OCEANOLOGICA ACTA, 1981, N° SP

Geology of Barbados : implications for an accretionary origin

Active margins
Subduction
Accretionary prism
Tectonics
Caribbean
Barbados

Marges actives
Subduction
Prisme d'accrétion
Tectonique
Caraïbes
Barbades

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ABSTRACT

The Barbados Ridge composes the major part of the forearc region of the Lesser Antilles magmatic arc. The toe of the ridge is almost certainly the locus of modern accretion of sediment from the subducting Atlantic seafloor. The pre-Pleistocene geology of the island of Barbados, which exposes the crest of the Barbados Ridge, is best explained by accretion, implying that the ridge as a whole is an accretionary prism. Important elements of the island geology in this interpretation are the occurrence of much if not all of the pre-Pleistocene rocks in fault-bounded packets and the juxtaposition of age-overlapping abyssal pelagite and continent-derived fan deposits in such packets. The orientation of tectonic structures on Barbados, however, implies that the Paleogene subduction that created the older part of the prism occurred in a differently configured zone from the present one.

Oceanol. Acta, 1981. Proceedings 26th International Geological Congress, Geology of continental margins symposium, Paris, July 7-17, 1980, 259-265.

RÉSUMÉ

Géologie de la Barbade : implications pour une origine par accrétion.

La ride de la Barbade forme la plus grande partie du domaine de "force arc" de l'arc magmatique des Petites Antilles. Le front de la ride est presque certainement le siège d'une accrétion actuelle de sédiments issus du fond atlantique en subduction. La géologie des terrains pré-pléistocènes de l'île de la Barbade, où affleure la crête de la ride de la Barbade, s'explique très bien par une accrétion impliquant que la ride, dans son ensemble, soit un prisme. Dans cette interprétation, les éléments importants de la géologie de l'île sont l'existence d'unités entièrement limitées par des failles, pour l'essentiel des séries pré-pléistocènes, et la juxtaposition dans ces unités, de séries pélagiques abyssales et de séries d'éventails sédimentaires dérivés d'un continent, séries qui sont partiellement de même âge. Cependant, les directions des structures tectoniques sur la Barbade impliquent que la subduction paléogène qui créa la partie ancienne du prisme, se soit produite dans une zone autre que celle de la subduction actuelle.

Oceanol. Acta, 1981. Actes 26e Congrès International de Géologie, colloque Géologie des marges continentales, Paris, 7-17 juil. 1980, 259-265.

INTRODUCTION

The Barbados Ridge and the Tobago Trough (Fig. 1), which lie between the southern Lesser Antilles magmatic arc and the deep Atlantic seafloor, compose one of the world's broadest forearc regions, here called the Barbados forearc. There seems to be little dispute that the toe of the Barbados forearc is the site of modern accretion of sediments from the west-subducting Atlantic seafloor. It remains a question, however, whether the entire forearc has grown by seafloor offscrape or whether the inner forearc had a substantially different tectonic evolution. The island of Barbados provides the only exposure (about 50 km^2) of the forearc and an opportunity to investigate the shallow fine structure of the inner forearc near its apparently thickest point. The onland geologic study of Barbados described below indicates that an earlier Cenozoic accretionary origin is indeed likely for this part of the forearc but that the orientations and motions of converging tectonic elements differed substantially from those of the modern arc system.

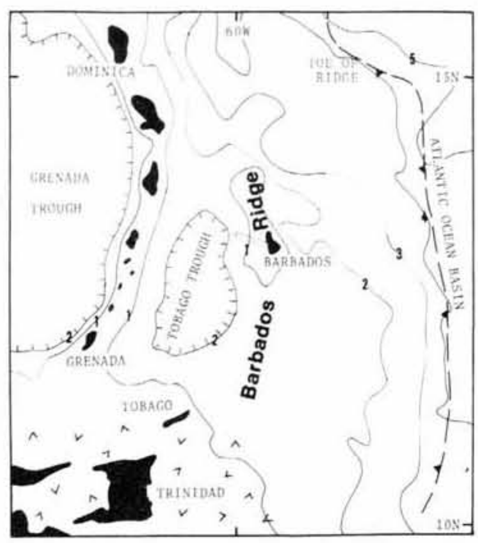

Figure 1

Barbados forearc and adjacent regions ; hachures show probable region of South American borderland ; depth contours in kilometers.

