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THE CARIBBEAN-SOUTH AMERICAN PLATE BOUNDARY, ARAYA PENINSULA, EASTERN VENEZUELA

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ABSTRACT

Preliminary results of a structural geologic study of the low to intermediate P/T metamorphic rocks of the Araya Peninsula, the El Pilar fault zone, and the fold and thrust belt south of the El Pilar fault are consistent with recent plate-tectonic models for the interaction of the Caribbean and South American lithospheric plates. The rocks of the Araya Peninsula underwent two synmetamorphic phases of isoclinal folding (D_{1a} and D_{1b}); the fold axes are parallel to the major principal extension axes (X) which trend east-northeasterly. The D_{1a} and D_{1b} structures are crosscut by north-south striking extensional kink bands, shear zones, and normal faults (D_{1c}) which indicate late synmetamorphic east-west extension. The next phase of folding (D_2) is characterized by tight to open postmetamorphic, northeast trending folds, generally vergent to the southeast and accompanied by southeast vergent thrust faults (northwest vergent folds and thrust faults are relatively rare). The youngest phase of folding (D_3) is characterized by north-northwest trending folds, accompanied by east-northeast and west-southwest vergent thrust faults. The structures in the fold and thrust belt, south of the El Pilar fault, underwent the last two phases of folding (D_2 and D_3) recognized north of the fault. Along the El Pilar fault, upper Tertiary and lower Quaternary rocks are deformed by D_3 structures. It is proposed that the D_{1a}, D_{1b}, and D_{1c} structures formed in an accretionary complex-forearc terrane as the result of right-oblique convergence of the Proto-Caribbean and Farallon plates during the mid to Late Cretaceous. The D_2 structures may have formed during the Oligocene and Miocene as a result of the eastward passing of the Lesser Antilles/Aves Ridge and Leeward Antilles volcanic island arcs along the northern margin of South America. The D_3 structures have formed from Miocene to Recent and are related to "restraining bends" of the east-west striking strike-slip faults which make up the present plate boundary.

INTRODUCTION

The Caribbean-South American plate boundary zone is complex and, in eastern Venezuela, it may be as wide as 300 km (Robertson and Burke, 1989). It is bounded in the north (north of La Blanquilla Island; fig. 1) by a south-dipping thrust fault (Beck, 1985) and in the south by the frontal thrust of the Serrania del Interior foreland fold and thrust belt (Rossi, 1985; Rossi et al., 1987). The boundary zone has been divided into four tectonostratigraphic terranes: the Leeward Antilles volcanic island arc terrane, the Margarita terrane, the Cordillera de la Costa belt, and the foreland fold and thrust belt of the Serrania del Interior (Stephan, 1985; Beck, 1985; Bellizzia, 1986). The first three terranes are separated in the south from the foreland fold and thrust belt by the east-west striking El Pilar fault which is a right-lateral strike-slip fault (Vierbuchen, 1984) and is still active today (Pérez and Aggarwal, 1981). The northern three terranes are tectonically intermixed. In general, though, the Leeward Antilles arc terrane is north, and the Cordillera de la Costa belt south.

Case et al. (1984) defined the Leeward Antilles terrane to consist of the Dutch islands Aruba, Curaçao, and Bonaire and the Venezuelan islands Las Aves, Los Roques, and La Orchilla. The Leeward Antilles (volcanic island arc) terrane is defined here to include Case's Leeward Antilles terrane, but also (fig. 1) the islands La Blanquilla and Los Hermanos and part of Margarita Island, Tobago, and the Carúpano and Tuy-Cariaco basins. Late Cretaceous and earliest Paleogene trondhjemites occur on the islands La Blanquilla and Margarita (Schubert and Moticska, 1973; Santamaría and Schubert, 1974). Late Cretaceous basalt and andesite basement was penetrated by drilling in the Tuy-Cariaco and Carúpano basins (Bellizzia, 1986; Castro and Mederos, 1985). Mid-Cretaceous volcanic and plutonic rocks occur on Tobago (Sharp and Snoke, 1988). Volcanism in the western Leeward Antilles arc ceased at about 80 Ma (Beets et al., 1984), but may have continued till about 64 Ma on La Blanquilla. Mid- to Late Eocene andesites and quartz diorites on the Los Testigos Archipelago (Schubert and Moticska, 1973; Santamaría and Schubert, 1974) and in nearby wells (Bellizzia, 1986) may not be related to the Leeward Antilles arc, but rather to the Lesser Antilles arc (which stretches from Grenada in the south to Saba in the north).

The Margarita terrane (fig. 2, named Coastal Fringe - Margarita terrane by Stephan (1985)) consists of dismembered ophiolite and metasediments containing eclogite and blueschist inclusions. The ophiolitic rocks are found on Margarita (Maresch, 1975; Chevalier, 1987) and on the Araya and Paria peninsulas (Schubert, 1971; Seijas, 1972; González de Juana et al., 1972). In some deep wells in the Carúpano Basin, pre-Tertiary volcanic rocks were recovered which have MORB characteristics (Castro and Mederos, 1985). These rocks have been proposed to be fragments of oceanic lithosphere, formed in the late Jurassic to early Cretaceous when North and South America drifted apart (Maresch, 1975; Beets et al., 1984). Eclogite knockers occur only on Margarita Island. Blueschists have been recovered in deep wells in the Carúpano Basin (Castro and Mederos, 1985; Pereira, 1985). The occurrence of a glaucophane schist has been reported by Campos (in Bellizzia, 1986) on the mainland, east of the Araya Peninsula. These metamorphic assemblages have formed at high pressure (up to 12 kb)/ temperature (P/T) conditions in a subduction complex (Maresch and Abraham, 1981; Navarro, 1981). Most of these rocks were retrograded in the epidote amphibolite and greenschist facies (at pressures of 6 kb and less) during the Late

