bonaire Block. They characterize the Falcón Basin, (now inverted), the Gulf of Venezuela, the Urumaco Trough, La Vela Bay, Golfo Triste and the depressions that separate the Netherlands and Venezuela Antilles. Lake Maracaibo is a young pull-apart in the same system.

Drilling adjacent to Aruba penetrated an Oligocene – Recent record of rapid subsidence of weathered Cretaceous basement (Curet, 1992). The Cayosal-1x well in the Golfo Triste encountered Oligocene coarse-grained siliciclastic rocks above Eocene shelf deposits. The Falcón Basin suffered Oligocene extension prior to Miocene inversion. Moderate to very deep marine shales of the Pecaya Formation lie unconformably on lightly metamorphosed Eocene. Extensional alkaline basaltic intrusion in the Falcón Basin occurred in the Oligocene – Miocene (Muessig, 1978). La Vela Bay is an offshore extension of the Falcón Basin. The Urumaco Trough subsided in the Oligocene. Oligocene Carbonera sandstones overlie Middle Eocene section in the Maracaibo Basin. The data show that pull-apart extension began in the Oligocene (35-30 my ago).

Removal of extension between the Aruba-Blanquilla islands restores Blanquilla approximately 300 km westward to the present location of Las Aves. Here, it lay along the strike of the Boconó Fault, the pathway of its northeast translation. The reconstruction shows that from the Oligocene to Present, only 300 km or so of dextral displacement has occurred between the Caribbean and northern South America (average rate around 1 cm/y) (Stainforth, 1969, estimated 300 km offset along the El Pilar Fault).

B14. *Middle America shows a regional pattern of northeast trending extensional faults formed during regional, Jurassic-Cretaceous sinistral offset between North and South America. They show that the Caribbean Plate was in place when they developed.*

Figure 7 is a compilation of northeast trending extensional faults (sources: IFP Caribbean Geological Map, Exxon map of the World, many other references in bibliography) between North and South America. The faults occur in Southern North America, in the northwestern Gulf of Mexico, in the Yucatán Basin, along the southeast margin of the Nicaragua Rise, on the Maya and Chortis Blocks, in the Venezuelan Basin (Case and Holcombe, 1980; Diebold et al., 1999) and along northern South America. They show a regional structural coherence indicating a shared tectonic history between the Caribbean and its neighbours. Note, here that there is no indication of a regional Caribbean radial pattern that would be expected from doming (Glen and Ponce, 2002) above a mantle plume (championed by Kerr, 1995 and Kerr et al., 1996).

Extension in the Venezuelan Basin occurred prior to formation of smooth Horizon B'' (i.e., pre-Senonian extension) (Diebold et al., 1999). Holcombe et al. (1990)

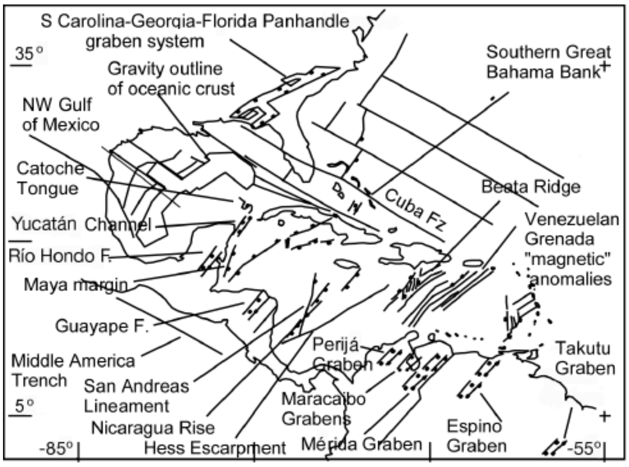


FIGURE 7 | **Northeast trending extensional strain in Middle America includes Triassic-Jurassic rifts in the southern United States and in northern S America, extended continental crust in the Gulf of Mexico, eastern offshore N America, eastern Yucatán, the Nicaragua Rise and western Venezuelan Basin/Beata Ridge. Parallelism of Jurassic rifts on Yucatán and in Honduras with the regional Middle America strain show that the Maya and Chortis Blocks have not rotated.**

noted the undisturbed nature of upper Cretaceous-Recent sediments next to the Hess Escarpment, indicating that the latter is at least as old as late Cretaceous. Driscoll and Diebold (1997) remarked that the character of reflections in the Venezuelan crust resembles wedges elsewhere in the world that are associated with the cessation of continental rifting and the onset of seafloor spreading (Rosendahl et al., 1992). The extensional faults in the southeast of North America and along northern South America formed during Triassic-Jurassic rifting.

The regional extension relates to regional sinistral stress (strain ellipses of Fig. 2B) resulting from N60°W offset of North America relative to South America (oceanic fractures along eastern seaboard of North America, trend of the Central America Trench; Fig. 7; James, 2002b, 2005b). It indicates an inter-American origin for the Caribbean Plate.

B15. *The Chortis block has always been at the western end of the Caribbean area – there was no space for a Caribbean sized plate to enter from the Pacific.*

Major (50° or more) anticlockwise rotation of the Chortis Block (Dengo, 1985; Ross and Scotese, 1988) postulated by Pacific models is required if space were to have existed for entry of the Caribbean Plate.

Marked thickness changes of Jurassic strata (Gordon, 1993, pers. com., 2004) occur over the N35°E trending Guayape fault of Honduras. Rogers et al. (submitted*a*) show its Jurassic origins and Rogers (pers. com., 2004) reflects on its (Jurassic) rift origins. The N35°E trending Rio Hondo Fault that crosses the Maya Block separates thin or absent Jurassic to the northwest from thicker Jurassic to the southeast (López-Ramos, 1975).

The Guayape and Río Hondo faults parallel Jurassic rifts in southeast North America and in northern South America and N35°E trending Triassic-Jurassic megashears in Mexico (Rueda-Gaxiola, 2003; Fig. 7). Neither Maya nor Chortis has rotated.

B16. *Palaeomagnetic data from western Cuba and Central America negate major differential movement of the Caribbean relative to South America.*

Alva-Valdivia et al. (2000, 2003) studied palaeomagnetism in rocks of the Guaniguanico Terrane, western