BARBADOS FOREARC

The, crest of the Barbados Ridge (Fig. 1) lies above the subduction trace of the Caribbean and Atlantic crystalline lithospheres, as defined approximately by the seaward limit of concentrated epicenters (Bowin, 1976). The ridge consists chiefly of disturbed low velocity, low density layered rock above oceanic crust (Officer *et al.*, 1959 ; Westbrook, 1975 ; Mascle *et al.*, 1980). Westbrook's (1975) model of the ridge layer based on refraction data thickens west from a knife-edge at the toe of the ridge to more than 20 km at the crest. The Barbados Ridge, about 250 km wide at the latitude of Barbados, narrows abruptly to less than half that width at 15°N (Fig. 1). Between the Barbados Ridge and Lesser Antilles magmatic arc lies the Tobago Trough, a well defined forearc basin containing at least 4 km of undisturbed sediment at its center (Bunce *et al.*, 1971 ; Westbrook, 1975 ; Mascle *et al.*, 1980). Reflection profiles of these workers also show that strata on the outer flank of the forearc basin are upwarped and increasingly deformed with depth, implying protracted uplift and perhaps, arcward migration of the crestal or inner region of the Barbados Ridge. The southern boundary of the Barbados forearc apparently trends east and lies just offshore of the crystalline terranes of the South American borderland such as those exposed in Tobago (Fig. 1).

Reflection profiles show that relatively undisturbed sediment layers above Atlantic crust can be traced as much as 50 km below the ridge layer west from the toe of the forearc north of about 15°N (Chase, Bunce, 1969 ; Westbrook, 1975 ; Peter, Westbrook, 1976 ; Marlow *et al.*, 1974 ; Mascle *et al.*, 1980). Underthrusting of the toe is less evident south of 15°N, either because of inadequate seismic depth penetration or of different sediment transfer mechanisms due to greater ocean floor sediment thickness. Profiles off the southern forearc, however, seem to indicate deformation of Atlantic sediments east of the forearc toe whereas this is absent east of the northern forearc. Taken at face value, the lateral variation in structure at the toe may be related to sediment thickness and proportional values of shear strength and perhaps, flexural rigidity, as noted by Moore (1979). Lateral changes in configuration of the Atlantic slab may also play a role in structural variations in the forearc toe.

Evidence that favors an accretionary evolution of the entire ridge is *a*) the forearc morphology (Karig, 1974 ; Seely, 1978) of the ridge as a whole between a forearc basin and modern offscrape trace and above the lithospheric subduction trace ; *b*) deformation of outer forearc basin sediments, including apparently young layers, indicating that the crest of the Barbados Ridge is still active as an outer rise (or trench-slope break) and responding to modern accretion ; *c*) the apparent continuity and uniform velocity between the crest and toe of the ridge-forming layer of deformed sedimentary rocks ; and *d*) the architecture of Barbados island as a series of fault packets of terrigenous, pelagic, debris flow and hemipelagic rocks, as discussed below. Arguments that might be used against an accretionary origin of the inner forearc are *a*) the large components of NS shortening that affected all pre-Pleistocene rocks exposed on the island of Barbados (Speed, 1980) ; and *b*) the existence of a magnetic source below the western flank of the Barbados Ridge (Westbrook, 1975).

Westbrook (1975) and Peters and Westbrook (1976) found that the magnetic field over the Barbados Ridge is flat except for a linear positive anomaly of as much as 100 nT some 30-40 km west of the ridgecrest. Westbrook (1975) modeled the anomaly with induced sources as either extensive deep weakly magnetized rocks at the base of the low density layer or as a shallower tabular mass within the western limb of the ridge. The former source might be taken as continental basement to the ridge, in support of Meyerhoff and Meyerhoff's (1972) assertion that South American crust underlies the Barbados Ridge and that the ridge is unrelated to subduction. Westbrook's (1975) shallow model, however, might be taken to indicate the existence of a remnant ophiolite wedge of a form envisioned by Seely (1978) between nonmagnetic low velocity layers of the Tobago Trough and Barbados Ridge sedimentary rocks. The ophiolite, if it exists, must be well serpentinized because it has no recognized gravity and velocity effects. Figure 2 shows a model profile of the Barbados Ridge based on Westbrook's (1975) seismic model and the assumption that a trapped ophiolite wedge and suprajacent abyssal pelagic rocks front the west side of the ridge. As defended below, the model assumes that the entire ridge is an accretionary prism.