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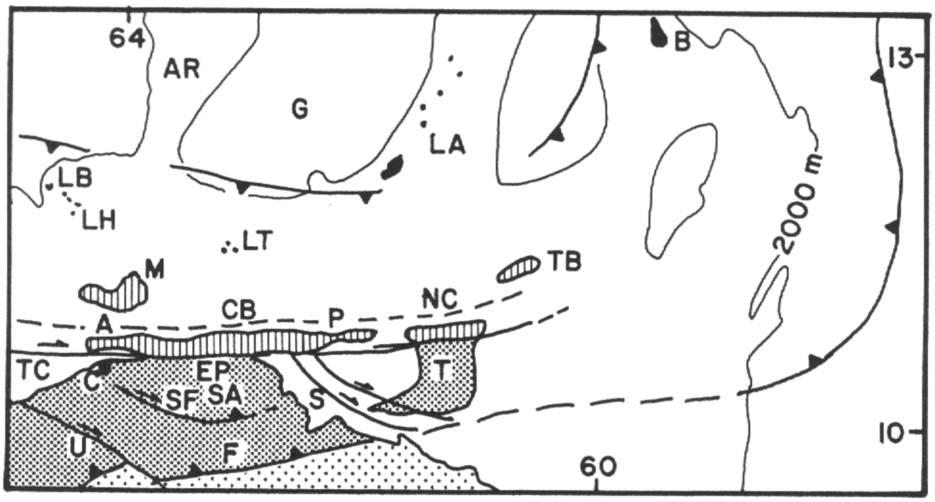

Figure 1. Terrane map of the southeastern Caribbean and northeastern Venezuela (after Stephan, 1985; Beck, 1985; Speed, 1985; Rossi et al., 1987; Robertson and Burke, 1989). Vertically ruled: Margarita and Cordillera de la Costa belts; densely stippled: foreland fold and thrust belt; sparsely stippled: autochthonous; A: Araya Peninsula, AR: Aves Ridge; B: Barbados; C: Cumaná; CB: Carúpano Basin; EP: El Pilar fault zone; F: Frontal thrust; G: Grenada Basin; LA: Lesser Antilles; LB: La Blanquilla Island; LH: Islas Los Hermanos; LT: Los Testigos Archipelago; M: Margarita Island; NC: North Coast fault zone; P: Paria Peninsula; S: Soldado fault zone; SA: Serrania del Interior; SF: San Francisco fault zone; T: Trinidad; TB: Tobago; TC: Tuy-Cariaco Basin; U: Urica fault zone.

Cretaceous (Santamaría and Schubert, 1974; Loubet et al., 1985; Chevalier, 1987).

Most of the Araya (fig. 2) and Paria peninsulas is underlain by metasediments assigned to the Cordillera de la Costa belt (Schubert, 1971; González de Juana et al., 1972; Seijas, 1972). Recently (Bellizzia, 1986; Chevalier, 1987), a large portion of the metasediments of Margarita (Juan Griego Group) has been included in this belt as well, although they contain numerous eclogite and amphibolite knockers. The sedimentary protolith of the Cordillera de la Costa belt may have been deposited on the passive northern continental margin of South America during late Jurassic and early Cretaceous time (Bellizzia, 1986); granitic gneisses in the Cordillera de la Costa belt in north central Venezuela have Paleozoic and Precambrian crystallization ages (Ostos, 1990). The rocks were metamorphosed in the epidote amphibolite and greenschist facies probably during the Late Cretaceous.

The region south of the El Pilar fault (fig. 2) is underlain by a non-metamorphic sequence of Cretaceous and Tertiary sediments. Cretaceous and Paleogene sediments were deposited on the passive continental margin of northern South America and were deformed in a southeast vergent fold and thrust belt during the Oligocene and Miocene (Rossi et al., 1987). The deformed rocks are unconformably overlain by generally coarse-grained sediments of Miocene (partly deformed) and younger age.

Maresch (1974) and Talukdar and Loureiro (1982) were among the first to interpret the geology of northern Venezuela in terms of plate tectonic theory. Their models do not require large displacements: one or more volcanic island arcs and subduction complexes developed off the coast of Venezuela and, ultimately, collided with the mainland resulting in south vergent fold and thrust belts. The interpretation of northern Venezuelan geology changed drastically, however, when more detailed data became available about the relative motions of the North and South American and Pacific basin lithospheric plates through time (e.g. Morgan, 1981; Engebretson et al., 1985). As a result, most recent models (e.g. Duncan and Hargraves, 1984; Ross and Scotese, 1988; Pindell et al., 1988; Pindell and Barrett, 1990) have most tectonic belts of Venezuela formed far to the west, as a result of Cretaceous interaction of the Pacific (Farallon) plate and the South American continent. These belts were thought to have been transported eastward within the Caribbean-South American transform boundary as a result of the relative eastward migration of the Caribbean plate. The emplacement of the terranes onto the South American continent may have been entirely the result of dextral strike-slip motion (Robertson and Burke, 1989) or transpression (Pindell et al., 1988). Speed (1985) proposed that the structures in eastern Venezuela could be best explained by northwesterly subduction and collision of the Lesser Antilles arc with South America.

The present study dealing with the structural evolution of the rocks on the Araya Peninsula (fig. 1 and fig. 2) was carried out in an attempt to test the often conflicting plate tectonic models for the area. The conclusions are preliminary, because this study has not yet been entirely completed and interpretations are often based on poorly-known age relationships. Several samples from the area are being prepared for $^{40}Ar/^{39}Ar$ dating, but results are not yet available.

GEOLOGY OF THE ARAYA PENINSULA

Lithologies

Schubert (1971) divided the metamorphic rocks of the Araya Peninsula into four east-northeast trending belts, each characterized by a particular rock assemblage for which a formation name was coined. These belts or formations are from north to south: Manicuare, Laguna Chica, Carúpano, and

