OCEANOLOGICA ACTA, 1981, N° SP

A summary of Deep Sea Drilling Project Leg 67. Shipboard results from the Mid-America trench transect off Guatemala

DSDP
Guatemala
Subduction
Tectonic
Trench

DSDP
Guatemala
Subduction
Tectonique
Fosse

J. Aubouin [a], R. von Huene [b], J. Azéma [a], G. Blackinton [c], J. A. Carter [c], W. T. Coulbourn [d], D. S. Cowan [e], J. A. Curiale [f], C. A. Dengo [g], R. W. Faas [h], W. Harrison [f], R. Hesse [i], D. M. Hussong [c], J. W. Ladd [j], N. Muzylev [k], T. Shiki [l], P. R. Thompson [j], J. Westberg [d].

[a] Département de Géologie Structurale, Université Pierre et Marie Curie, 4, place Jussieu, 75230 Paris.
[b] US Geological Survey, Menlo Park, California 94025, USA.
[c] Department of Geology and Geophysics, University of Hawaii, Honolulu, Hawaii 96822, USA.
[d] Scripps Institution of Oceanography, La Jolla, California 92093, USA.
[e] Department of Geological Sciences, University of Washington, Seattle, Washington 98195, USA.
[f] School of Geology and Geophysics, University of Oklahoma, Norman, Oklahoma 73019, USA.
[g] Center for Tectonophysics, Texas A & M University, College Station, Texas 77843, USA, and ICAITI, Guatemala, Central America.
[h] Department of Geology, Lafayette College, Easton, Pennsylvania 18042, USA.
[i] Technische Universität, Munchen, FRG.
[j] Lamont-Doherty Geological Observatory, Palisades, New York 10964, USA.
[k] Geological Institute of USSR, Academy of Sciences, Moscow, USSR.
[l] Department of Geology and Mineralogy, Kyoto University, Kyoto, Japan.

ABSTRACT

The Middle America Trench off Guatemala was transected by 24-channel seismic-reflection surveys, seismic-refraction surveys, and drilling with the *Glomar Challanger.* The drilling was done at three sites on the oceanic Cocos plate and four sites on the Caribbean plate. These plates converge at about 10 cm/yr as indicated by global plate reconstruction. At all drill sites sediment of upper miocene through Quaternary age is almost entirely hemipelagic mud with interbedded thin volcanic ash, except in the trench where mud and fine sand turbidites less than 400,000 years old are ponded. However, the underlying rocks are very different. On the oceanic Cocos plate a basal chalk sequence of lower and middle Miocene age is overlain by a thin interval of abyssal clay. In contrast is the Cretaceous to lower Miocene claystone sequence recovered only at a site 3 km landward of the trench axis where drilling penetrated the hemipelagic slope deposits. A large amount of sediment along with ocean crust has been subducted during the present (Miocene to Quaternary) episode of subduction, and parts of the continental framework may have been subducted as well. No current tectonic model satisfactorily explains the surprising occurence of Cretaceous to Miocene claystone at the foot of the continent.

Oceanol. Acta, 1981. Proceedings 26th International geological Congress, Geology of continental margins symposium, Paris, July 7-17, 1980, 225-232.

RÉSUMÉ

Bilan des résultats de bord du Leg 67 (Deep Sea Drilling Project : fosse d'Amérique centrale au large du Guatemala).

La fosse d'Amérique centrale a été étudiée selon un profil au large du Guatemala, par sismique réflexion (24 canaux), sismique réfraction, et forage du Glomar Challenger. Les forages ont été effectués à 3 sites sur la plaque de Cocos et 4 sites sur la plaque caraïbe. Le taux de convergence, déduit du mouvement global des plaques, est de 10 cm par an. A tous les sites, les sédiments, du Miocène supérieur au Quaternaire, sont presque entièrement des boues hémipélagiques interstratifiées de fines couches de cendres volcaniques ; sauf dans la fosse où se sont déposées des turbidites de boues et sables fins, d'âge plus récent que 400 000 ans. Cependant les roches sous-jacentes sont très différentes. Sur la plaque de Cocos, une séquence basale de craie d'âge Miocène inférieur et moyen, est recouverte par un fin niveau d'argiles abyssales. Au contraire, une séquence de schistes argileux, d'âges allant du Crétacé supérieur au Miocène inférieur, a été forée, à moins de 3 km de la fosse, sous les dépôts hémipélagiques du bas de la pente continentale. Une partie importante des sédiments ont été entraînés avec la croûte océanique pendant le présent épisode de subduction, du Miocène au Quaternaire, de même, probablement, qu'une partie de la pente continentale elle-même. Aucun modèle tectonique courant n'explique de manière satisfaisante l'existence de la série crétacée-miocène au pied de la marge continentale.