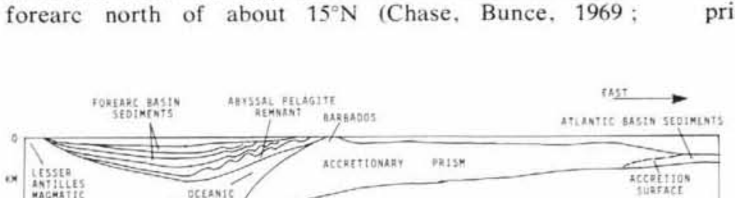

Figure 2

Structural model of Barbados forearc, modified from Westbrook, 1975.

GEOLOGY OF THE ISLAND OF BARBADOS

Barbados exposes about 50 km^2 of deformed sedimentary rocks below uplifted Holo-Pleistocene reef-related cover in the Scotland district. Figure 3 shows a geologic map of the district and Figure 4 provides a diagrammatic section emphasizing major relationships among faults and lithic suites. Lithotypes at the surface exist in wells to depths as great as 4.5 km (Baadsgaard, 1960) and apparently characterize Westbrook's (1975) thick ridge-forming model layer. Thus, although the area of exposure of the ridge foundation is miniscule, Barbados seems to provide a representative sample of inner forearc constitution. The only published previous field studies on Barbados are those of Senn (1940 ; 1948).

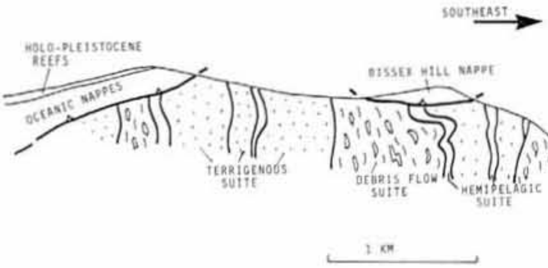

Figure 3
Progress geologic map of the Scotland district, Barbados.

As indicated in Figures 3 and 4, the Scotland district is composed of fault-bounded packets of two types (Speed, 1980 ; 1981 ; Larue, Speed, 1981) : 1) shallowly inclined sheets or nappes : the Oceanic nappes (the Oceanic Formation of Senn, 1940) and the Bissex Hill nappe ; and 2) a series of steeply dipping, east-trending packets. Some twenty steep packets have been identified in a local area of detailed study from Chalky Mount to Cattlewash (Fig. 3) ; steep faults exist elsewhere in the Scotland district, but their traces have yet to be mapped. Each steep packet contains but one of the three rock suites, two of which are equivalent to Senn's (1940) Scotland and Joe's River Formations (Table).

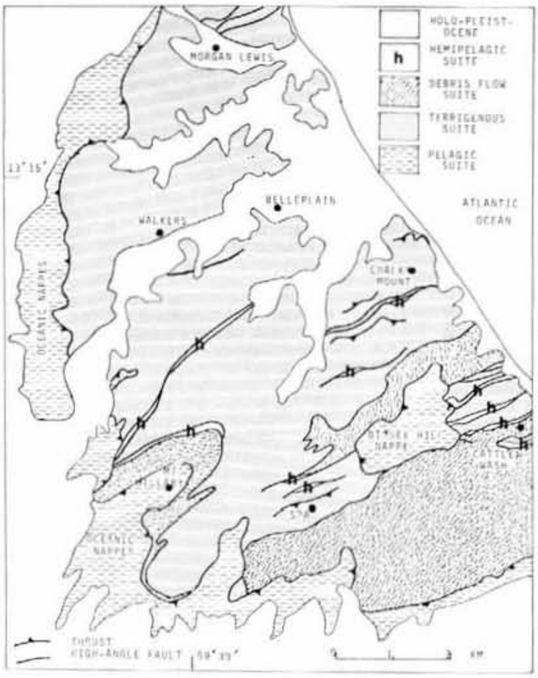

Figure 4
Diagrammatic cross section of the Scotland district showing relationships among nappes, steep fault packets, and lithic suites.