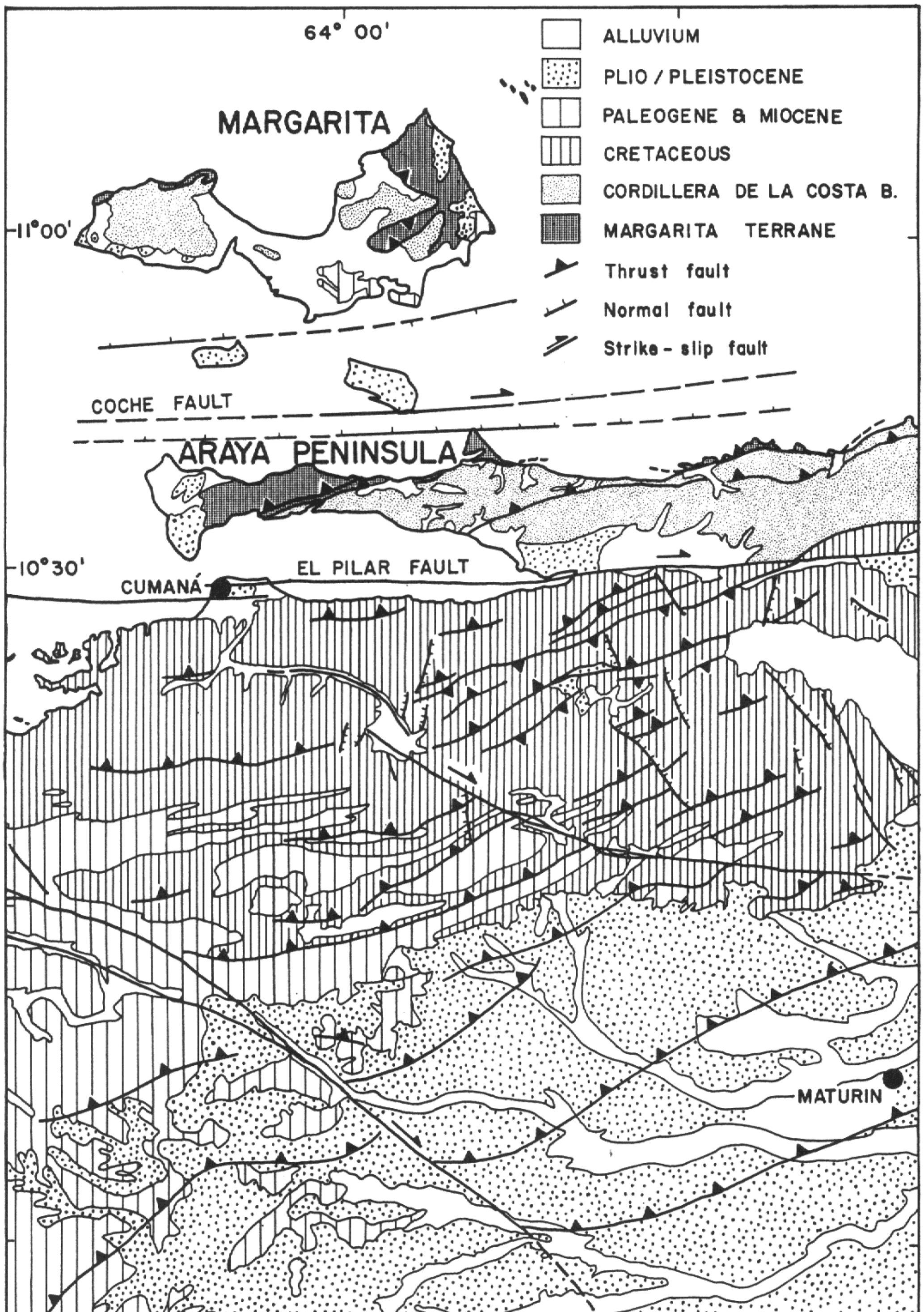

Figure 2. Simplified geologic map of the Caribbean-South American plate boundary zone at the approximate longitude of Isla de Margarita and the Araya Peninsula, after Schubert (1971), Bellizzia et al. (1976) and Rossi (1985).