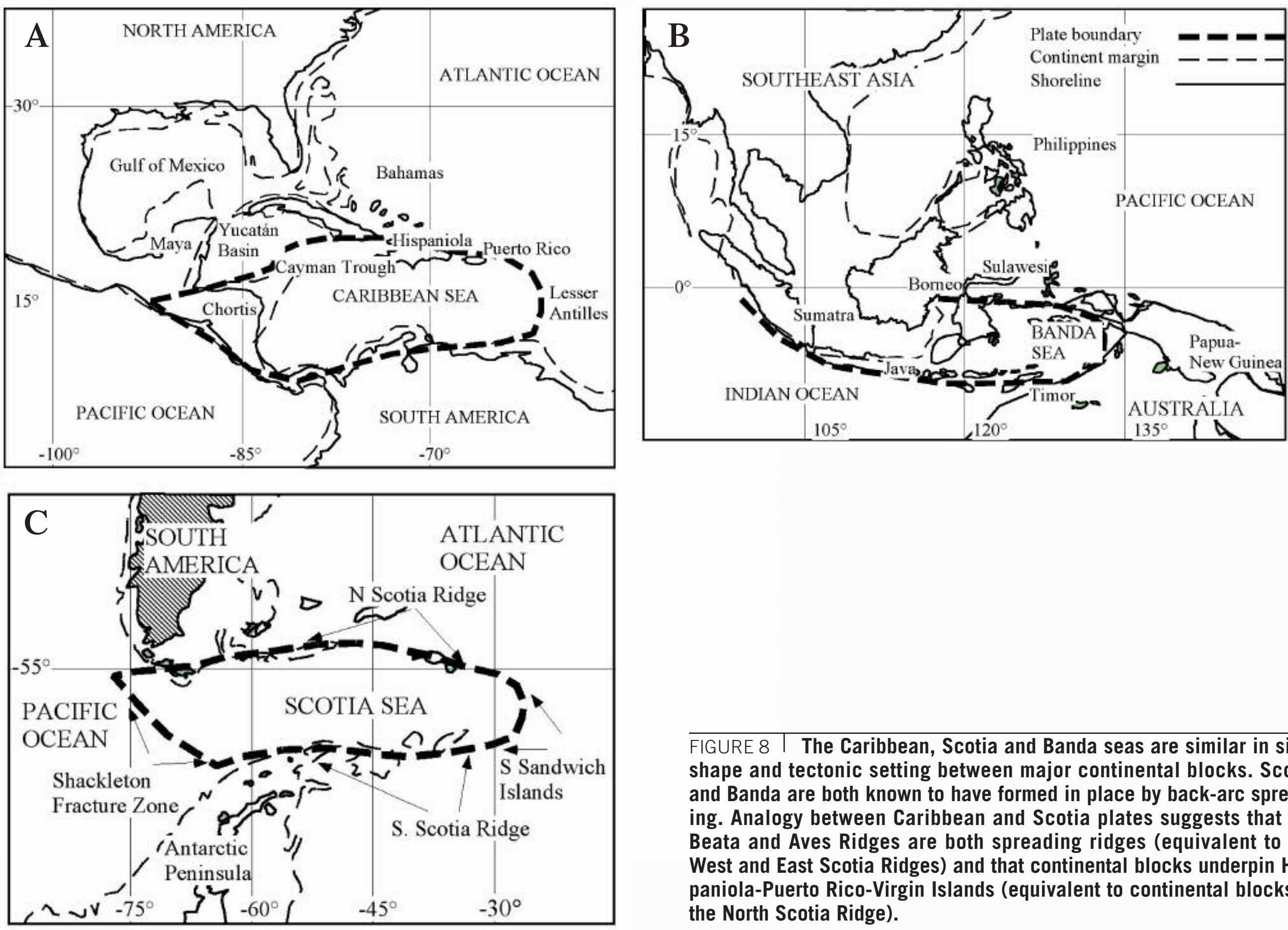


FIGURE 8 **The Caribbean, Scotia and Banda seas are similar in size, shape and tectonic setting between major continental blocks. Scotia and Banda are both known to have formed in place by back-arc spreading. Analogy between Caribbean and Scotia plates suggests that the Beata and Aves Ridges are both spreading ridges (equivalent to the West and East Scotia Ridges) and that continental blocks underpin Hispaniola-Puerto Rico-Virgin Islands (equivalent to continental blocks of the North Scotia Ridge).**

Cuba, and found a palaeopole that did not significantly differ from North American Jurassic-Cretaceous poles. It suggests that no major latitudinal displacements have occurred since the Jurassic.

Frisch et al. (1992) reported that palaeomagnetic data from the ophiolite complexes of the Pacific coast of Costa Rica and western Panamá formed in an equatorial position and moved approximately 10° northward since. This conforms to the movement of South America. Di Marco et al. (1995) determined that the Chorotega Block, which forms most of southern Central America and was the western edge of the Caribbean Plate during the Late Cretaceous-Paleocene, originated close to its present latitude and has not rotated relative to South America since the late Cretaceous. Southern Central America, like Chortis (B 15), has always been at the western end of the Caribbean area

B17. *Comparison of the Caribbean, Scotia and Banda areas indicate similar origins.*

The Caribbean, Scotia and Banda plates are strikingly similar in form and dimension (Fig. 8), around 3 000 km long E-W and 700-800 km wide north-south. They share similar, extensional tectonic settings between large continental masses. The similarity suggests that the three plates had a common origin. The Scotia and Banda plates are both shown by magnetic anomalies and drilling to have formed by spreading in place (Hamilton, 1979; Honthaas et al., 1998; Cunningham et al., 1998; Barker, 2001). The analogy between the Caribbean and Scotia plates has important implications for understanding of the Caribbean Beata and Aves ridges and for the distribution of continental fragments in the area (James, 2002b, 2003, 2005b).

B18. *An inter-American origin of the Caribbean Plate offers a simple account of regional geology.*

The inter-American origin of the Caribbean Plate accommodates regional geology in simple terms (James, 2002b, 2003, 2005b). It shows a shared history of Jurassic rifting, Jurassic-Late Cretaceous sinistral offset and extension, Paleogene plate-margin shortening and Oligocene-Recent strike-slip with its continental and oceanic neighbours. It requires no changes of subduction polarity, no hot spot or plume, no major rotations of island-arcs or continental blocks, no major plate migration and no major changes in migration direction. It contrasts sharply (Occam's Razor-sharp) with the geometrically improbable and needlessly complex Pacific models.

CONCLUSIONS

Arguments proposed to support a Pacific origin for the Caribbean Plate do not hold up to close scrutiny. Entry of a Pacific-derived plate would have involved unlikely, geometrically complex and highly diachronous events. These would have included changes in direction of subduction, changes in direction of plate migration, major (1000s of km) plate migration, major rotation of large parts of an island arc, major rotations of the Maya and Chortis blocks and diachronous development of flysch/wildflysch deposits as the entering plate interacted with neighbouring elements. The internal structural conformity of the Caribbean Plate and of the Maya and Chortis blocks with regional geology of Middle America shows that no major rotations have occurred. Coeval, regionally developed deposits of Albian shallow water limestones, Paleocene-Middle Eocene flysch/wildflysch deposits, Middle Eocene limestones, and a regional Late Eocene hiatus developed in an inter-American location, not a changing Pacific-Caribbean location. Neogene displacement of the Caribbean relative to North and South America amounts to no more than 300 km. The Pacific model is complex and improbable and is not supported by geological data. The inter-American model is simple and feasible; it accounts for geological data.

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REFERENCES

Ager, D.V., 1986. Migrating fossils, moving plates and an expanding Earth. Modern Geology, 10, 377-390.

Aiello, I.W., Chiari, M., Principi, G., Garcia, D., 2004. Stratigraphy of Cretaceous radiolarian cherts of Cuba (absent). 32nd IGC - Florence, IGCP Project 433 Caribbean Plate Tectonics, abstracts. Web download or Abstract CD.

Alivia, F., Tappmeyer, D., Aves, H., Gillet, M., Klenk, C., 1984. Recent studies of basins are encouraging for future exploration of Honduras. Oil and Gas Journal, Sept. 17, 139-149.

Alva-Valdivia, L.M., Coguitchaishvili, A., Cobiella-Reguera, J., Urrutia-Fucuguachi, J., Fundora, M., Grajales-Nishimura, J.M., 2000. Paleomagnetism of the Guaniguanico Terrane, Western Cuba: a Pilot Study. Tercera Conferencia Internacional Sobre La Geologia de Cuba, El Golfo de Mexico y el Caribe Noroccidental, Abstracts, 1.