The nappes consist of pelagic rocks and the Bissex Hill Formation and form a structural cap above the steep fault packets (Fig. 3 and 4). Evidence that the nappes are not autochthonous is : 1) folded beds within the nappes are discordant to their base ; 2) meager exposures and trenches indicate a fault or tectonic breccia at lower nappe contacts ; 3) ages of lowest exposed rocks in the nappes vary laterally (Early to Late Eocene) ; and 4) the age ranges of rocks of the nappes and terrigenous rocks of the subjacent steep packets overlap, as discussed below. The Oceanic nappes probably consist of at least several thrust sheets of pelagic rocks as indicated by exposed faults and lateral differences in composition of contemporaneous rocks. The displacement of the nappes is poorly known ; at present, a NNW or

Table
Pre-Pleistocene lithotypes of the Scotland district ; nomenclature of Senn (1940) in parentheses.

	STRUCTURAL UNITS	ROCKS	DEPOSITIONAL AGE	DEPOSITIONAL ENVIRONMENT
NAPPES STEEP FAULT PACKETS	*Oceanic nappes* pelagic suite (Oceanic Fm.)	Foraminiferal-nanno-plankton-radiolarian marl + radiolarian earth + ash	Early Eocene-Late Oligocene	Deep oceanic
	Bissex Hill nappe Bissex Hill Fm.	Foraminiferal arenite	Early Miocene	Upper slope, resedimented (?)
	Pelagic suite	Marl + radiolarian earth	Middle Eocene	Deep oceanic
	Hemipelagic suite	Radiolarian earth + marl + quartz sandstone + mudstone	Early Eocene + ?	Slope basins ?
	Terrigenous suite (Scotland Fm.)	Quartz sandstone + conglomerate + mudstone	Paleocene to post Middle or Late Eocene	Trench wedge or fans
	Debris flow suite (Joe's River Fm.)	Organic pebbly mudstone + bedded mudstone/ss + blocks	?	Slumped lower slope deposits

SSE direction seems most likely and the magnitude is probably large with respect to subjacent rocks. The age of last motion of the nappes is no older than Late Oligocene, and at least as young as Early Miocene for the Bissex Hill nappe.

The steep packets are composed of rocks of the terrigenous, hemipelagic, and debris flow suites (Table). Each is identified by major differences in lithotypes and(or) structural character. Their fault boundaries are mostly sharp, but some, especially those bounding hemipelagic masses, include tectonic breccia (Speed, 1981 ; Larue, Speed, 1981). Transport direction on one of the steep faults (the Chalky Mount fault zone of Speed, 1981) is left-oblique with an easterly pitch of about 30°. The magnitude of displacement on such faults has been great enough to juxtapose strongly contrasting lithotypes of the terrigenous suite. Based on dimensions of fan facies models (*e.g.*, Walker, 1978), magnitudes of at least a few kilometers are reasonable. The ages of motions between the steep fault packets are uncertain because ages of rocks in such packets are poorly known.

Rocks of the Scotland district are entirely sedimentary and comprise four lithic suites, as outlined in the Table. Metamorphic and locally derived igneous rocks are absent. The pioneering geologic study of Barbados (Senn, 1940) assumed that stratigraphic continuity exists among rocks of the Scotland district. However, new work indicates that stratigraphic successions cannot be correlated between packets and that age ranges of rocks in at least some of the four suites overlap. Depositional contacts between rocks of different suites are apparently absent except for two occurrences : 1) the transition from hemipelagic to terrigenous beds within a block in the debris flow suite ; and 2) the apparently unconformable base of the Miocene Bissex Hill Formation on older pelagic rocks in the Bissex Hill nappe (Larue, Speed, 1981). Thus, it is apparent that the four suites are not derived from a depositional succession, and as inferred below, some contemporaneous lithotypes may not even have been depositionally contiguous.

The pelagic rocks consist of biogenic and volcanogenic particles that apparently accumulated at sites remote from terrigenous input. Such rocks have yielded Early Eocene to Miocene ages in surface samples (Senn, 1948 ; Saunders, 1965 ; Saunders, Cordey, 1968 ; Riedel, Sanfillipo, 1971 ; Lohmann, 1974 ; W. R. Riedel, written comm., 1980). Faunas in Eocene pelagite represent abyssal to deep bathyl sites (P. L. Steineck, written comm., 1980) whereas those in Miocene beds (Conset Marl) indicate shallower depths (1.0 to 1.5 km ; Steineck, Murtha, 1980). Paleobathymetry of Oligocene pelagite is not yet well enough constrained to know whether a steady or sudden (Miocene) shallowing occurred. It should be noted, however, that the Miocene rocks are not clearly in depositional continuity with older pelagic rocks.