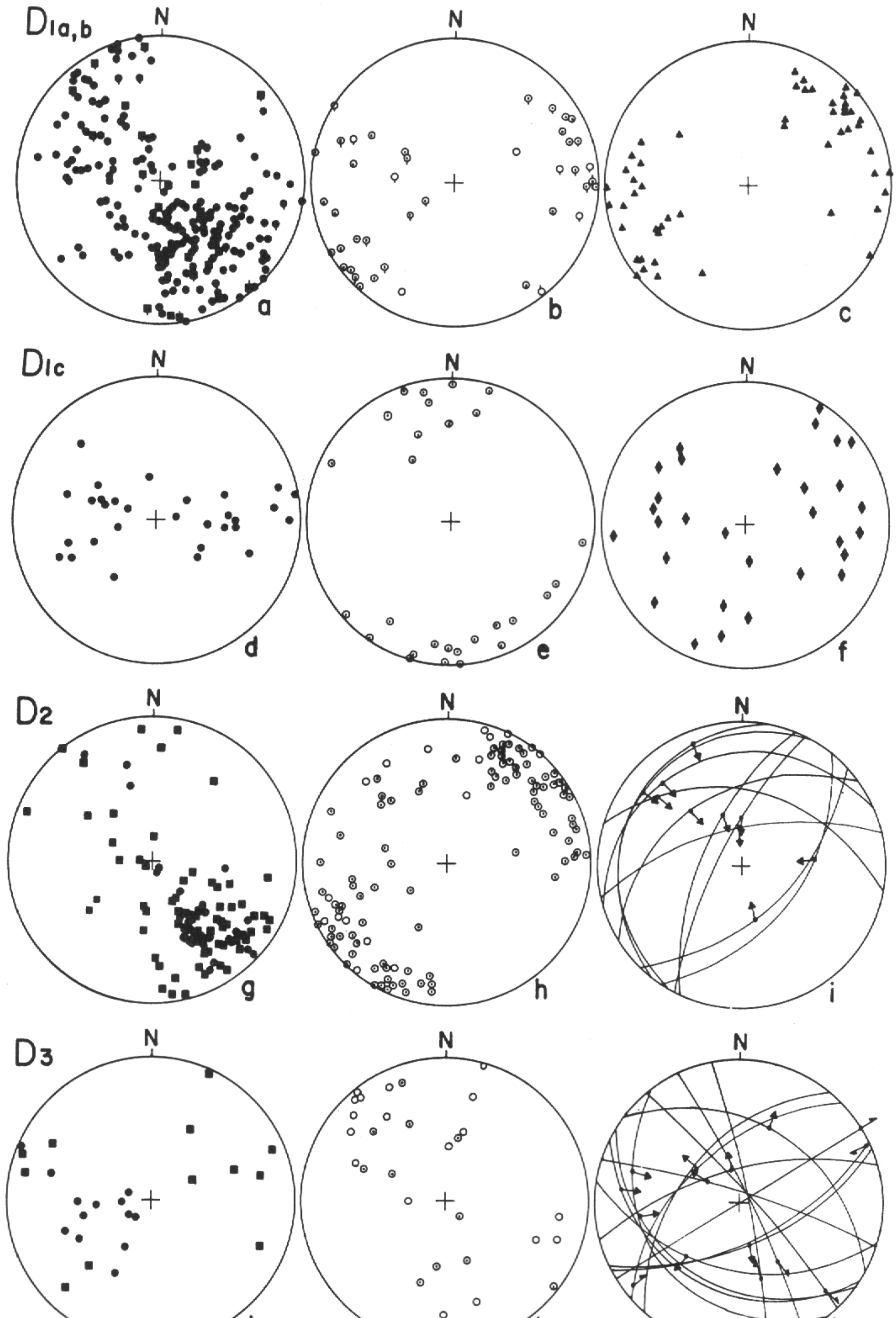

Figure 3. Equal-area, lower-hemisphere projections of structural elements of D_{1a} and D_{1b} (figs. a, b, c; tick marks indicate D_{1b} structures), D_{1c} (figs. d, e, f), D_2 (figs. g, h, i), and D_3 deformation (figs. j, k, l). Poles to foliations and cleavages (dots), poles to fold axial planes (squares), fold axes (circles), intersection and crenulation lineations (dotted circles), stretching lineations (triangles), slip directions (diamonds), faults (great circles; dots on great circle indicate slip direction; arrows pointing outward indicate normal faults or faults with normal component; arrows pointing toward center indicate thrust faults or faults with thrust component; arrows with half arrowhead indicate sense of strike-slip faults).

Tunapui formations. Bellizzia (1986) included the Laguna Chica Formation in the Margarita terrane and the other three formations in the Cordillera de la Costa belt. In the present study, the Manicuare Formation is included in the former, because of its relatively high-pressure metamorphic assemblages. The four belts are separated by steep faults along which the latest displacements resulted from strike-slip motion (Schubert, 1971).

The Manicuare Formation consists of muscovite-biotite schist, kyanite schist, garnet-staurolite schist, quartzite, and two-feldspar gneiss. Kyanite occurs also in quartz veins. The age of the protolith is unknown.

The Laguna Chica Formation consists of quartzite, chlorite schist, amphibole schist, phyllite, and serpentinite. Chevalier (1987) correlated it with the El Copey Formation, east of the Araya Peninsula, which contains similar rocks and, additionally, meta (pillow) basalt, metatuff, metaconglomerate (Seijas, 1972), and epidote-glaucophane schist (Campos, in Bellizzia, 1986). The age of deposition of these rocks is unknown but Vierbuchen (1984) proposed a Lower Cretaceous (Barremian) age on the basis of lithologic similarities with dated rocks east of the Araya Peninsula.

The Carúpano Formation consists of calcareous phyllite, dark gray marble, graphitic and calcareous micaschist, and micro-conglomerate. No fossils have been found in this formation, but Vierbuchen (1984) proposed it to be a lateral facies equivalent of the Albian/Aptian Tunapui Formation.

The Tunapui Formation consists of chlorite-muscovite schist, meta-conglomerate, graphitic phyllite, quartzite, and some limestone. Albian and Aptian ammonites were reported in this formation, east of the Araya Peninsula (Vierbuchen, 1984).

The Manicuare Formation, according to Schubert (1971), was metamorphosed in the epidote amphibolite facies at temperatures of 480°C and pressures of 5 to 6 kb and was retrograded at temperatures of 350° to 450°C and pressures of 3 to 4 Kb. The metamorphic grade of the other three belts is lower (greenschist facies), except for the exotic glaucophane schist reported in Bellizzia (1986). The age of metamorphism on Araya is unknown. An augengneiss on the Paria Peninsula yielded an amphibole K/Ar age of 128± 11.0 Ma and a whole-rock K/Ar age of 53± 3.0 Ma (Santamaría and Schubert, 1974).

Structural Geology of the Araya Peninsula

It has been shown by Schubert (1971) and Vignali (1979) that the structural grain of the Araya Peninsula is controlled by east-northeast to northeast trending folds and faults which deform the metamorphic foliation. Vignali (1979) recognized two generations of isoclinal folds formed during the regional metamorphism. In the present study, five generations of folds were recognized: two generations of isoclinal folds (D_{1a} and D_{1b}), one generation of kink folds related to extensional shear zones (D_{1c}), one generation of northeast trending folds (D_2), and one of north-northwest trending folds (D_3). The D_{1a} structures are the oldest and D_3 folds are the youngest. The first three generations (D_{1a} to D_{1c}) are probably the result of one continuous deformation. Structural elements of the Araya Peninsula are shown in Fig. 3 and simplified models of the structures are shown in Fig. 4. All four belts of the Araya Peninsula have undergone the same deformational history: every generation of folds (D_{1a} to D_3) is found in each belt. Furthermore, the metamorphic rocks of Margarita Island have suffered the same deformations as those of the Araya Peninsula (Guth and Avé Lallemant, this volume).

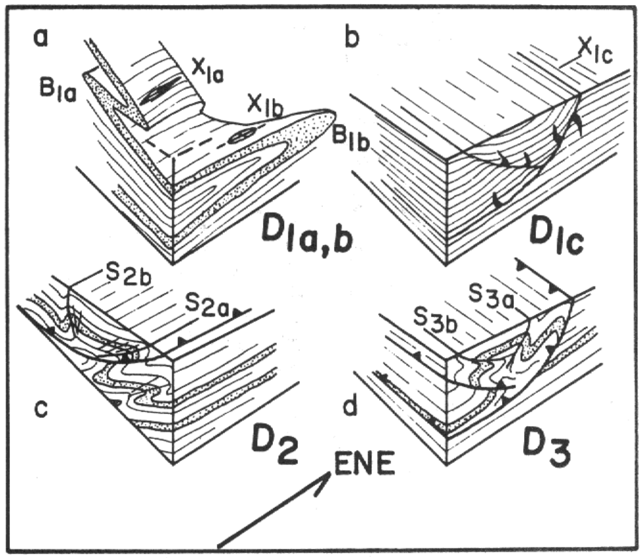

Figure 4. Sketches of deformational structures in metamorphic rocks of the Araya Peninsula. 1) D_{1a} and D_{1b} structures: isoclinal B_{1a} fold, B_{1b} sheath fold, major principal extensions X_{1a} and X_{1b}, all trending northeasterly. b) D_{1c} structures: northeast and southwest dipping extensional shear zones/normal faults with sigmoidal quartz veins (black); major principal extension X_{1c}. c) D_2 structures: southeast vergent thrust fault and fold with rare northwest vergent fold; S_{2a} and S_{2b} are fold-axial planes. d) D_3 structures: northeast and southwest vergent thrust faults and folds; S_{3a} and S_{3b} are fold axial planes.