Alva-Valdivia, L.M., Coguitchaishvili, A., Cobiella-Reguera, J., Urrutia-Fucuguachi, J., Fundora, M., Grajales-Nishimura, J.M., Rosalese, C., 2002. Paleomagnetism of the

Guaniguanico Cordillera, western Cuba: a pilot study. Available online
Anderson, T.H., Schmidt, V.A., 1983. The evolution of Middle America and the Gulf of Mexico-Caribbean Sea region during Mesozoic time. Geological Society of America Bulletin, 94, 941-966.
Antoine, J.W., Martin, R.G., Pyle, T.G., Bryant, W.R., 1974. Continental Margins of the Gulf of Mexico. In: Burk, C.A., Drake, C.L. (eds.). The Geology of Continental Margins. Springer Verlag, 683-309.
Aspden, J.A., McCourt, W.J., 1986. Mesozoic oceanic terrane in the central Andes of Colombia. Geology, 14, 415-418.
Aspden, J.A., Litherland, M., 1992. The geology and Mesozoic collisional history of the Cordillera Real, Ecuador. Tectonophysics, 205, 187-204.
Audemard, F.M., 1991. Tectonics of Western Venezuela. Doctoral Thesis. Rice University, Houston, Texas, 245 pp.
Audemard, F.M., 1993. Triangle zones of the Maracaibo Basin, American Association of Petroleum Geologists/Sociedad Venezolana de Geología, International Congress and Exhibition, Caracas, Abstracts, 35 pp.
Ave Lallement, H.G., Gordon, M.B., 1999. Deformation history of Roatan Island: implications for the origin of the Tela Basin (Honduras). In: Mann, P. (ed.). Caribbean Sedimentary Basins, Sedimentary Basins of the World, Elsevier, 197-218.
Azema, J., Sornay, J., Tournon, J., 1979. Discovery of upper Albian with ammonites in the volcano-sedimentary material of the Nicoya Complex, Guanacaste, Costa Rica. Societe Geologique de France, Paris, France-Compte Rendu Sommaire des Seances de la Société Géologique de France, 3, 129-131.
Bandy, O.L., Casey, R.E., 1973. Reflector Horizons and Paleobathymetric History, Eastern Panama. Geological Society of America Bulletin, 84, 3081-3086.
Barbosa, G., Fernández, J.A., Barrientos, J., Bottazi, G., 1997. Costa Rica, Petroleum geology of the Caribbean margin. The Leading Edge, 1787-1794.
Barker, P.F., 2001. Scotia Sea tectonic evolution: implications for mantle flow and palaeocirculation. Earth-Science Reviews, 55, 1-39.
Bartolini, A., Larson, R.L., 2001. Pacific microplate and the Pangea supercontinent in the Early to Middle Jurassic. Geology, 29, 8, 735-738.
Beck, C., Ogawa, Y., Dolan, J., 1990. Eocene paleogeography of the southeastern Caribbean, relations between sedimentation on the Atlantic abyssal plain at site 672 and evolution of the South America margin, Proceedings Ocean Drilling Program, Scientific Results, 110, 7-15.
Beets, D.J., 1977. Cretaceous and early Tertiary of Curaçao. 8th Caribbean Geological Conference. Amsterdam, Geophysical Union of America, Papers of Geology, Guide to Field Excursions, 10, 18-28.
Beets, D.J., Maresch, W.V., Klaver, G.T., Mottana, A., Bocchio, R., Beunk, F.F., Monen, H.P., 1984. Magmatic rock series and high-pressure metamorphism as constraints on the tectonic history of the southern Caribbean. In: Bonini, W.E., Hargraves, R.B., Shagam, R. (eds.). The Caribbean-South American Plate Boundary and Regional Tectonics. Geological Society of America, Memoir 162, 95-130.
Bell, J.S., 1972. Geotectonic evolution of the southern Caribbean area. Studies in Earth and Space Sciences (Hess Volume). Geological Society of America, Memoir 132, 367-386.
Bird, D.E., Hall, S.A., Casey, J.F., 1999. Tectonic evolution of the Grenada Basin, Caribbean Basins. Elsevier Sedimentary Basins of the World Series, 4, 389-416.
Boiteau, A., Butterlin, J., Michard, A., Saliot, P., 1972. The Purial Ophiolite Complex (Oriente, Cuba) and its high pressure metamorphism: problems of dating and correlation. Comptes Rendus Academie des Sciences, Ser. D, vol. 275, 895-898.
Bolz, A., Calvo, C., 2002. Calizas Lutetianas del arco interno Paleógeno de Costa Rica. Revista Geológica de América Central, 26, 7-24.
Bouysse, P., 1984. The Lesser Antilles Island Arc, structure and geodynamic evolution. Initial Reports, Deep Sea Drilling Program, LXXVIIA, 83-103.
Bouysse, P., 1988. Opening of the Granada back-arc Basin and evolution of the Caribbean plate during the Mesozoic and Early Paleogene. Tectonophysics, 149, 121-143.
Bouysse, P., Westercamp, D., Andreieff, P.,1990. The Lesser Antilles Island Arc: Proceedings. Ocean Drilling Program, Scientific Results, 110, 29-44.
Bouysse, Ph., Andreieff, P., Richard, M., Baubron, J.C., Mascle, A., Maury, R.C., Westercamp, D., 1985. Aves Swell and northern Lesser Antilles Ridge, rock dredging results from Arcante 3 Cruise, Géodynamique des Caraibes, Symposium Paris, Editions Technip, 27, 65-76.
Bowin, C.O., 1968. Geophysical study of the Cayman Trough. Journal of Geophysical Research, 73, 5159-5173.
Bowland, C.L., Rosencrantz, E., 1988 Upper crustal study of the western Colombian Basin, Caribbean Sea. Geological Society of America Bulletin, 100, 534-546.
Burkart, B., 1983. Neogene North American-Caribbean plate boundary across northern Central America: Offset along the Polóchic Fault. Tectonophysics, 99, 251-270.
Burkart, B., Deaton, B.C., Dengo, C., Moreno, G., 1987. Tectonic wedges and offset Laramide structures along the Polóchic Fault of Guatemala and Chiapas, Mexico: Reaffirmation of large Neogene displacement. Tectonics, 6, 4, 411-422.
Calais, E., Mercier de Lepinay, B., 1991. From transtension to transpression along the northern Caribbean plate boundary off Cuba: implications for the Recent motion of the Caribbean Plate. Tectonophysics, 186, 329-350.
Calvo, C., Bolz, A., 1994. Albian to Campanian explosive island arc volcanism in Costa Rica, A new basis for plate reconstructions of western Caribbean, Terra Nostra. Latinamerika Kolloquium, Schriften de Alfred Wegener Stiftung 2/94, 14 Abstracts, 11-12 pp.
Case, J.E., Holcombe, T.L., 1980. Geologic-Tectonic map of the Caribbean Region. U.S Geological Survey Miscellaneous Investigation Series I01100, scale 1:2 500 000.

Chigne, N., Hernández, L., 1990. Main aspects of petroleum exploration in the Apure area of Southwestern Venezuela, 1985-1987. In: Brooks, J. (ed.). Classic Petroleum Provinces. Geological Society of London, Special Publication, 50, 55-75.