The terrigenous suite comprises quartzose turbidite and mudstone of continental provenance. A spectrum of fan facies is represented (Speed, 1980). Upward thickening successions climaxed by tabular massive and graded sandstones of depositional lobes are most abundant. Successions of coarse channelized rocks and interchannel strata of inner fan facies also exist. The range of depositional ages of the terrigenous rocks is virtually unknown. A Paleocene or Early Eocene age is known from a short mudstone interval in a drill core (J. B. Saunders, oral commun., 1978), and resedimented faunas collected from two or three coarse turbidites by A. Senn indicate a maximum age of Middle or Late Eocene (Speed, 1980). Thus, rocks of the terrigenous suite may represent a significant time span, and their configuration in fault slices permits them to have been deposited over a broad region. Although the terrigenous rocks can be related to current fan models (Mutti, 1977 ; Walker, 1978), there is no implication whether they came from a single or multiple fans, or whether the fan was of the apical, base-of-slope type or a longitudinal trough fill.

The hemipelagic suite contains radiolarian earth, minor marl, and occasional interbeds of turbidite. The turbidites contain quartz and mud pebbles which indicate sedimentation at sites with access to primary terrigenous influx or to resedimented debris from nearby terrigenous rocks. An Early Eocene age is known for hemipelagic rocks from three fault packets (W. R. Riedel, written comm., 1980).

The debris flow (?) suite is predominantly foliated diamictite (melange), an assembly of well-oriented angular blocks of terrigenous sandstone and clay ironstone, soft green mudstone granules, and minor pelagite lenses in a scaly cleaved organic mudstone matrix. It also includes intervals of thin terrigenous mudstone and muddy turbidite (Larue, Speed, 1981). The age range of deposition of such rocks is unknown. The provisional interpretation of accumulation by debris flow is based on vague stratification by clast size and orientation locally within the diamictite and by the inclusion of thin-bedded muddy rocks and mudclasts which may have been slope deposits. The strong lithic affiliation of the rock clasts to rocks of the terrigenous suite suggests the latter suite underlaid the slope that supplied the debris flows.

The Miocene Bissex Hill Formation (Senn, 1948 ; Saunders, 1968) lies with probable angular unconformity on Oligocene ? (Lohmann, 1974) and Eocene (Riedel, Sanfillipo, 1971) pelagite of the Bissex Hill nappe. The formation consists chiefly of coarse foraminifera, the benthic fauna of which has a paleodepth of approximately 0.3 to 0.5 km according to Steineck and Murtha (1980). Coarse-grained quartz, glauconite, and lithic components, however, are sprinkled through this chiefly massive deposit, suggesting that it is not in fact pelagic. It seems more likely that the Bissex Hill Formation contains resedimented particles that were derived in part from a relatively shallow source and possibly deposited at considerably greater depths.

All rocks of the Scotland district are deformed, but the degree varies, as follows : 1) beds in nappes are generally less deformed than those of steep slices ; 2) the number, tightness, and(or) orientations of fold sets differ among most major packets ; and 3) some packets show deformation gradients related to fault boundaries and to intrapacket thrusts (Speed, 1981). Moreover, both steep packets and nappes are openly folded.

Studies to date in packets of terrigenous rocks (Speed, 1981 ; Larue, Speed, 1981) have resolved one to three phases of folding. Axial planes of all phases strike east ± 45° and verge both northerly and southerly, predominantly northerly. The deformation of each packet is related in that each has undergone shortening with a large north-south component, and this orientation seems to exist throughout intrapacket folding. Penetrative structures are absent, and rare spaced anastomosing (scaly) cleavage is restricted to the muddy matrix of disrupted sandstones which occur locally in fault walls. Deformation apparently took place under relatively shallow brittle-ductile conditions.