Both D_{1a} and D_{1b} folds are synmetamorphic. They are isoclinal. The fold axes of both trend east-west to northeast-southwest (fig. 3b). Thus, they are difficult to separate, except for the rare outcrops where the second is seen to deform the first. Numerous east-northeast trending stretching lineations and stretched pebble elongations (parallel to the major extension axis X of the finite strain ellipsoid) (fig. 3c) were observed. They are related to both D_{1a} and D_{1b} deformations. A few D_{1b} sheath folds were observed indicating east-northeasterly extension. Kinematic indicators suggest that dextral shear has occurred on the S_{1a} foliations.

The third (D_{1c}) deformation is characterized by a conjugate set of north-trending extensional kink bands, extensional shear zones, and normal faults, dipping to the east or the west (fig. 3d) with north-trending fold axes (fig. 3e). Displacement directions trend easterly or westerly (fig. 3f). This deformation is late synmetamorphic, and is characterized by dissolution and deposition of quartz and calcite along the shear planes. No radiometric ages exist for the metamorphic rocks of the Araya Peninsula. However, the deformations on Araya can be correlated with those on Margarita Island (Guth and Avé Lallemant, this volume): radiometric ages of 70 to 80 Ma (K/Ar, amphibole) may date the age of uplift and thus, the age of the

D_{1c} folding event (Santamaría and Schubert, 1974; Loubet et al., 1985; Chevalier et al., 1988).

The fourth generation of folds (D_2) is clearly postmetamorphic. The S_{1a} and S_{1b} foliations (fig. 3a) were folded about northeast trending fold axes (fig. 3h). Most folds are southeast vergent and have northwest dipping axial planes and cleavages (fig. 3g), but northwest vergent folds also occur. Often it can be shown that the D_2 folds are related to thrust faults, mostly northwest and sometimes southeast dipping (fig. 3i). The D_2 event postdates D_{1c} and predates deposition of Pliocene rocks on the Araya Peninsula. This deformation can be correlated with the main deformation in the Serrania del Interior, which according to Rossi (1985) occurred during the Miocene, but may have started in the Oligocene.

A fifth generation of folds (D_3) is characterized by north-northwest trending axial planes and cleavages (fig. 3j) and fold axes (fig. 3k). These folds are related to a conjugate set of thrust and reverse faults which dip northeast and southwest (fig. 3l). East-northeasterly trending normal faults (fig. 3l) may be related to the D_3 phase. The D_3 structures are only locally developed and they are not penetrative. On Araya, no time constraints have been found beyond the fact that these structures postdate D_2 structures. However, they can be correlated with structures along the El Pilar fault (Vierbuchen, 1984), in the hills south of Cumaná (Ascanio, 1972), and along the San Francisco fault zone (fig. 1) suggesting that they formed in Pliocene to Recent time.

PLATE TECTONIC MODEL

Relative plate motion trajectories of South America with respect to North America indicate that from the Late Triassic until the Eocene (49 Ma) North and South America were drifting apart and that from Eocene to Recent, the two plates converged slightly (Pindell et al., 1988). Thus, it is difficult to conceive that the Cretaceous Leeward Antilles volcanic island arc and the Cretaceous metamorphism of the Margarita terrane and the Cordillera de la Costa belt are related to plate convergence, subduction, and collision of the Proto-Caribbean and South American plates. It is much more likely that these terranes are allochthonous and were formed far to the west as the result of the interaction of the Farallon plate and the Proto-Caribbean plate (Ross and Scotese, 1988; Pindell et al., 1988; Pindell and Barrett, 1990). The structures in the Araya Peninsula are compatible with such hypothesis.

The Margarita terrane containing the high $^P/_T$ eclogite and blueschist knockers, must have formed in a subduction complex (e.g., Ernst, 1988). The D_{1a}, D_{1b}, and D_{1c} structures were formed one after the other at decreasing depth: on Margarita Island D_{1a} formed at 40 km depth and D_{1c} at 20 km (Maresch and Abraham, 1981) and on the Araya Peninsula D_1 formed at 20 km depth, D_{1b} may have formed at 10 km (Schubert, 1971), and D_{1c} at even shallower levels. The major principal extension axes (X-axes) of all three phases are subparallel to the terrane boundaries. Such a situation has been described before in blueschist terranes in Japan (Faure, 1985; Toriumi and Noda, 1986) and was ascribed to suture-parallel simple shear in an oblique subduction zone. Kinematic indicators related to the D_{1a} deformation on Araya suggest that the Venezuelan terranes formed in a right-oblique subduction zone.

The D_{1c} structures clearly indicate suture-parallel extension. Similar structures have been described before in areas of oblique plate convergence; e.g. in the Kuril arc (Kimura, 1986), in the Ryukyu arc (Kuramoto and Konishi, 1989), and the Aleutian arc (Ryan and Scholl, 1989). As the three synmetamorphic deformational phases D_{1a}, D_{1b}, and D_{1c} appear to have formed consecutively while the rocks were being decompressed, it is suggested here that they all formed by suture-parallel extension but with a component of dextral simple shear. This suture-parallel extension may be the result of an increase of obliquity of plate convergence (obliquity is 0°, if the relative plate convergence is perpendicular to the subduction zone; if the obliquity increases to 90°, the plate boundary becomes a transform fault). It is known that forearc terranes, bounded by the subduction zone and a suture-parallel intra-arc strike-slip fault, can be displaced parallel to the subduction zone at a rate equal to the suture-parallel component of the plate convergence velocity (Jarrard, 1986; Avé Lallemant and Oldow, 1988). If the obliquity increases because of the arcuate shape of the volcanic island arc, the suture-parallel displacement rate of the forearc terrane has to increase with the consequence that the terrane will be stretched parallel to the suture. At the same time the subduction component decreases and to reestablish isostatic equilibrium, the subduction complex is uplifted (Avé Lallemant and Guth, 1990). This hypothesis is not inconsistent with plate tectonic models for the Caribbean (fig. 5a). Between about 100 and 70 Ma a fragment of the Farallon plate may have moved northeastward in between North and South America (Ross and Scotese, 1988). The Aves Ridge and the Leeward Antilles (AR and LA in fig. 5a, respectively) were at this time a northeast-facing volcanic arc. Plate convergence was right-oblique and the increase in obliquity (from P to Q in fig. 5a) caused D_1 stretching in and uplift of the accretionary complex as observed on Margarita Island and the Araya Peninsula. At about 80 Ma, the obliquity increased to 90° (point R in fig. 5a), subduction ceased, the Leeward Antilles arc became extinct (Beets et al., 1984), and uplift of the accretionary complex continued. This accretionary complex differs from most other complexes in that it not only includes oceanic rocks (ultramafic and mafic rocks, and deep-water or distal sedimentary rocks), but also continental margin deposits (graphitic and calcareous shales and sandstones, limestone, and conglomerate) and even slivers of Paleozoic and Precambrian granitic gneisses (Ostos, 1990), presumably scraped off northwestern South America.

