42. GUATEMALA MARGIN: A MODEL OF CONVERGENT EXTENSIONAL MARGIN?[1]

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ABSTRACT

The results of DSDP Legs 67 and 84, during which a transect of holes was drilled across the Middle America Trench off Guatemala, show no accretion at the front of that subduction zone since early Eocene time. The tectonic evolution of the Trench includes extensional structure on the landward as well as the seaward Trench slopes. The Guatemalan margin is proposed as the model of the convergent-extensional active margin (CE margin).

INTRODUCTION

Two major types of continental margins, passive and active, are distinguished in the classical view of plate tectonics. Passive margins develop as a result of rifting and spreading along an ocean ridge, and are marked by extensional and occasional transcurrent structure within a single plate. Active margins develop as a result of the subduction of an oceanic plate beneath a continent or island arc, and are often marked by compressional and transcurrent structure along the boundary between the plates.

Compressional stress is emphasized as playing a major role along active margins; earthquake focal mechanisms and the global plate-motion schemes are cited as evidence of compression. Global plate motion certainly indicates plate convergence, but compressional stress requires friction between plates across the subduction zone, and if the friction is low, the compressional stress will be correspondingly little. Thus, convergence does not necessitate compression.

RESULTS OF DSDP LEGS 67 AND 84: SUBDUCTION WITHOUT ACCRETION

The concept of the accretionary prism is related to the foregoing view of compressional stress with considerable friction between plates. A succession of wedges accumulates at the front of the continental margin, in proportion to the amount of the seafloor subducted and the corresponding amount of sediment available for accretion. A gradual uplift and rotation of the imbricate stack results from continued operation of this process, and tectonic slices of oceanic material are superposed in a reverse stratigraphic order, with the older at the top and the younger at the bottom of the prism (Seely et al., 1974; Seely, 1979).

As the concept of the accretionary prism evolved, marine seismic data were cited to support the general model, and landward-dipping reflections (Fig. 1B) were interpreted as reflections from fault planes of the imbricated ocean sediment in the Middle America, Marianas, and Japan trenches (Moore, Watkins, et al., 1979, 1982; Karig, 1971).

The combined study of seismic reflection records and Deep Sea Drilling Project (DSDP) cores from active margins showed, however, that the reflections are not necessarily from fault planes. Landward-dipping reflections could be not only bedding planes, but also older tectonic features; sedimentation is very complex, and tectonic histories contain both compressional and extensional episodes. Geophysical data from below the cover of slope deposits will not, taken alone, provide sufficient criteria for interpreting a margin's tectonic evolution; corresponding geological data concerning rock history must also be considered in weighing the possible interpretations.

Only on the Barbados margin (DSDP Leg 78A) did drilling give direct evidence of accretion (Biju-Duval et al., 1981). The top (upper Miocene to Quaternary) of the Upper Cretaceous to Quaternary oceanic sediment sequence is repeated, and although the contact with the main subduction zone was not drilled, reversals in the stratigraphic order were recovered and high pore pressures (300 psi) were measured.

Drilling on the Mexican margin (DSDP Leg 66) of the Middle America Trench (Acapulco Trench) provided indirect evidence of accretion (Moore, Watkins, et al., 1979, 1982). Coarse-grained sediment, ranging from upper Miocene to Quaternary, was drilled on the margin. Quaternary sand was first recovered in the Trench (Site 486), then older (upper Miocene) sand was drilled upslope (Site 492), and Pliocene sand was recovered at the site in between (midslope, Site 491). This disposition was interpreted as resulting from at least three tectonic slices in reverse stratigraphic order, as in the accretionary model. Clearly, this is only one interpretation, one implying that coarse-grained sediments are confined to trench deposits. But sand could also be trapped and ponded in basins on the margin, as shown by the drilling off Guatemala (Aubouin, von Huene, et al., 1982) and in many

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places around the Pacific, such as the Peru–Chile Trench (Schweller et al., 1981; Sheperd and Moberly, 1981; Thornburg and Kulm, 1981).