The most fully examined and best exposed packet of terrigenous rocks (packet 5 of Speed, 1981) is about 400 m maximum width between bounding faults and contains three fold phases (Fig. 5). The first folds are chevron and nearly recumbent ; limbs of the fundamental halfwave of the first set were initially quasiplanar for at least 300 m from the hinge. Second folds are relatively high frequency and fold first fold limbs about axial planes that dip between south and west. Many second folds of the inverted limb of the fundamental first fold are inverted (Fig. 5). The spatial density of second folds increases from near zero along the centerline of the fault packet to a nearly continuous waveform at the northern fault boundary. The fold gradient and orientation of second folds relative to the fault indicate the folds represent shear strain in the fault walls created by left-oblique slip (pitch 30°-50°) of packet 5 with respect to adjoining packets to the north. Third folds are large and open and have similar orientation range as second folds ; however, they fold the packet boundary as well as rocks within. To sum up, packet 5 evidently contains pre-, syn-, and post-fault folds.

Rocks of the debris flow suite possess sequential deformation features (scaly cleavage, folds of layers and cleavage) with orientation ranges like those in packets of terrigenous rocks. Rocks of the hemipelagic suite, on the other hand, contrast with those of other steep packets by their seemingly minor deformation. Hemipelagic beds are commonly in steep east-striking homoclines or open asymmetric folds but are only rarely tightly folded. Radiolaria in such rocks are apparently undeformed.

The nappe-restricted pelagic rock suite is variably folded ; open major folds are most common, but a couple which are associated with thrusts are tight and overturned. Axial traces of such folds are easterly, and vergence is both north and south. The latest folds on Barbados have northeast-striking axial planes and developed after nappe emplacement.

To conclude, the deformation histories of all fault packets, both steep slices and nappes, seem to be related in the rotation of layers about axes within 45° of east and by the common orientations of axial planes which indicate north-south components of shortening with or without shear strain related to fault slip. There is as yet no recognized preferred sense of overriding by fold vergence. Because their boundary faults do not apparently cut the Oceanic nappes, juxtaposition of steep fault packets apparently took place before nappe emplacement, within the duration Middle Eocene-Pliocene. The nappes are tentatively interpreted to have attained their present sites in the Miocene or Pliocene.

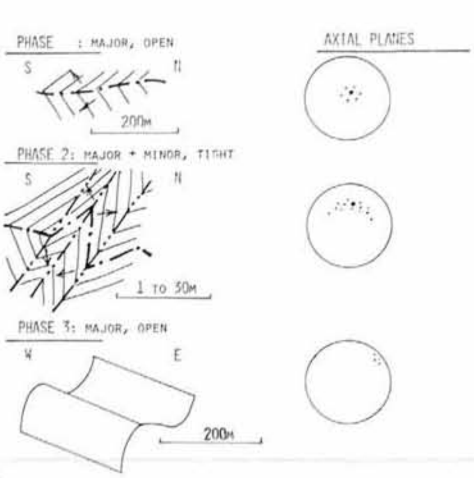

Figure 5

Fold sequence in terrigenous rocks of packet 5 of Speed (1981).

INTERPRETATIONS RELATIVE TO AN ACCRETIONARY ORIGIN

Within the limitations of incomplete dating and field study of rock units and tectonic features, the geology of Barbados is best interpreted as a product of seafloor offscrape, thus permitting the entire Barbados Ridge to be accretionary. The juxtaposition in fault packets of diverse sedimentary lithotypes of deep marine origin supports an accretionary model. In particular, the proximity of the pelagic suite, which seems to have been deposited in isolation from continental sediment, and the age-overlapping terrigenous suite is hard to explain otherwise.

The four pre-Pleistocene lithic suites of the Scotland district can be assigned to contemporaneous depositional realms in a model forearc (Fig. 6) which might represent the Barbados Ridge in the Eocene or Oligocene. The model assumes that subduction was initially intraoceanic and that the forearc basin evolved above a trapped ophiolite wedge bearing a cover of abyssal pelagite. Accumulation of pelagic material continued on a forearc terrace that was the arcward flank of the deeply submerged accretionary prism. Such material included biogenic and arc-derived particles, and the ratio of calcitic to siliceous tests probably increased with time as the terrace shallowed by continued accretion. With the onset of subduction, a conduit may have been created for egress of continental sediment, presumably from South America (Speed, 1980), to more distant oceanic sites. Thus, the terrigenous suite is envisioned as a trench wedge (Schweller, Kulm, 1978), perhaps with fining and thinning oceanward of the trench axis. Axial flows of siliciclastic sediment in the trench may also have deposited drapes of mudstone and muddy turbidite on the lower trench slopes. Such deposits, together with blocks of subjacent terrigenous rocks that were earlier accretants, sporadically peeled off the lower slope as debris flows and came to rest in the trench. Hemipelagic rocks were deposited in slope basins, generally above the level of large siliciclastic mud input but in proximity to sources of quartz sand from older accreted terrigenous sediments.