Between 50 and 65 Ma (Pindell et al., 1988; Ross and Scotese, 1988) the Aves Ridge collided with the Bahama platform and the Caribbean plate started to migrate eastward with respect to South America (fig. 5b). The main contact between the Caribbean and South American plates jumped to the south and the Margarita and Cordillera de la Costa terranes were included in the Caribbean plate. During the eastward migration of the Caribbean, these terranes were situated in a transpressional tectonic setting. It is in this setting that the D_2 structures in the Araya Peninsula were formed. The following hypothesis relates these structures to eastward displacement of the Lesser Antilles/Aves Ridge and Leeward Antilles arcs which acted as a snowplow pushing the allochthonous accretionary wedge and the autochthonous passive margin deposits sideways to the southeast (fig. 6). In the model, the Caribbean plate (CP) moves eastward with respect to the South American plate (SAP) at a rate of $_SV_C$. Along the oblique contact P_0Q_0 strike-slip motion occurs at a rate V_T. The component V_N, normal to P_0Q_0, causes a slice (T_1) of the sedimentary apron overlying the South

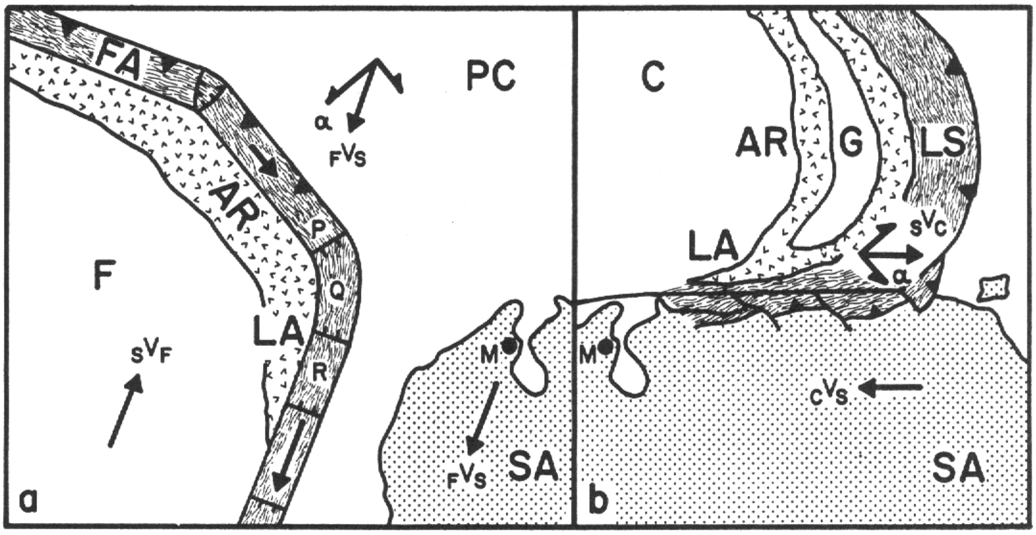

Figure 5. Plate tectonic reconstructions of the southeastern Caribbean for Senonian (a) and Miocene (b) times, modified after Ross and Scotese (1988); AR = Aves Ridge, C = Caribbean plate, F = Farallon plate, FA = forearc terrane, G = Grenada Basin, LA = Leeward Antilles, LS = Lesser Antilles, M = Maracaibo, PC = Proto-Caribbean plate, SA = South America. a) Relative rate of convergence of PC with respect to F is $_FV_S$. At point P, convergence is right-oblique with obliquity a of 30°; suture-parallel velocity of FA is $_FV_S \sin 30° = \frac{1}{2}\ _FV_S$. Plate boundary at R is a transform; thus, obliquity is 90° and the relative velocity of FA at R is $_FV_S \sin 90° = {}_FV_S$. Thus, suture-parallel displacement rate of FA increased by 100% from P to R causing stretching (suture-perpendicular normal faults). b) Relative displacement rate of C with respect to SA is $_SV_C$. Boundary between C and SA is a transform. Southeast-directed thrusting in northern Venezuela is the result of $_SV_C \sin a$.