Christie, D.M., Duncan, R.A., McBirney, A.R., Richards, M.A., White, W.M., Harpp, K.S., Fox, C.G., 1992. Drowned islands downstream from the Galapagos hotspot imply extended speciation times. Nature, 355, 246-248.

Christman, R.A., 1953. Geology of St. Bartholomew, St. Martin, and Anguilla, Lesser Antilles. Geological Society of America Bulletin, 64, 65-96.

Cobiella-Reguera, J.L., 2000, Jurassic and Cretaceous Geological History of Cuba. International Geology Review, 42, 594-616.

Corvalan, J., 1989. Geologic-tectonic framework of the Andean region. In: Ericksen, G.E., Canas Pinochet, M.T., Reinemund, J.A., (eds.). Geology of the Andes and its Relation to Hydrocarbon and Mineral Resources. Symposium, Santiago, Chile, 1985, Circum-Pacific Council for Energy and Mineral Resources Earth Science Series, 11, 405-414.

Crawford, F.D., Szelewski, C.E., Alvey, G.D., 1985. Geology and exploration in the Takutu Graben of Guyana and Brazil. Journal of Petroleum Geology, 8(1), 5-36.

Cuevas, E.D., Maurasse, F.J-M.R., 1995. Radiolarian biostratigraphy of the Conset Bay Series, Barbados, West Indies. 3rd Geological Conference of the Geological Society of Trinidad and Tobago and 14th Caribbean Geological Conference, Abstracts, 20.

Cunningham, A.P., Barker, P.F., Tomlinson, J.S., 1998. Tectonics and sedimentary environment of the North Scotia Ridge region revealed by side-scan sonar. Journal of the Geological Society of London, 155, 941-956.

Curet, E.A., 1992. Stratigraphy and evolution of the Tertiary Aruba Basin. Journal of Petroleum Geology, 15, 283-304.

Daly, M.C., 1989. Correlations between Nazca/Farallon plate kinematics and forearc basin evolution in Ecuador. Tectonics, 8(4), 769-790.

Dalziel, I.W.D., Forsythe, R.D., 1985. Andean Evolution and the Terrane Concept. In: Howell, D.G. (ed.). Tectonostratigraphic Terranes of the Circum-Pacific Region, 565-581.

Damborenea, S.E., Manceñido, O., 1979. On the palaeogeographic distribution of the pectinid genus Weyla (Bivalvia, lower Jurassic). Palaeogeography, Palaeoclimatology and Palaeoecology, 27, 85-102.

Davison, I., Taylor, M., Longacre, M., 2003. Central Atlantic Salt Basins Correlation. AAPG International Meeting, Barcelona, extended abstracts.

De Wever, P., Azema, J., Tournon, J., Desmet, A., 1985. Discovery of Lias-Lower Dogger ocean material on Santa Elena Peninsula (Costa Rica, Central America). Pierre & Marie Curie Universite, Nancy Universite Compte Rendue, Ser., 2, 300(15), 759-764.

Dengo, G., 1968. Estructura geológica, historia tectónica y morfología de América Central. Guatemala Instituto Centroamericano de Investigación y Tecnología Industrial, Centro Regional de Ayuda Técnica, Agencia para el Desarrollo Internacional, 45.

Dickey, P.A., 1980. Barbados as a fragment of South America ripped off by continental drift. Transactions Caribbean Geological Conference, 51-52.

Di Marco G., Baumgartner, P.O., Channell, J.E.T., 1995. Late Cretaceous-early Tertiary paleomagnetic data and a revised tectonostratigraphic subdivision of Costa Rica and western Panama. In: Mann, P. (ed.). Geologic and Tectonic Development of the Caribbean Plate Boundary in Southern Central America. 1-27.

Diebold, J., Driscoll, N., EW-9501 Science Team, 1999. New Insights on the Formation of the Caribbean Basalt Province Revealed by Multichannel Seismic Images of Volcanic Structures in the Venezuela Basin. In: Mann, P. (ed.). Caribbean Sedimentary Basins, Sedimentary Basins of the World. Elsevier, 561-589.

Dillon, W.P., Vedder, J.G., 1973. Structure and development of the continental margin of British Honduras. Geological Society of America Bulletin, 84, 2713-2732.

Dolan, J.F., Beck, C., Ogawa, Y., Klaus, A., 1990. Eocene-Oligocene sedimentation in the Tiburón Rise/ODP Leg 110 area, an example of significant upslope flow of distal turbidity currents. Proceedings Ocean Drilling Program, Scientific Results, 110, 47-63.

Donnelly, W., 1989. Geologic history of the Caribbean and Central America. In: Bally, A.W., Palmer, A.R. (eds.). The Geology of North America, An Overview. Vol. A, 299-321.

Donnelly, T.W., Beets, D., Carr, M.J., Jackson, T., Klaver, G., Lewis, J., Maury, R., Schellenckens, H., Smith, A., Wadge, G., Westercamp, D., 1990. History and tectonic setting of Caribbean magmatism. In: Dengo, G. (ed.). The Geology of North America.The Caribbean Region. Vol. H, chapter 13, 339-374.

Dorreen, J.M., 1951. Rubble bedding and graded bedding in Talara formation of Northwestern Peru. Bulletin American Association of Petroleum Geologists, 35(8), 1829-1849.

Douglass, R.C., 1961. Orbitolinas from Caribbean Islands. Journal of Paleontology, 35, 5, 475-479.

Driscoll, N.W., Diebold, J.B., 1997. Deformation of the Caribbean region: One plate or two? Geology, 26(11), 1043-1046.

Driscoll, N.W., Diebold, J.B., 1999. Tectonic and stratigraphic development of the eastern Caribbean: new constraints from multichannel seismic data. In: Mann, P. (ed.). Caribbean Sedimentary Basins, Sedimentary Basins of the World. Elsevier, 591-626.

Duncan, R.A., Hargraves, R.B., 1984. Plate tectonic evolution of the Caribbean region in the mantle reference frame. Geological Society of America Memoir, 162, 81-93.

Echevarría-Rodríguez, G., Hernández-Pérez, G., López-Quintero, J.O., López-Rivera, J.G., Rodríguez-Hernández, R., Sánchez-Arango, J.R., Socorro-Trujillo, R., Tenreyo-Pérez, R., Yparraguirre-Pena, J.L., 1991. Oil and gas exploration in Cuba. Journal of Petroleum Geology, 14, 259-274.

Edgar, N.T., Ewing, J.I., Hennion. J., 1971. Seismic refraction and reflection in Caribbean Sea. American Association of Petroleum Geologists Bulletin, 55(6), 833-870.

Escalante, G., 1990. The geology of southern Central America and western Colombia. In: Dengo, G., Case, J.E. (eds.). The Caribbean Region. The Geology of North America, Geological Society of America, Vol. H, 201-230.

Fox, P.J., Schreiber, E., Heezen, B.C., 1971. The geology of the Caribbean crust, Tertiary sediments, granitic and basic rocks from the Aves Ridge. Tectonophysics, 12(2), 89-109.

Freeland, G.L., Dietz, R.S., 1972. Plate tectonic evolution of the Caribbean-Gulf of Mexico region. 6th Caribbean Geological Conference, Venezuela, Transactions, 259-264.