The results of drilling on active margins can only be explained using other models in addition to the classical accretionary model. Instead of uplift during subduction, subsidence was observed on the Japan (Langseth et al., 1981; von Huene et al., 1982; Karig et al., 1983) and Marianas trench margins (Hussong and Uyeda, 1981). Instead of very young sediment at the front of the continental slope, old material was recovered in the Middle America Trench (Upper Cretaceous and Eocene) during Legs 67 and 84 (Aubouin et al., 1979; von Huene et al., 1980; Aubouin, von Huene, et al., 1982). The Leg 84 results are essential (Fig. 1A). In four holes a pre-early Eocene ophiolitic basement was recovered, confirmed by the dredging of Aptian–Albian cherts at two surface outcrops close to Site 570 (von Huene, Friesen, et al., this volume) and by the radiometric data obtained on the basement 78, 132, and 168 m.y. old, (respectively, at Site 567; Bellon, Maury, et al., this volume). If the Campanian-Maestrichtian limestones were recovered in place at the very front of the slope (Sites 494 and 567), a Cretaceous unconformity was also recovered in two holes. So the ophiolitic basement of the Guatemala Trench landward slope could belong to the substratum of Central America, because similar ophiolites crop out in Guatemala and Costa Rica. As a consequence, no net accretion has occurred in the Middle America Trench off Guatemala, at least since the very beginning of the Eocene (around 60 Ma), if not since the pre-Campanian (around 70 Ma). The ophiolitic complex at the front of the slope was drilled to perhaps 20 m above subduction zone, where high pore pressures (350 psi above hydrostatic pressure) caused collapse of the hole and abandonment of drilling.

In the Miocene to Quaternary sediment of the Trench landward slope, sand was recovered, demonstrating that sandy facies are not restricted to the Trench. The Miocene sequence at Site 568 in the midslope area is thicker and coarser than the presently ponded turbidites filling the Trench axis.

The combined results of Legs 67 and 84 thus demonstrate that (1) landward-dipping seismic reflections representing major discontinuities are ancient and not features formed during the present tectonic regime (Fig. 1C); (2) there has been no net accretion of the sediment entering the Middle America Trench off Guatemala since early Eocene time; and (3) sandy sediment is not invariably a facies deposited only in the trench and not on the slope, and without other diagnostic data sandy facies cannot be used as a paleoenvironmental indicator.

GUATEMALA TRENCH, END-MEMBER MODEL

The Middle America Trench off Guatemala has been as well studied as any subduction trench in the world. Only there has a trench axis been drilled to igneous ocean crust (Sites 499 and 500 of Leg 67), and only there has a landward trench slope been drilled to basement in four places (Sites 566, 567, 569, and 570 of Leg 84); the Middle America Trench is the first, and so far the only, trench to have been surveyed precisely with Seabeam (Aubouin, Stephan, et al., 1982) and Deep Tow (Moore, Lonsdale, et al., 1982). The data from all these investigations allow us to propose a Guatemala Trench model (Fig. 2) strongly supported by seismic and geologic data.

Reprocessing of the principal seismic records along the IPOD Guatemalan transect (GUA-13 and 18) has imaged structure not seen in the earlier displays of Ladd et al. (1982) (von Huene et al., this volume). The structure of a series of benches on the lower slope (Fig. 3) consists of poorly bedded slope deposits truncated along an irregular escarpment at the landward bench edge. Escarpments along thrust faults are generally formed by folds, and are straight. The benches are therefore interpreted as scarps from large-scale failure of the slope along a series of seaward-dipping normal faults. Such large-scale failure is consistent with the smaller-scale normal faulting on the lowest bench. Although Deep Tow data (Moore, Lonsdale, et al., 1982) may indicate a local accreted ridge at the foot of the slope, the principal structure in GUA-18 is truncation at the foot of the Trench slope.

The Cocos Plate has a horst-and-graben structure inherited from seafloor spreading at the East Pacific Rise, as shown by Cyamex diving (Rangin and Francheteau, 1981). The horst and graben enter the Trench obliquely, dividing it into a succession of diamond-shaped basins separated by bottlenecks corresponding, respectively, to graben and horst of the ocean plate. Landward of the Trench axis, the Cocos Plate continues into the subduction zone beneath the continental margin.

These features in the seismic reflection records (Ladd et al., 1982; von Huene et al., this volume) and in the Seabeam (Aubouin, Stephan, et al., 1982) and Deep Tow (Moore, Lonsdale, et al., 1982) surveys are confirmed by drilling results (Fig. 1A). The Cocos Plate ocean crust that was drilled at the foot of the continental slope (Leg 67, Site 500) is 150 m higher than in the adjacent graben (Site 499; Figs. 1A and 2), and cores show clear extensional features, specifically normal faults, in the otherwise undisturbed Miocene chalk; sediment subducted with the lower plate shows little compressional strain.