Oceanol. Acta, 1981. Actes 26[e] Congrès International de Géologie, colloque Géologie des marges continentales, Paris, 7-17 juil. 1980, 225-232.

INTRODUCTION

The Mid-America Trench transect off Guatemala is the second of two geophysical and drilling transects recommended for the International Program of ocean Drilling (IPOD) across the convergent margin of southern Mexico and Central America. The first, a transect off Oaxaca, Mexico, was drilled on Leg 66 of the *Glomar Challenger* to investigate a convergent margin where the leading edge is a complex tectonically accreted during the Neogene and from the mid-slope landward the terrane is a truncated Precambrian and Paleozoic continental framework (Moore *et al.*, 1979). Off Guatemala our principal objective was to study this margin where geophysical data indicated continuous accretion and imbrication (Seely *et al.*, 1974). Seely and his colleagues made a case for the imbricate thrust model that is widely accepted and this model is supported by the multichannel seismic reflection site surveys (Ladd *et al.* 1978 ; Ibrahim *et al.* 1979).

This paper is patterned after a more complete report prepared on the preliminary results of Leg 67, in which the data from the cores are discussed in greater detail (Aubouin *et al.*, 1979 ; von Huene *et al.*, 1980).

GEOLOGIC SETTING

The Middle America trench is separated by the Tehuantepec ridge in two segments (Aubouin, Tardy, 1980) : the Acapulco segment in the north and the Guatemala segment in the south. A corresponding feature on land, is the active Polochic-Motagua fault zone, which separates the mexican cordillera (Sierra Madre) to the north, from the true Central American terraine to the south. The Polochic-Motagua has been a fundamental boundary of the southern end of the North American continent for a long time : the present motion is a sinistral west-east stike slip, but at the end of the Cretaceous it was a North-South compression with overthrusting of (Caribbean) ophiolites over the end of the Sierra Madre and the Peten platform (= Yucatan platform).

The Acapulco segment of the Middle America Trench lies along the North American continent ; the Guatemalan segment runs along Central America, which is basically a tectonic edifice of old oceanic crust covered by tertiary volcanics. The Acapulco segment abruptly truncates the Sierra Madre structures ; the trench axis is at 45° to the Miocene tectonics axis of the Sierra Madre del Sur and there is only a very narrow continental shelf along tho coast. The Guatemala segment does not cut the Central American structure : the trench axis is parallel to the tectonic edifice that crops out for instances in the Nicoya peninsula (Costa Rica) and there is a wide continental shelf, which is underlain by a tertiary basin with a thick sedimentary sequence (Seely, 1979).

It has been inferred that the Mesozoic igneous rock cropping out in the Nicoya peninsula underlies the Tertiary basin on the continental shelf. A strong magnetic anomaly, running along the continental shelf, can be projected from the Nicoya peninsula along the edge of the shelf (Ladd *et al.*, 1978). Mesozoic sequences crop out, from north to south, in the Santa Elena, Nicoya, Osa, Azuero peninsulas. They consist of :

1) the Nicoya complex, a sequence of oceanic sediments (graywackes, cherts, radiolarites) associated with volcanics (diabasis, pillow lavas), containing rocks of uppermost Jurassic, lower Cretaceous, middle Cretaceous, and upper Cretaceous age ;