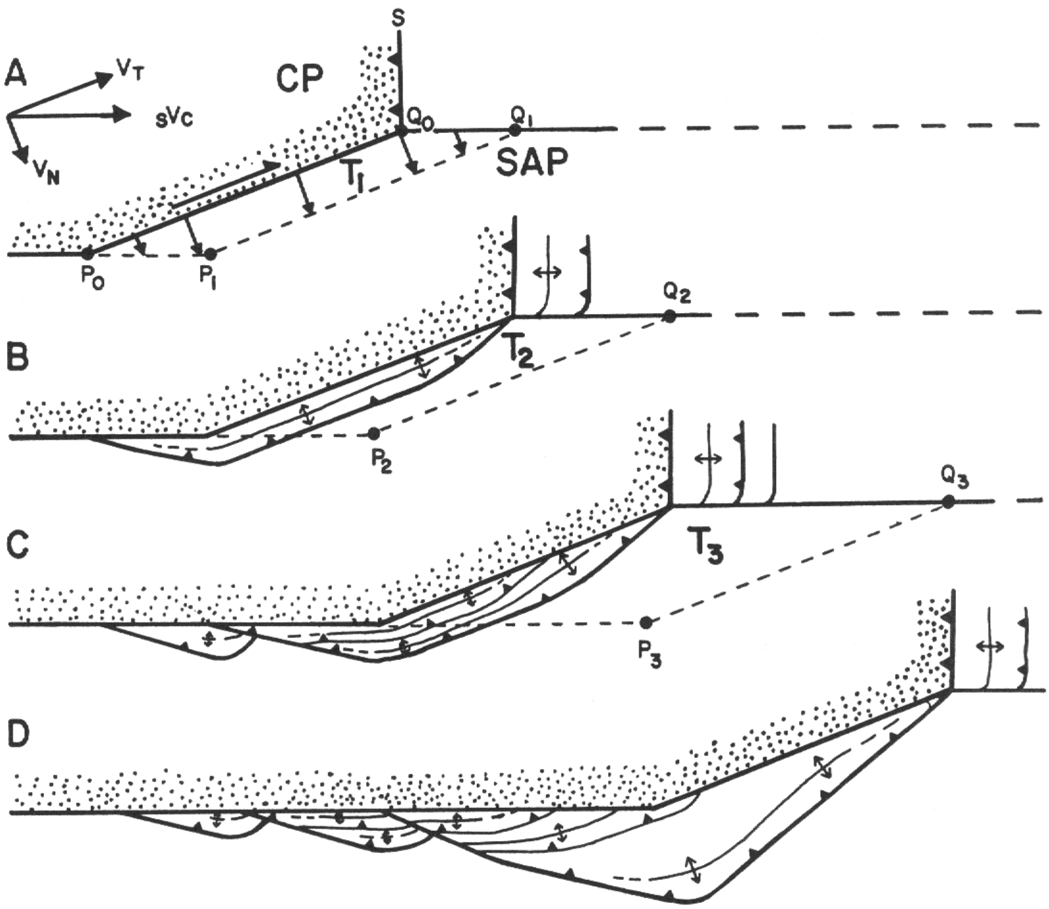

Figure 6. "Snowplow" model for the structural development of the Serrania del Interior fold and thrust belt. See text for explanation.

American basement to be folded and thrust toward the south-southeast. At the same time, relatively thin, distal continental margin sediments are being folded and thrust eastward and partly subducted at the subduction zone S. When the Caribbean plate arrives at P_1Q_1, another slice (T_2) is folded and thrust to the south-southeast. Folds in the first thrust slice (T_1) riding piggy-back style on T_2 may be tightened. This process repeats itself several times (fig. 6C, D). This model is consistent with the decreasing age of deformation and of the basal unconformity in the foreland basin from west to east (e.g. Bellizzia, 1986) and with the style of deformation. However, seismicity along the Urica and San Francisco faults and within the fold and thrust belt (Vierbuchen, 1978) cannot be explained by the snowplow model because the Lesser Antilles arc passed by the area a long time ago. The deformation responsible for the seismicity may be relted to the small convergence between North and South America (Pindell et al., 1988).

The D_3 structures, recognized in the Araya Peninsula, are much better developed near the El Pilar fault (Vierbuchen, 1984) and the San Francisco fault. Similar structures occur in the Miocene to lowermost Pleistocene clastic deposits near Cumaná (Ascanio, 1972). These structures may be related to restraining bends and left stepping of the dextral east trending El Pilar strike-slip fault (fig. 2).

A speculative north-south cross section through the entire Caribbean-South American plate boundary zone at the approximate longitude of Margarita Island and the Araya Peninsula is shown in Fig. 7. The plate boundary zone is almost 300 km wide and consists of allochthonous belts which all share a common decollement surface. This entire zone may be called an "orogenic float" after Laubscher (see Oldow et al., 1989). The cross section is to some extent based on Bellizzia et al. (1976), Biju-Duval et al. (1983), Case et al. (1984), and Rossi (1985). The following eleven comments are related to the locations 1 to 11 in Fig. 7:

(1) The thickness of the Caribbean oceanic crust is taken from Case et al. (1984). It is not known whether it consists of volcanic arc material (Aves Ridge) or of the typical anomalously thick Caribbean oceanic crust.

(2) South-dipping reflectors, north of La Blanquilla Island, may indicate minor Neogene underflow of the Caribbean plate underneath the South American plate (Biju-Duval et al., 1983), related to Neogene convergence between North and South America.

(3) A major positive Bouguer anomaly (Bellizzia et al., 1976) may require the occurrence of a peridotite slab at depth. This slab may have been emplaced during the Oligocene/Miocene D_2 deformation.

(4) The western Leeward Antilles arc was active until about 80 Ma (Beets et al., 1984). Latest Cretaceous/earliest Paleogene biotite K/Ar dates of trondhjemites of La Blanquilla Island (Santamaría and Schubert, 1974) may be uplift ages or may indicate a somewhat later cessation of arc magmatism in the east.

(5) The Atlantic oceanic crust, subducted at the Lesser Antilles subduction zone, is stretched and boudinaged. Presently, it may be a rather wide ductile shear zone.

(6) Serpentinized peridotites, schists, arc plutons, and Eocene sediments exposed on Margarita Island are thrust northward during the Oligocene to Miocene D_2 deformation (Guth and Avé Lallemant, this volume). The contact between the Eocene and older rocks is sheared. Peridotite bodies larger than those exposed on Margarita may occur at depth to explain a major positive Bouguer anomaly over Margarita Island (Bellizzia et al., 1976).

(7) Between Margarita Island and the Araya Peninsula several east-west striking dextral strike-slip faults have been postulated. Here, only one such fault, the Coche fault (Feo-Codecido et al., 1984) is shown; it (fig. 1) may be the continuation of the North Coast fault zone, north of Trinidad (Robertson and Burke, 1989). Several Neogene east-west striking normal faults observed by Biju-Duval et al. (1983) and in Bellizzia (1986) are not shown for simplicity (but see fig. 2).

(8) Several east-west trending faults (not shown in fig. 7 for simplicity) were mapped in the Araya Peninsula (fig. 2) by Schubert (1971). These faults separate higher-grade metamorphic rocks to the north from lower-grade ones to the south. Thus, they can be interpreted as thrust faults which have been active during the Oligocene/Miocene. Slickenside lineations (Schubert, 1971) indicate that they became strike-slip faults subsequently.

(9) The dextral El Pilar strike-slip fault has been active from the Oligocene to the Present (Pérez and Aggarwal, 1981; Vierbuchen, 1984). As Oligocene/Miocene shortening in the foreland fold and thrust belt amounted to at least 40 km (Rossi, 1985) and perhaps even two to three times as much (Felipe Audemard, personal communication, 1990), the El Pilar fault must have migrated southward considerably along the same decollement surface lying beneath the fold and thrust belt.

(10) Several thrust faults (fig. 2) have been mapped in the Serrania del Interior fold and thrust belt (Bellizzia et al., 1976; Rossi, 1985); only five are shown in fig. 7 for simplicity. It should be noted that nothing is known about the deeper parts of the belt.