Thus, as the Cocos Plate flexes down into the subduction zone, the tensile stress from plate bending causes an extensional horst-and-graben structure, which breaks along the original plate grain inherited from the spreading ridge, rather than parallel to the axis of flexure. This is rather normal trench phenomenon. The less common features along the IPOD transect are the normal faults on the landward slope of the Trench (Figs. 1 and 3). The landward normal-faulted slope is documented by the Seabeam survey and seismic reflection records GUA-13 and 18 (Fig. 3). Along this part of Guatemala, the Trench axis has, then, the morphology of a very large graben.

The Guatemala Trench was thus proposed as a model of "convergent-extensional active margin" (CE active margin) (Aubouin, Bourgois, et al., 1982, 1984). The collapse of the Trench landward slope can be explained as resulting from subsidence of the oceanic Cocos Plate in the subduction zone. Perhaps the ocean-plate subsidence was accelerated slightly, thereby causing a loss of support beneath the landward plate: subsidence may have been caused by thinning of the continental crust or by thermal flux (Langseth et al., 1981). Whatever the fundamental cause, collapse is obviously aided by pore pressure at near-lithostatic levels, as measured during failure of the hole at Site 567 just above the top of the subduction zone. This elevated pore pressure essentially causes the upper plate to ride with very little friction above the subducting lower plate (von Huene and Lee, 1982). Certainly, the subduction of all ocean-floor sediment and accommodation of the ocean-floor relief requires extensive decoupling of plates across the Guatemalan subduction zone.

DISCUSSION

Could the Guatemala model be related to its special position south of the sinistral Polochic-Motagua strike-slip zone (i.e., extensional to the south, where the Caribbean Plate is going east, and compressional to the north)? Or is it a more general phenomenon, the CE active margin, as we have proposed?

One must note that the Barbados margin, which could be the model of classical convergent-compressional active margin (CC active margin), involves a thick trench-fill sequence of terrigenous sediments, derived partly from the Orinoco and Amazon submarine deltas, and so differs from the Guatemala Trench, where the fill is only 200 m thick. The thickness of oceanic sediment involved in subduction could be one of the main factors determining accretion or non-accretion, even though not more than the top of the sedimentary trench-fill is accreted in the Barbados Trench. But other determinants include rate of convergence and age of the ocean crust.

Quite a few examples of extensional structures have been shown on convergent margins. Superficial slumping is common on trench slopes where tectonism causes oversteepening and subsequent failure. However, fundamental normal faulting is known in the Aleutian area off Kodiak Island (Fisher, 1979), the Marianas (Hussong and Uyeda, 1981), Peru-Chile (Thornburg and Kulm, 1981; von Huene et al., in press), and Japan (Langseth et al., 1981; von Huene et al., 1982). Generally, the amount of data for these areas is sufficient to evaluate the role of these faults in the development of the margins, whether passive or active. Nevertheless, this discussion is only a first approach to the problem of CE margins, and we think that extension is now too well known to be readily dismissed as a special case or as a shallow mass-movement of superficial origin.