The model of Figure 6 is successful in that rocks of the terrigenous and debris flow suites would undergo similar accretionary histories and thus could have acquired comparable tectonic fabrics, as observed. The model predicts that depositional contacts between debris flow and terrigenous rocks may exist, although none is recognized thus far. It also accounts for the lesser deformation of rocks of the hemipelagic suite than those of adjacent fault packets

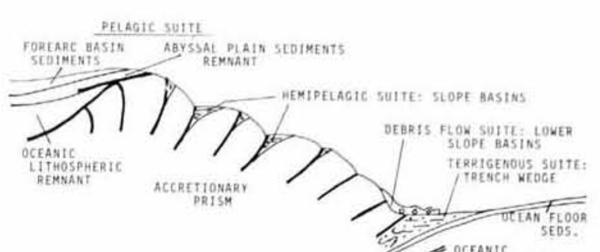

Figure 6

Diagram indicating possible depositional realms of the four lithic suites of the Scotland district, assuming an accretionary origin of the entire Barbados forearc.

because the former have not undergone accretion. The model, however, does not explain why the hemipelagic suite contains chiefly siliceous tests ; here, I must assume that the hemipelagic slices represent the deep roots of slope basin deposits formed rather low on the slope and that younger, more calcareous equivalents deposited higher on the slope have been largely eroded. The model must assume that pelagic rocks of the subducting Atlantic seafloor are totally consumed or, at least, not transferred to an external part of the accretionary prism. The paucity of abyssal pelagite in prisms with abundant terrigenous sediment seems to be widespread (Scholl *et al.*, 1977).

The deformation history of rocks of the terrigenous and debris flow suites in the steep fault packets can also be interpreted to record an accretionary origin. In general, axial surfaces of early or pre-fault folds are at high angles to faults whereas younger and fault-related folds are more nearly parallel to the steep faults. Employing the model of arcward rotation of accreted sediment packets from near-horizontal at the prism toe to vertical or overturned at the outer rise (or trench-slope break) (Karig, 1974 ; Karig, Sharman, 1975), the steep faults of Barbados may represent originally shallowly inclined accretion surfaces (Fig. 7 *a*). If so, the pre-fault folds would have had originally steep axial surfaces that perhaps record initial shortening in trench sediments against and(or) below the prism toe before detachment from the subducting plate. The fault-related folds, created during detachment and(or) later slip within the accretionary prism, thus may have been initially more shallowly inclined and rotated to steeper attitudes (Fig. 7 *b*). Steep packets that seem not to have early, now-recumbent folds may simply not have undergone large shortening before detachment, perhaps because they lacked competent strata.

The arcward rotation of fault packets during prism growth may have caused the outer rise to migrate arcward, as proposed by Seely (1978). Thus, outer rise motions could have deformed the inner forearc, deepening the Tobago Trough, and progressively folding and underthrusting the trapped abyssal pelagites and succeeding outer forearc basin pelagic deposits. The underthrust pelagic rocks, which became the nappes of Barbados, presumably detached from an horizon within the pelagic succession, such as Eocene horizon A'', or perhaps from the trapped ophiolite.

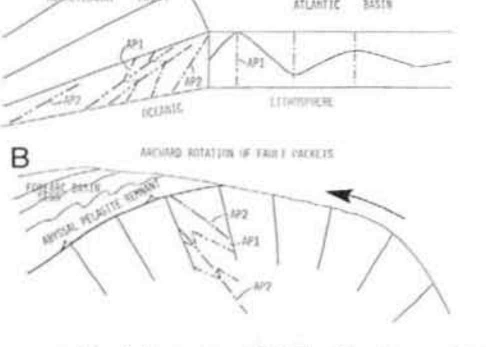

Figure 7

Accretionary model of phase 1 and 2 folds (Fig. 5) ; A : first folds formed with initially steep axial planes in trench just outboard of offscrape trace ; second folds contemporary with detachment of sediment packet below prism. B : arcward (counterclockwise) rotation of accreted packets and folds to position on outer rise and underthrusting of trapped pelagic rocks and outer forearc basin strata by accreted rocks passing outer rise ; AP is axial plane.