Frisch, W., Meschede, M., Sick, M., 1992. Origin of the Central American ophiolites, Evidence from paleomagnetic results. Geological Society of America Bulletin, 104, 1301-1314.

Gansser, A., 1973. Facts and theories on the Andes. Geological Society of London, Quarterly Journal, 129, 93-131.

Glen, J.M.G., Ponce, D.A., 2002. Large-scale fractures related to inception of the Yellowstone hotspot. Geology, 30(7), 647-650.

Gordon, M.B., 1993. Revised Jurassic and Early Cretaceous (Pre-Yohoa Group) stratigraphy of the Chortis Block: Paleogeographic and tectonic implications. In: Pindell, J.L., Perkins, R.F. (eds.). Mesozoic and early Cenozoic Development of the Gulf of Mexico and Caribbean Region: A context for hydrocarbon exploration. Gulf Coast Association of Economic Paleontologists and Mineralogists Foundation, 143-154.

Gordon, M.B., Avé-Lallement, H.G., 1995. Cryptic strike-slip faults of the Chortis Block. Geological Society of America, Abstracts with Programs, 27, 227-228.

Guedez, V., 1985. Revisión geologíca y evaluación exploratoria del sector de Monay-Carora. VI Congreso Geológico Venezolano, 3103-3143.

Guzmán-Speziale, M., 1989. The triple junction of the North America, Cocos, and Caribbean plates, Seismicity and tectonics. Tectonics, 8(5), 981-997.

Hall, S.A., Ghosh, N., Casey, J.F., Burke, K.C., 1995. Age and formation of oceanic basement beneath the Colombian and Venezuela basins, magnetic anomaly evidence. 3rd Geological Conference of the Geological Society of Trinidad and Tobago and 14th Caribbean Geological Conference, Abstracts, 30-31. Caribbean plates, Seismicity and tectonics. Tectonics, 8, (5), 981-997.

Hamilton, W., 1979. Tectonics of the Indonesian Region. U.S. Geological Survey Professional Paper, 1078, 345 pp. Harllow et al., 2004.

Helmers, H., Beets, D.J., 1977. Cretaceous of Aruba. 8th Caribbean Geological Conference, Bonaire and Aruba, Guide to geological excursions on Curaçao, 29-35.

Hess, H.H., 1938. Gravity anomalies and island arc structure with particular reference to the West Indies. Proceedings of the American Philosophical Society, 79(1), 71-96.

Hess, H.H., Maxwell, C.J., 1953. Caribbean Research Project. GSA Bulletin, 64(1), 1-6.

Hilst, R. van der, 1990. Tomography with P, PP and pP delay-time data and the three dimensional mantle structure below the Caribbean Region. Geologica Ultraiectina, Mededelingen van de Faculteit Aardwetenscahppen der Rijsuniversiteit te Utrecht, 67, 250 pp.

Hoernle, K., van den Bogaard, P., Werner, R., Lissinna, B., Hauff, F., Alvarado, G., Garbe-Schonberg, D., 2002. Missing history (16-71 Ma) of the Galápagos hotspot: Implications for the tectonic and biological evolution of the Americas. Geology, 30(9), 795-798.

Holcombe, T.L., Ladd, J.W., Westbrook, G., Edgar, N.T., Bowland, C.L.,1990. Caribbean marine geology; Ridges and basins of the plate interior. In: Dengo, G., Case, J.E., (eds.). The Caribbean Region. The Geology of North America. Geological Society of America, vol. H, 231-260.

Honthaas, C., R'hault, J.P., Maury, R.C., Bellón, H., Hémond, C., Malod, J.A., Cornée, J.J., Villeneuve, M., Cotton, J., Burhanuddin, S., Guillou, H., Arnaud, N., 1998. A Neogene back-arc origing for the Banda Sea basins: geochemical and geochronological constraints from the Banda ridges (East Indonesia). Tectonophyisics, 298, 297-317.

Hunter, V.F., 1974. The Mid-Tertiary Stratigraphic Unit of the Southern Caribbean Area. Verhandl. Naturf. Ges. Basel, 84(1), 172-190.

Hunter, V.F., 1995. Limestone buildups as ecotectonic indicators within the Tertiary of the southern Caribbean region. 3rd Geological Conference of the Geological Society of Trinidad and Tobago and 14th Caribbean Geological Conference, Abstracts, 3 pp.

Iturralde-Vinent, M., 1994. Cuban Geology: A new plate tectonic synthesis. Journal of Petroleum Geology, 17(1), 39-71.

Iturralde-Vinent, M., 1996. Cuencas sedimentarias del Paleoceno-Eoceno de Cuba. Boletín Sociedad Venezolana de Geólogos, 20(1-2), 75-80.

Iturralde-Vinent, M. 1997. Introducción a la geología de Cuba In: Furrazola Bermúdez, G., Núñez-Cambra, K. (eds.). Estudios sobre geología de Cuba. La Habana, Instituto de Geología y Paleontología, 35-68.

Iturralde-Vinent, M., 1998. Sinopsis de la constitución geológica de Cuba. Acta Geologica Hispanica 33(1-4), 9-56.

Iturralde-Vinent, M., 2000. IGCP Project 433 Caribbean Plate Tectonics; 17th Symposium on the Geology of Latin America (17th LAK), Institute for Geology and Paleontology, University of Stuttgart,

Iturralde-Vinent, M., 2001. Paleontological evidences of the early evolution of the Caribbean Seaway. The NAPC 2001, Berkeley, California, Technical Program.

Iturralde-Vinent, M., 2002. Tectonic evolution of the western Caribbean Plate boundary. 16th Caribbean Geological Conference, Barbados, Abstracts, 88.

Iturralde-Vinent, M., MacPhee, R., 1999. Paleogeography of the Caribbean region, implications for Cenozoic biogeography. Bulletin American Museum of Natural History, 238, 1-95.

Iturralde-Vinent, M., Millán, G., Korpas, L., Nagy, E., Pajón, J., 1996. Geological interpretation of the Cuban K-Ar database. In: Iturralde-Vinent, M. (ed.). Ofiolitas y Arcos Volcánicos de Cuba, Project 364 Caribbean Ophiolites and Volcanic Arcs, Special Contribution, 1, 48-69.

Jaillard, E., Soler, P., Carlier, G., Mourier, T., 1990. Geodynamic evolution of the northern and central Andes during early to middle Mesozoic times: a Tethyan model. Journal Geological Society of London, 147, 1009-1022.

James, K.H., 1997. Distribution and tectonic significance of Cretaceous-Eocene flysch/wildflysch deposits of Venezuela and Trinidad. VIII Venezuelan Geological Congress, Margarita, Sociedad Venezolana de Geologos, 415-421.

James, K.H., 2000. The Venezuelan Hydrocarbon Habitat, Part 1, Tectonics, structure, palaeogeography and source rocks. Journal of Petroleum Geology, 23(1), 5-53.

James, K.H., 2002a. Cretaceous-Eocene flysch deposits of the Caribbean area: Chronological record of discussions and implications for tectonic history and early phases of hydrocarbon generation, 16th Caribbean Geological Conference, Barbados, Abstracts.

James, K.H., 2002b. A simple synthesis of Caribbean geology. 16th. Caribbean Geogical Conference, Barbados, Abstracts.