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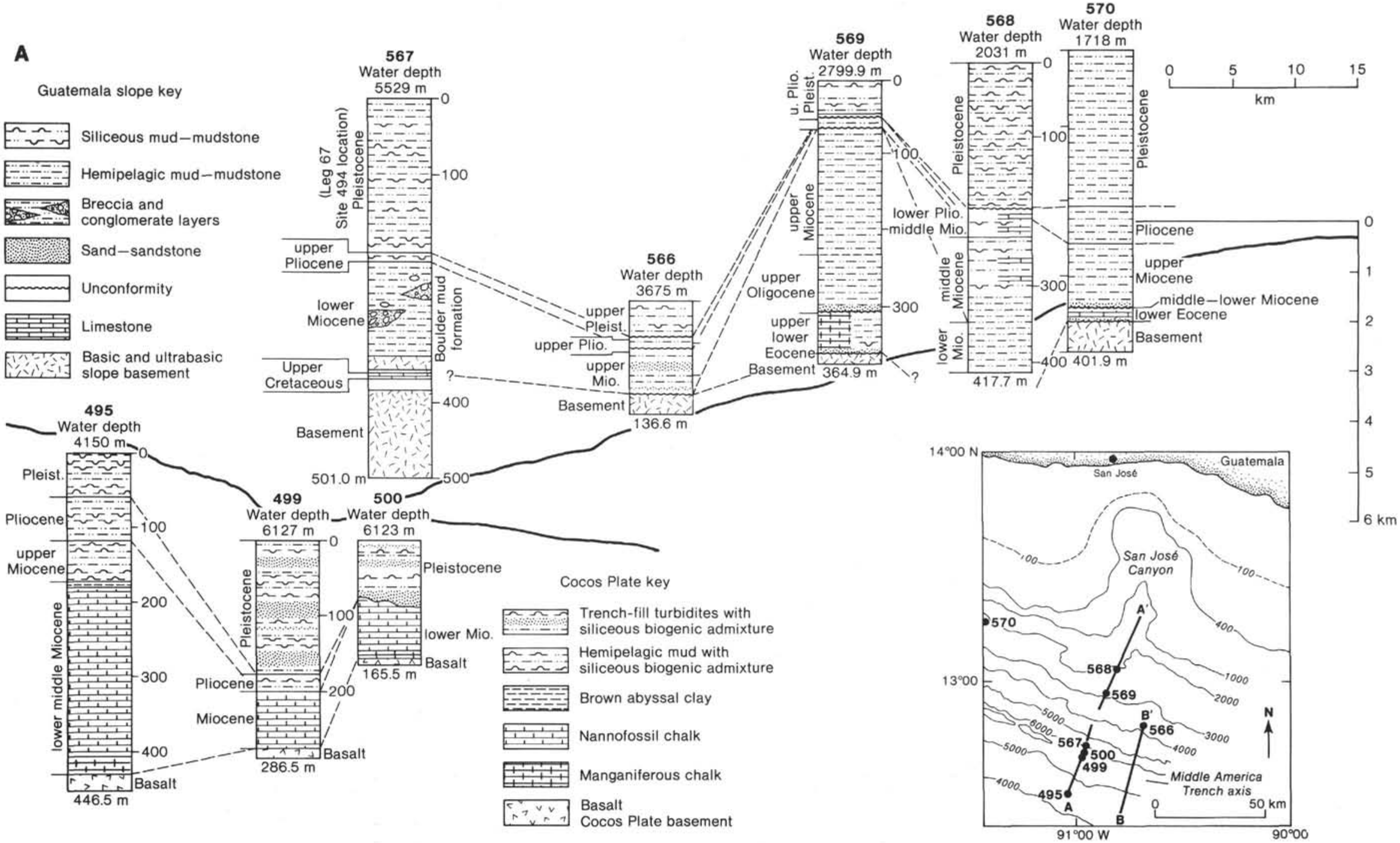
A
Guatemala slope key
Siliceous mud—mudstone
Hemipelagic mud—mudstone
Breccia and conglomerate layers
Sand—sandstone
Unconformity
Limestone
Basic and ultrabasic slope basement
567
Water depth
5529 m
(Leg 67 Site 494 location) Pleistocene
upper Pliocene
lower Miocene
Boulder mud formation
Upper Cretaceous
Basement
501.0 m
566
Water depth
3675 m
upper Pleist.
upper Plio.
upper Mio.
Basement
136.6 m
569
Water depth
2799.9 m
u. Plio. Pleist.
upper Miocene
lower Plio.
middle Mio.
upper Oligocene
upper lower Eocene
Basement
364.9 m
568
Water depth
2031 m
Pleistocene
middle Miocene
lower Mio.
417.7 m
570
Water depth
1718 m
Pleistocene
Pliocene
upper Miocene
middle—lower Miocene
lower Eocene
Basement
401.9 m
km
6 km
495
Water depth
4150 m
Pleist.
Pliocene
upper Miocene
lower middle Miocene
Basalt
446.5 m
499
Water depth
6127 m
Pleistocene
Pliocene
Miocene
Basalt
286.5 m
500
Water depth
6123 m
Pleistocene
lower Mio.
Basalt
165.5 m
Cocos Plate key
Trench-fill turbidites with siliceous biogenic admixture
Hemipelagic mud with siliceous biogenic admixture
Brown abyssal clay
Nannofossil chalk
Manganiferous chalk
Basalt Cocos Plate basement
14°00 N
Guatemala
San José
San José Canyon
13°00
Middle America Trench axis
50 km
91°00 W
90°00