Although the geology of Barbados can be interpreted as arising by accretion, the strikes of folds and faults differ markedly from those indicating EW shortening and N-striking accretion surfaces that would be predicted from the present normal subduction of the Atlantic seafloor below a NS-trending arc-trench system. Therefore, appeal must be made either to 1) large rotation of initially EW shortened elements created by the existing subduction configuration ; or to 2) development of the older (inner) part of the accretionary prism under a subduction system of different orientation from that of the present.

The first hypothesis is unlikely as explained by Speed (1981) because 1) shortening directions in Paleogene rocks throughout the southeastern Caribbean and adjacent South America are approximately NS ; 2) penetrative right-lateral shear of the Caribbean with respect to South America could not yield such large and regionally uniform rotations ; and 3) rigid block rotations could not be expected to provide the regional uniformity of rotation, especially where both continental and arc elements are involved. Moreover, earlier oblique convergence along the present Atlantic-Caribbean boundary can be discounted as a means of creating the observed NS shortening (Speed, 1981).

Therefore, it seems more probable that early accretion in the Barbados forearc occurred in a different subduction configuration from the present. Ladd's (1976) calculation of closure between North and South America in the Paleogene suggests that the Caribbean plate was partly consumed in that interval (Ladd, Watkins, 1978). Such subduction may have been intraoceanic in part and along a more easterly-trending zone than the present one. Figure 8 *a* shows a

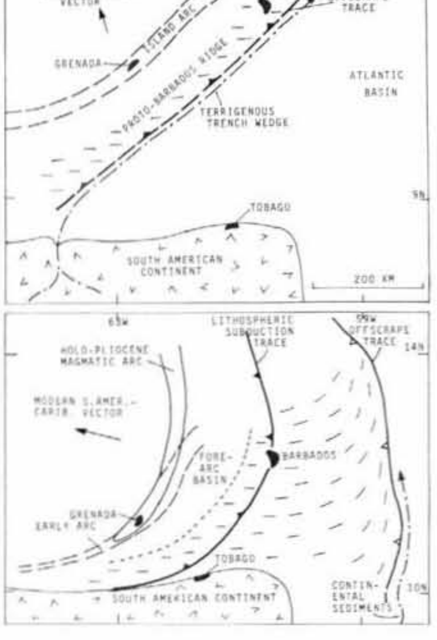

Figure 8

Conceptual model of evolution of Barbados forearc. upper frame : Paleogene arc-trench system and precursor to Barbados forearc undergoing approximate north-south shortening. Lower frame : possible relationship of early arc to present one and change of shortening orientation in accretionary prism. Short dashes are axial traces, assumed normal to shortening direction.

conceivable configuration of a Paleogene arc that, given the right plate velocities, could yield approximately NS shortening in accreted sediment packets and left-oblique slip within the prism.

The western reach of the postulated early arc may have collided with South America late in the Paleogene, yielding NS shortening in the continental borderland (Fig. 8 *b*). In the Neogene, reorganization of plate motions (Ladd, 1976) established the present subduction configuration which may have generated a new magmatic arc and EW shortening in Neogene accretants. The source of terrigenous sediment from South America may have shifted during the forearc evolution from a drainage off the north coast to the east coast, as currently exists (Fig. 8). The southern half of the new magmatic arc was apparently built on the old arc, as implied by the superposition of the Late Neogene volcanos on a foundation of deformed Paleogene arc-derived rocks (Tomblin, 1975). The northeasterly extent of the old arc is uncertain.

To conclude, the geology of Barbados supports an origin of the entire Barbados Ridge by accretion of trench sediments from the subducting Atlantic against a Caribbean magmatic arc. Paleogene subduction that created the inner prism, however, occurred in a differently configured zone from the present one, probably with a more easterly trend, and was conceivably related in part to NS closure of North and South America in the Paleogene.

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