James, K.H., 2003. A Simple Synthesis of Caribbean Geology. AAPG International Conference, Barcelona, Extended Abstracts Compact Disc.

James, K.H., 2005a. Paleocene to-Middle Eocene flysch-wildflysch deposits of the Caribbean area: a chronological compilation of literature reports, implications for tectonic history and recommendations for further investigation. 16th. Caribbean Geogical Conference, Barbados, Transactions, Caribbean Journal of Earth Sciences, 39, 29-46.

James, K.H., 2005b. A simple synthesis of Caribbean geology: Transactions. 16th Caribbean Geological Conference, Barbados. Caribbean Journal of Earth Sciences, 39, 71-84.

James, E., Mitchell, S.F., 2002. Stratigraphy of the Eocene Chapelton Formation at Dump, Central Jamaica. 16th Caribbean Geological Conference, Barbados, Abstracts, 56.

Jordan, T.E., Gardeweg, M., 1989. Tectonic evolution of the Late Cenozoic Andes. Oxford Monographs on Geology and Geophysics, 8, 193-207.

Jordan, T.E., Isacks, B.L., Allmendinger, R.W., Brewer, J.A., Ramos, V.A., Ando, C.J., 1983. Andean tectonics related to geometry of subducted Nazca plate. Geological Society of America Bulletin, 94, 341-361.

Kennan, L., Pindell, J., 2003. Terrane accretion in the Northern Andes: the Caribbean connection. AAPG International Meeting, Barcelona, Abstracts, A 49.

Kerr, A.C., 1995. Geochemistry and Petrogenesis of Curaçao Picrites and Basalts: Plume Tails and Heads at the Base of the Caribbean Plateau? Eos., Transactions, American Geophysical Union, 76(46), F614.

Kerr, A.C., Tarney, J., 2005. Tectonic evolution of the Caribbean and northwestern South America: The case for accretion of two Late Cretaceous oceanic plateaus. Geology, 33, 4, 269-272.

Kerr, A.C., Tarney, J., Marriner, G.F., Nivia, A., Saunders, A.D., 1997. The Caribbean-Colombian Cretaceous Igneous Province: The Internal Anatomy of an Oceanic Plateau. In: Mahoney, J.J., Coffin, M.F. (eds.). Large Igneous Provinces, Continental, Oceanic, and Planetary Flood Volcanism. American Geophysical Union, Geophyisical Monograph 100, 123-144.

Kerr, A.C., Tarney, J., Marriner, G.F., Klaver, G.T., Saunders, A.D., Thirwall, M.F., 1996. The geochemistry and petrogenesis of the late Cretaceous picrites and basalts of Curaçao, Netherlands Antilles: a remnant of an oceanic plateau. Contributions Mineral Petrology, 124, 29 -43.

Kerr, A.C., Marriner, G.F., Arndt, N.T., Tarney, J., Nivia, A., Saunders, A.D., Duncan, R.A., 1996. The petrogenesis of komatiites, picrites and basalts from the Isle of Gorgona, Colombia; new field, petrographic and geochemical constraints. Lithos, 37, 245-260.

Kesler, S.E., 1971. Nature of ancestral orogenic zone in nuclear Central America. American Association of Petroleum Geologists Bulletin, 55, 2116-2129.

Khudoley, K., Meyerhoff, A., 1971. Paleogeography and geological history of the Greater Antilles. Geological Society of America, Memoir 129, 199.

Kluge, R., Baumann, A., Toetz, A., Maresch, W.V., Stockhert, B., Troesch, M., 1995. New geochronological constraints on the crustal history of Margarita Island. 3rd Geological Conference of the Geological Society of Trinidad and Tobago and 14th Caribbean Geological Conference, Abstracts, 41.

Kolarsky, R.A., Mann, P., Monechi, S., 1995. Stratigraphic development of southwestern Panama as determined from integration of marine seismic data and onshore geology. In: Mann, P. (ed.). Geologic and Tectonic Development of the Caribbean Plate Boundary in Southern Central America, 159-200.

Kugler, H.G., 1953. Jurassic to Recent sedimentary environments in Trinidad. Bulletin Associacion Suisse des Geologues et Ingenieurs du Petrole, 20(59), 27-60.

Lara, M.E., 1993. Divergent wrench faulting in the Belize southern lagoon: implications for Tertiary Caribbean plate movements and Quaternary reef distribution. American Association of Petroleum Geologists Bulletin, 77, 1041-1063.

Lebron, M.C., Perfit, M.R., 1993. Stratigraphic and petrochemical data support subduction polarity reversal of the Cretaceous Caribbean arc. Journal of Geology, 101, 389-396.

Leicester meeting, 2001. Report on the Workshop on the Geochemistry of the Caribbean plateau and Cretaceous island arc terranes, and their implications for the geodynamics of the Caribbean. Leicester, Abstract on www.ig.utexas.edu/-CaribPlate/CaribPlate.

Leroy S., Mauffret, A, Patriat, P., Mercier de Lépinay, B., 2000. An alternative interpretation of the Cayman trough evolution from a reidentification of magnetic anomalies. Geophysical Journal International, 141(3), 539-557.

Lew, L.R., 1985. The geology of the Santa Elena Peninsula, Costa Rica, and its implications for the tectonic evolution of the Central America-Caribbean region. Doctoral thesis. Pennsylvania State University, 509 pp.

Lewis, J.F., 1990. Cuba. In: Lewis J.F., Draper, G., (eds.). Geology and tectonic evolution of the northern Caribbean margin. In: Dengo, G., Case, J.E. (eds.). The Caribbean Region. The Geology of North America. Geological Society of America, vol. H, 78-93.

Lewis, J.F., 2002. Is there a regional Albian unconformity in the Greater Antilles? 16th Caribbean Geological Conference, Abstracts.

Lewis, J.F., Draper, G., 1990. Geology and tectonic evolution of the northern Caribbean margin. In: Dengo, G., Case, J.E. (eds.). The Caribbean Region. The Geology of North America. Geological Society of America, vol. H, 77-140.

Litherland, M., Aspden, J.A., 1992. Terrane-boundary reactivation: A control on the evolution of the Northern Andes. Journal of South American Earth Sciences, 5(1), 71-76.

Lonsdale, P., Klitgord, K.D., 1978. Structure and tectonic history of the eastern Panama Basin. Geological Society of America Bulletin, 89, 981-999.

López Ramos, E., 1975. Geological summary of the Yucatán peninsula. In: Nairn, A.E.M., Stehli, F.G. (eds.). The Ocean Basins and Margins. 3, NY Plenum Press, 257-282.

Lundberg, N., 1983. Development of forearcs of intraoceanic subduction zones. Tectonics, 2(1), 51-61.

Malfait, B.T., Dinkleman, M.G., 1972. Circum-Caribbean Tectonic and Igneous Activity and the Evolution of the Caribbean Plate. Geological Society of America Bulletin, 83, 251-272.

Marchant, S., 1956. The Petroleum Geology of S.W. Ecuador, Symposium Sobre Yacimientos de Petroleo y Gas. XX Congreso Geologico Internacional, 64-88.

Maresch, W.V., Stockhert, B., Kruckhans-Luder, G., Toetz, A., Brix, M., 1993. Structural geology, fabric analysis, petrology and geochronology in concert: how does the Margarita crustal block fit the Caribbean tectonic puzzle? Geological Society of America Annual Meeting, Boston, Abstracts, A-71.