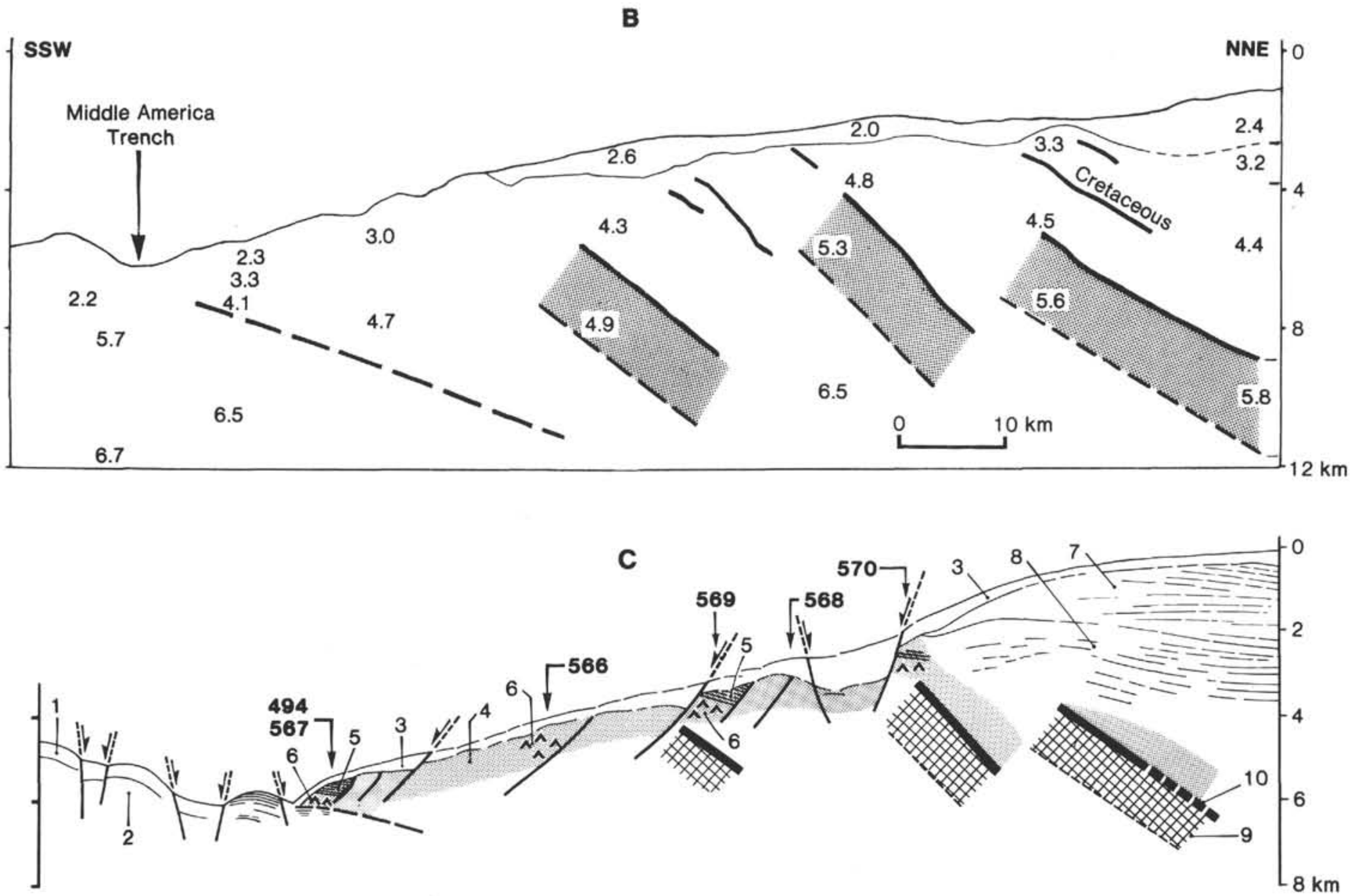

Figure 1. Data from the Middle America Trench off Guatemala. A. Simplified stratigraphic columns summarizing the lithostratigraphy and biostratigraphy of DSDP Legs 67 and 84 drill sites. B. Summaries of seismic-reflection and -refraction studies showing velocity structure and major landward-dipping reflectors on the Legs 67 and 84 transects. C. Interpretation of the structure of the Guatemalan margin. The major landward-dipping reflectors are interpreted as thrust faults bringing pre-Campanian ophiolitic slabs above the Upper Jurassic/Upper Cretaceous oceanic Nicoya Complex, as on land in Costa Rica. 1 = Miocene to