(11) A strong negative Bouguer anomaly has been interpreted by Potié (1989) to indicate a deep foreland basin which caused a down flexure of the crust. Other alternatives, such as lower bulk densities of the basin sediments and higher densities caused by repeated Cretaceous section in the hinterland may explain the gravity anomaly as well (Felipe Audemard, personal communication, 1990).

PRELIMINARY CONCLUSIONS AND PROBLEMS

The Caribbean - South American plate boundary zone in eastern Venezuela consists of four tectonostratigraphic terranes: 1) the Leeward Antilles volcanic island arc, 2) the Margarita terrane, a subduction complex or forearc terrane, characterized by high P/T metamorphic rocks, 3) the Cordillera de la Costa belt consisting of intermediate to low P/T metamorphic rocks, the protolith of which may have been deposited on a passive continental margin, and 4) the foreland fold and thrust belt of the Serrania del Interior. The first three terranes are probably of Cretaceous age; the fourth consists of Cretaceous and Paleogene passive margin deposits and Neogene orogenic sediments. The contact between the metamorphic belts and the foreland fold and

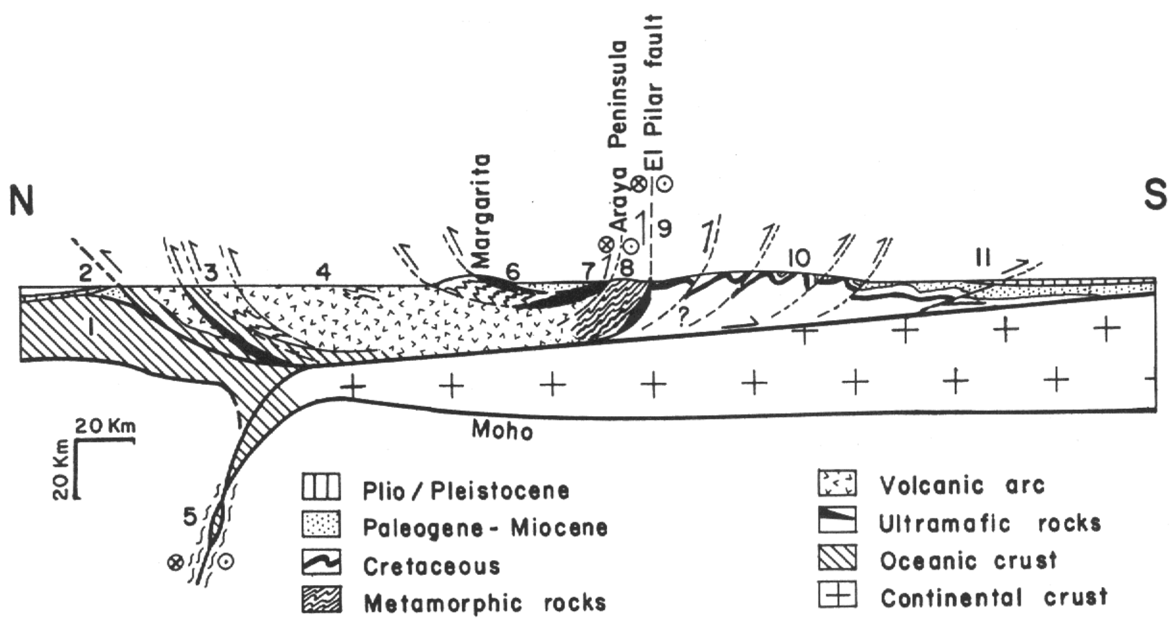

Figure 7. Speculative north-south cross section through the Caribbean - South American plate boundary zone at the approximate longitude of Isla de Margarita and Araya Peninsula. See text for discussion.

thrust belt, is the east trending right-lateral El Pilar strike-slip fault.

All terranes north of the El Pilar fault have undergone the same deformational history. Five generations of folds were recognized. The first three (D_{1a} to D_{1c}) may have formed in the Late Cretaceous; the fourth (D_2) in the Oligocene/Miocene; and the fifth in the Pliocene to Recent.

The first deformation (D_{1a}) is synchronous with high P/T metamorphism in the Margarita terrane and intermediate P/T metamorphism in the Cordillera de la Costa belt. It is characterized by isoclinal folds. The fold axes trend east-northeasterly and are parallel to the principal extension X_{1a}. The D_{1b} structures are coaxial and coplanar with D_{1a}. They formed at lower P/T conditions. The D_{1c} structures are late synmetamorphic. They clearly formed by east-west extension. This stretching parallel to the suture zone may be the result of increased obliquity of plate convergence (increase of the strike-slip component parallel to the suture) and thus of increased suture-parallel displacement rate of the forearc terrane.

The D_2 structures of Araya are mainly southeast vergent folds and thrust faults. They are correlated with the Oligocene/Miocene structures in the foreland fold and thrust belt in the Serrania del Interior. These structures resulted from southeastward displacement which may not have been the result of northwest-southeast convergence of South and North America, but of the eastward migration of the Caribbean plate. The Lesser Antilles/Aves Ridge and Leeward Antilles arcs may have acted as a "snowplow" pushing the terranes sideways toward the southeast.

The D_3 structures are directly related to the displacements along the El Pilar fault. They formed during the Pliocene to the Present.

Many problems are still to be solved. The main problems are related to poor age constraints. There are no faunal nor radiometric ages available for the Araya Peninsula. A few samples are currently being prepared for $^{40}Ar/^{39}Ar$ dating to constrain the age of metamorphism and/or uplift.

The age of formation of the Caribbean seafloor is not well-constrained either. The Caribbean crust is much thicker than normal oceanic crust (Case et al., 1984) and may represent an oceanic plateau formed within the Farallon plate. The collision of the plateau with the Proto-Caribbean plate is thought to be the cause of the flip of the subduction zone and the resulting insertion of this plateau (Caribbean plate) between North and South America (Pindell et al., 1988). The Caribbean plate is often correlated with the B" reflector which may be of Campanian age. If correct, the subduction reversal must be post-Campanian in age (Pindell et al., 1988; Pindell and Barrett, 1987). Ross and Scotese (1988) argue, however, for an Albian (~100 Ma) subduction reversal. Thus, it is imperative to start a deep-drilling program in the Caribbean to learn the composition and age of the Caribbean crust.

Another problem is related to the relatively local nature of the present study. Additional studies are needed in northern and northwestern Venezuela and in Columbia to test the proposed hypotheses. These studies should include structural analysis and age dating.

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