Mascle, et al., 1986. Synthesis of Shipboard Results: Leg 110 Transect of the Northern Barbados Ridge: Processing Ocean Drilling Program, Part A - Initial Reports, 110, 577-591.

Mattson, P.H., 1984. Caribbean structural breaks and plate movements. Geological Society of America Memoir, 162, 131-152.

Maury, R.C., Westbrook, G.K., Baker, P.E., Bouysse, P., Westercamp, D., 1990. Geology of the Lesser Antilles. In: Dengo, G., Case, J.E., (eds.). The Geology of North America, The Caribbean Region. Geological Society of America, vol. H, 141-166.

McCann, W.R., Pennington, W.D., 1990. Seismicity, large earthquakes and the margin of the Caribbean Plate. In: Dengo, G., Case, J.E. (eds.). The Caribbean Region. The Geology of North America. Geological Society of America, vol. H., 291-306.

McCourt, W.J., Aspden, J.A., Brook, M., 1984. New geological and geochronological data from the Colombian Andes: continental growth by multiple accretion. Journal Geological Society of London, 141, 831-845.

Meschede, M., 1998a. Geometric constraints for a near-American origin of the Caribbean Plate. 15th Caribbean Geological Conference, Field Guide and Abstracts, 87.

Meschede, M., 1998b. The impossible Galapagos connection: geometric constraints for a near-American origin of the Caribbean plate: Geol. Rundsch., 87, 200-205.

Meschede, M., Frisch, W., 1995. Non-Pacific origin of the Central American landbridge: structural, geochronological, and paleomagnetic studies at the western and northwestern margin of the Caribbean Plate. In: Ali et al. (eds.). Trans. 3rd Geol. Conf. GST&T and 14th Carib. Geol. Conf., 2, 364-386.

Meschede, M., Frisch, W., 1998. A plate-tectonic model for the Mesozoic and Early Cenozoic history of the Caribbean Plate. Tectonophysics, 296, 269-29.

Meyerhoff, A.A., Hatten, C.W., 1974. Bahamas Salient of North America: Tectonic framework, Stratigraphy, and Petroleum Potential. In: Burk, C.A., Drake, C.L. (eds.). The Geology of Continental Margins. New York, Springer-Verlag, 429-446.

Meyerhoff, A.A., Meyerhoff, H.A., 1971. Continental Drift, IV, the Caribbean "Plate". Journal of Geology, 80, 34-60.

Mills, R.A., Hugh, K.E., Feray, F.E., Swolfs, H.C., 1967. Mesozoic stratigraphy of Honduras. AAPG Bulletin, 51(9), 1711-1786.

Montgomery, H., Pessagno, E.A., Lewis, J.F., Schellekens, J., 1994. Paleogeography of Jurassic fragments in the Caribbean. Tectonics, 13(3), 725-732.

Morris, A.E.L., Taner, I., Meyerhoff, H.A., Meyerhoff, A.A., 1995. Tectonic evolution of the Caribbean region; Alternative hypothesis. In: Dengo, G., Case, J.E., (eds.). The Geology of North America. Geological Society of America, vol. H, 433-457.

Muessig, K.W., 1978. The central Falcón igneous suite, Venezuela: Alkaline basaltic intrusions of Oligocene-Miocene age. Geologie en Mijnbouw, 57, 261-266.

Nagle, F., 1972. Rocks from seamounts and escarpments on the Aves Ridge. VI Conferencia Geologica del Caribe, Margarita, Venezuela, Memorias, 409-413.

Perfit, M.R., Heezen, B.C., 1978. The geology and evolution of the Cayman Trench. Geological Society of America Bulletin, 89, 1155-1174.

Peter, G., Westbrook, G.K., 1976. Tectonics of Southwestern North Atlantic and Barbados Ridge Complex. American Association of Petroleum Geologists Bulletin, 60(7), 1078-1106.

Pindell, J.L., 1991. Geological arguments suggesting a Pacific origin for the Caribbean Plate. Transactions 12th Caribbean Geological Conference, St. Croix.

Pindell, J.L., 1993, Regional synopsis of the Gulf of Mexico and Caribbean evolution. GCSSEOM Foundation, 13th Annual Research Conference, 251-274.

Pindell, J.L., 2001. The Pacific Origin of the Caribbean Plate, with emphasis on Cuba. Leicester meeting, Abstract on www.ig.utexas.edu/CaribPlate/CaribPlate.

Pindell, J.L., 2003. Pacific Origin of Caribbean Oceanic Lithosphere and Circum-Caribbean Hydrocarbon Systems. AAPG International Meeting, Barcelona, Abstracts.

Pindell, J.L., Barrett, S.F., 1990. Geological evolution of the Caribbean region; A plate-tectonic perspective. In: Dengo, G., Case, J.E. (eds.). The Caribbean Region, The Geology of North America. Geological Society of America, vol. H, 405-432.

Pindell, J.L., Dewey, J.F., 1982. Permo-Triassic reconstruction of western Pangea and the origin of the Gulf of Mexico/Caribbean region. Tectonics, 1, 179-212.

Pindell, J., Kennan, L., 2002a. Critical assessment of Caribbean seismic tomography (Hilst, 1990) in light of Caribbean kinematic evolution. 16th Caribbean Geological Conference, Barbados, Abstracts, 97.

Pindell, J., Kennan, L., 2002b. Palinspastic paleogeographic evolution of Eastern Venezuela and Trinidad. 16th Caribbean Geological Conference, Barbados, Abstracts, 99.

Pindell, J., Kennan, L., 2003. Synthesis of Gulf of Mexico and Caribbean Tectonic Evolution: Pacific Model for Caribbean Lithosphere. AAPG International Meeting, Barcelona, Abstracts.

Pindell, J.L., Higgs, R., Dewey, J.F., 1998. Cenozoic palinspastic reconstruction, paleogeographic evolution, and hydrocarbon setting of the northern margin of South America. In: Pindell, J.L., Drake, C.L. (eds.). Paleogeographic Evolution and Non-glacial Eustasy, northern South America. Society of Economic and Petroleum Mineralogists Special Publication, 58, 45-85.

Pindell, J.L., Kennan, L., Barrett, S.F., 2000. Putting It All Together Again. AAPG Explorer, Oct. 2000, 34-37.

Pindell, J., Draper, G., Kennan, L., Stanek, K.P., Maresch, W.V., 2001. Evolution of the northern portion of the Caribbean Plate: Pacific origin to Bahamian collision. SA Abstracts from the IGCP Project 433-Caribbean Plate Tectonics, www.ig.utexas.edu/CaribPlate/CaribPlate.

Pindell, J., Draper, G., Kennan, L., Maresch, W.V., Stanek, K.P., 2002. Evolution of the northern portion of the Caribbean Plate, Pacific origin to the Bahamian collision. 16th Caribbean Geological Conference, Barbados, Abstracts, 98.

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

Pinet, B., Lajat, D., Le Quellec, P., Bouysse, Ph., 1985. Structure of Aves Ridge and Grenada Basin from Multichannel Seismic Data. Géodynamique des Caraibes Symposium, Paris, Editions Technip, 27, 53-56.