Pleistocene sediment cover of Cocos Plate; 2 = basalts; 3 = Pliocene to Pleistocene slope deposits; 4 = acoustic basement; 5 = upper Senonian to Miocene sediments; 6 = ophiolitic rocks; 7 = Oligocene and Miocene forearc sediments; 9 = interpreted as a Nicoya Complex remnant from magnetic and gravity data; 10 = major reflectors interpreted as a pre-Campanian overthrusting; from on-shore data it could be the same as the overthrusting of the Santa Elena Peridotite on the Nicoya Complex.

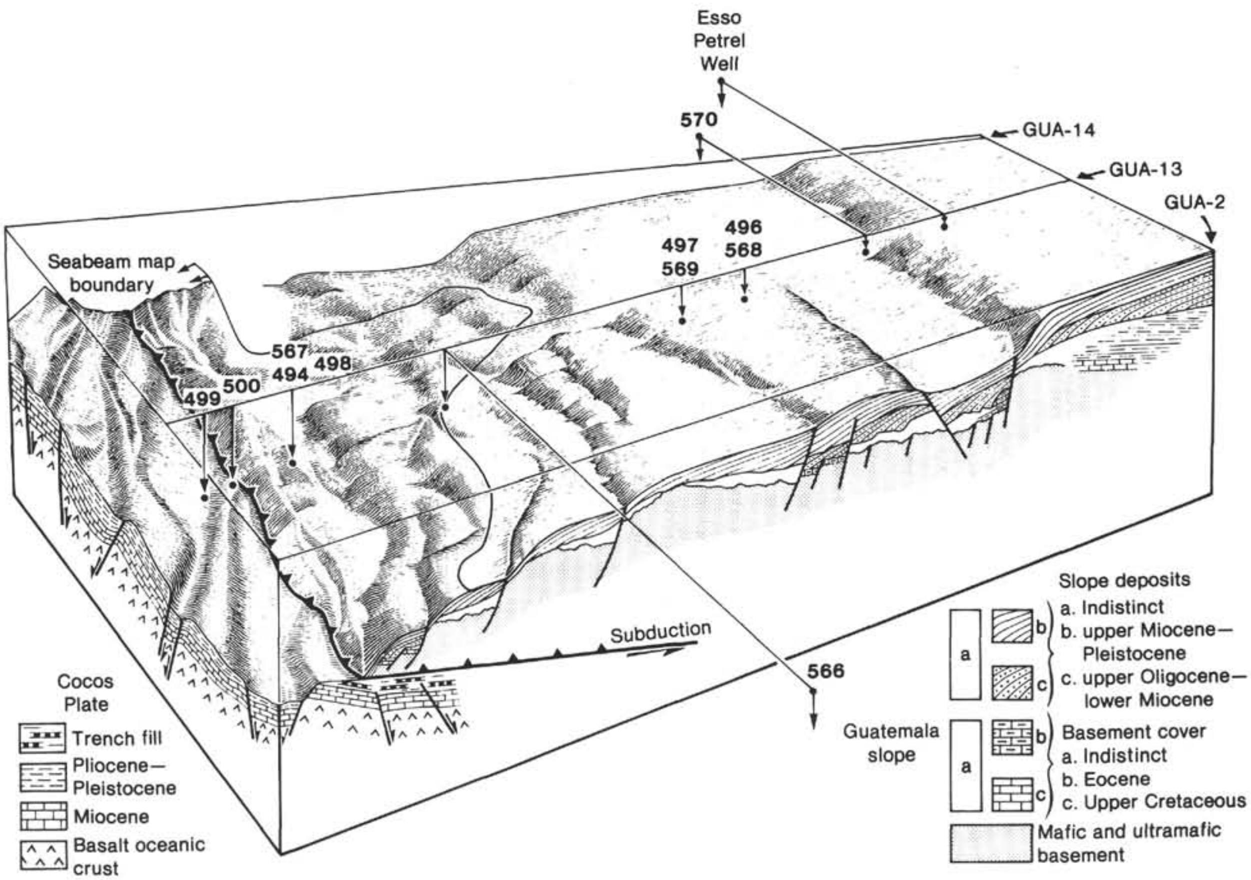

Figure 2. Block diagram showing the convergent zone between Cocos Plate and Caribbean Plate in the Middle America Trench off Guatemala.

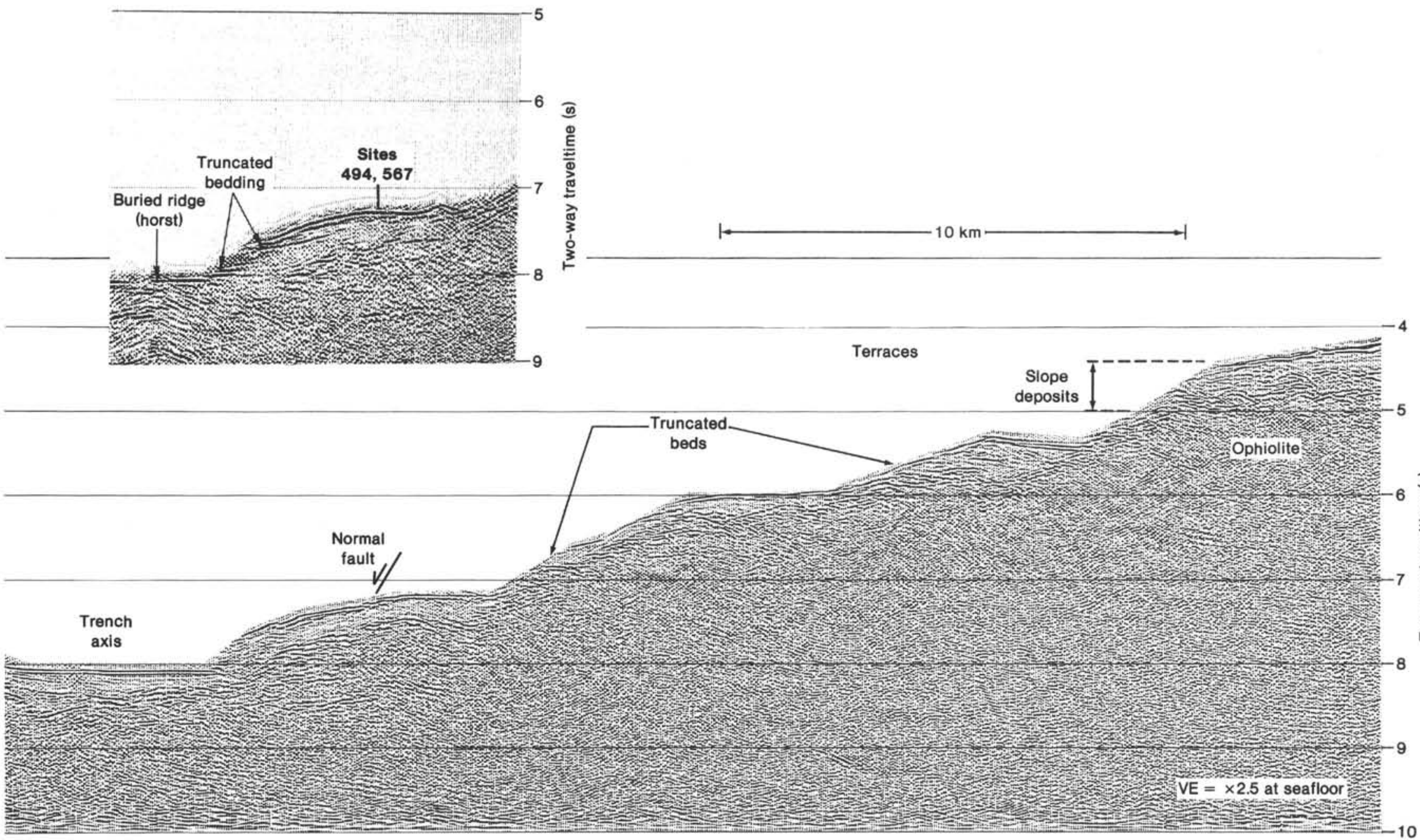

Figure 3. Part of migrated 24-channel seismic reflection records 13 and 18, showing structure of benches on the lower slope of the Trench. Elimination of diffractions from seafloor features reveals that reflections in slope deposits are truncated along the slope behind or on the landward edge of each bench. Small normal faults on the lowest bench of record 13 are not seen in the adjacent record 18, suggesting that they are only local.