Pubellier, M., Mauffret, A., Leroy, S., Vila, J.M., Amilcar, H., 2000. Plate boundary readjustment in oblique convergence, Example of the Neogene of Hispaniola, Greater Antilles. Tectonics, 19(4), 630-648.

Pszczolkowski, A., 1999. The exposed passive margin of North America in Western Cuba. In: Mann, P. (ed.). Caribbean Sedimentary Basins, Sedimentary Basins of the World. Elsevier, 93-121.

Révillon, S., Hallot, E., Arndt, N.T., Chauvel, C., Duncan, R.A., 2000. A Complex History for the Caribbean Plateau: Petrology, Geochemistry, and Geochronology of the Beata Ridge, South Hispaniola. Journal of Geology, 108, 641-661.

Robinson, E., 1967. Submarine slides in White Limestone Group, Jamaica. American Association of Petroleum Geologists Bulletin, 51, 569 - 578.

Rogers, R.D., Mann, P., Emmet, P.A., submitted*a*. Tectonic terranes of the Chortis Block (Honduras and Nicaragua) inferred from integration of regional aeromagnetic and geologic data. Tectonophysics.

Rogers, R.D., Mann, P., Scott, R.W., Patino, L., submitted*b*. Cretaceous intra-arc rifting, sedimentation and basin inversion in east-central Honduras. Sedimentary Geology.

Rogers, R.D., Mann, P., Emmet, P.A., Venable, M.M., submitted*c*. Late Cretaceous amalgamation of the western Caribbean Plate by collision between the continental Chortis Block and intraoceanic arc and oceanic plateau Tectonics.

Rosencrantz, E., 1990, Structure and tectonics of the Yucatan Basin, Caribbean Sea, as determined from seismic reflection studies. Tectonics, 9(5), 1037-1059.

Rosencrantz, E., 1993. Revised opening history of the Cayman Trough, Caribbean Sea. Geological Society of America Annual Meeting, Tectonics, Session 22, Abstracts, A-71.

Rosencrantz, E., Ross, M.I., Sclater, J.G., 1988. Age and spreading history of the Cayman Trough as determined from depth, heat flow, and magnetic anomalies Journal of Geophysical Research, 93(B3), 2141-2157.

Rosendahl, B.R., Meyers, J., Groschel, H., 1992. Nature of the transition from continental to oceanic crust and the meaning of reflection Moho. Geology, 20, 721-724.

Ross, M.I., Scotese, C.R., 1988. A hierarchical tectonic model of the Gulf of Mexico and Caribbean region. Tectonophysics, 155, 139-168.

Rueda-Gaxiola, J., 2003. The Origin of the Gulf of Mexico Basin and its Petroleum Subbasins in Mexico, Based on Red Bed and Salt Palynostratigraphy. In: Bartolini et al. (eds.). The Circum-Gulf of Mexico and the Caribbean: Hydrocarbon habitats, basin formation and plate tectonics. American Association of Petroleum Geologists, Memoir 79, 246-282.

Sageman, B.B., Speed, R.C., 2003. Upper Eocene limestones, associated sequence boundary, and proposed Eocene tectonics in Eastern Venezuela. In: Bartolini, C. et al. (eds.). The Circum-Gulf of Mexico and the Caribbean. Hydrocarbon Habitats, Basin Formation, and Plate Tectonics, 157-159.

Salvador, A., 1987. Late Triassic-Jurassic Paleogeography and Origin of Gulf of Mexico. American Association of Petroleum Geologists Bulletin, 71(4), 419-451.

Senn, A., 1944. Inventory of the Barbados Rocks and their Possible Utilization. Barbados, Department of Science and Agriculture, Bulletin, 1, 1-40.

Snoke, A.W., 1990. An evaluation of the petrogenesis of the accreted Mesozoic Island Arc of the Southern Caribbean. Second Geological Conference of the Geological Society of Trinidad and Tobago, Transactions, 222-243.

Stainforth, R.M., 1969. The concept of sea-floor spreading applied to Venezuela. Associación Venezolana de Geología, Minería y Petróleo, Boletín Informático, 12, 257-274.

Stuttgart Meeting. 17th Symposium on the Geology of Latin America (17th LAK), Institute for Geology and Paleontology, University of Stuttgart, October 11 to 13, 2000, www.ig.utexas.edu/CaribPlate/CaribPlate.

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

Takayama, H., Tada, R., Matsui, T., Iturralde-Vinent, M.A., Oji, T., Tajika, E., Kiyokawa, S., Garcia, D., Okada, H., Hasegawa, T., Toyoda, K., 2000. Origin of the Penalver Formation in northwestern Cuba and its relation to the K/T boundary impact event. Sedimentary Geology, 135, 295-320.

Tardy, M., Sigal, J., Gacon, G., 1974. Bosquejo sobre la estratigrafía y paleogeografía de los flysch Cretácicos del sector transversal de Parras, Sierra Madre Oriental, México. Instituto de Geología, UNAM, Serie Duval, 2.

Tardy, M., Lapierre, H., Freydier, C., Coulon, C., Gill, J.B., Mercier de Lepinay, B., Beck, C., Martinez, R.J., Talavera, M.O., Ortiz, H.E., Stein, G., Bourdier, J.L., Yta, M., 1994. The Guerrero suspect terrane (western Mexico) and coeval arc terranes (the Greater Antilles and the Western Cordillera of Colombia), a late Mesozoic intra-oceanic arc accreted to cratonal America during the Cretaceous. Tectonophysics, 230, 49-73.

Tomblin, J.F., 1970. Field guide to the Grenadines, Lesser Antilles: International Field Institute Guidebook to the Caribbean Island-Arc System. American Geological Institute (article individually paginated).

Tomblin, J.F., 1975. The Lesser Antilles and Aves Ridge. In: Nairn., A.E.M., Stehli, F.G. (eds.). The Ocean Basins and Margins. NY Plenum Press, 3, 467-500.

Vaughan, T.W., Wells, J.W., 1945. American old and middle Tertiary larger foraminifera and corals. Geological Society of America, Memoir 9, 175.

Villamil, T., Arango, C., Hay, W.W., 1999. Plate tectonic paleoceanographic hypothesis for Cretaceous source rocks and cherts of northern South America. Geological Societey of America Special Paper, 332, 191-202.

Viniegra, O.F., 1971. Age and evolution of salt basins of southeastern Mexico. American Association of Petroleum Geologists Bulletin, 55, 478-494.

Vivas, V., Macsotay, O., 2002. Cretaceous (Senonian)-Paleocene paleoceanographic continuity between the Caribbean Plate's abyssal facies (Venezuelan Basin) and the South American Plate's slope and shelf facies (northern Venezuela). 16th Caribbean Geological Conference, Barbados, Abstracts, 70.

Wadge, G., Burke, K., 1983. Neogene Caribbean Plate rotation and associated Central American tectonic evolution. Tectonics, 2, 633-643.

Westbrook, G., Mascle, A., Biju-Duval, B., 1984. Geophysics and structure of the Lesser Antilles forearc. In: Biju-Duval, B., Moore, J.C., et al. (eds.). Initial Reports Deep Sea Drilling Program, LXXVIIIA, 23-38.

White, G.W., Burke, K., 1980. Outline of the tectonic evolution of the Gulf of Mexico and the Caribbean region. Houston Geological Society Bulletin, 22, 8-13.

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