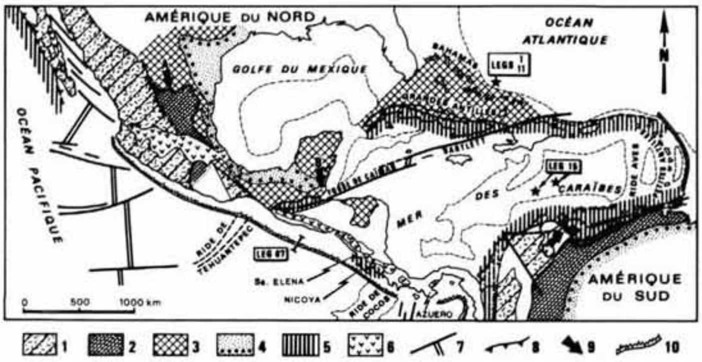
2) the Santa Elena complex, composed of a thick ultramafic body thrust upon a volcano-sedimentary sequence with a litho-facies similar to that of the Nicoya complex complex and consisting of uppermost Cretaceous sedimentary rock (upper Campanian-Maestrichtian) which rests unconformably upon peridotites (Azéma, Tournon, 1980) ;

3) the Azuero complex, showing green-schist facies rock derived from volcano-sedimentary sequence and underlying an unconformable uppermost Cretaceous sedimentary cover (upper Campanian-Maestrichtian).

A feature of great significance is the upper Campanian unconformity : a great tectonic event before the end of the Cretaceous affected all Central America. The Mesozoic sequences of Central America are quite differect from the age equivalent rock of the Mexican Sierra Madre north of the Polochic-Motagua fault zone. They are similar to the franciscan facies cropping out in Baja California, but different in detail ; they can be compared to the westernmost facies of Colombian cordillera, but the data are insufficient for a positive correlation.

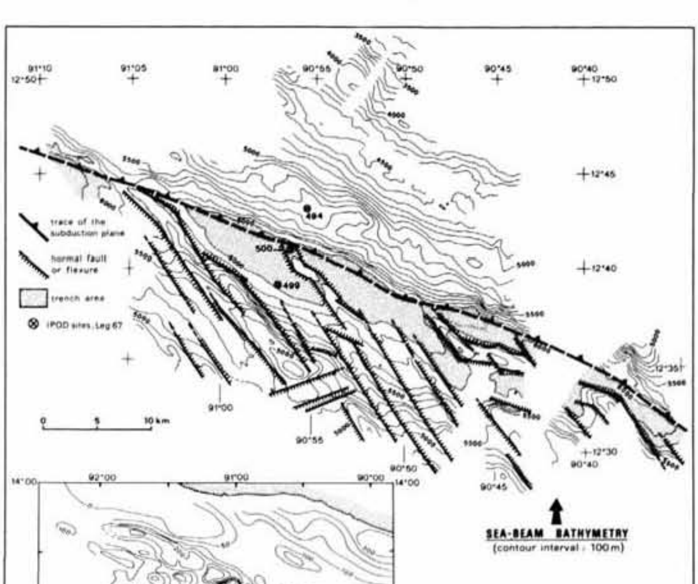
Normal convergence of the Cocos and Caribbean plates along the Middle America Trench off Guatemala has been proposed by various authors (Fig. 1 A) (Minster, Jordan, 1978 ; Jordan, 1975 ; Molnar, Sykes, 1969). The rate of convergence is estimated at 10 cm/yr since the late Miocene, and the compressional tectonism implied by plate convergence is compatible with the geology of the trench slope deduced largely from geophysics (Seely *et al.*, 1974 ; Ladd *et al.*, 1978 ; Ibrahim *et al.*, 1979). The geophysical data indicate that the oceanic crust is subducted beneath the trench landward slope. The subducted crust is overlain by a thick sequence of sediment containing some landward dipping reflections (Fig. 2). Near the top of the trench slope prominent landward dipping reflections become the seaward flank of the forearc basin that is filled with sediment as much as 8 km thick. This thick sediment probably underlies the coast above which tower the volcanoes of the magmatic arc. From a drill hole at the edge of the shelf, Seely (1979) documented an uplift that elevated the thick Mesozoic sequence to shelf depths in the Paleocene. Seely and his colleagues (1974) interpret the structure of the Guatemalan margin as one of stacked and tilted imbricate slices, on the basis of pervasive landward dips in seismic records, as well as a series of benches that may be likely places where large thrust faults have surfaced.

Figure 1



A

A. *(upper diagram) Plate tectonic diagram of the Caribbean area showing the relation of the Caribbean and Cocos plates along the Middle-America Trench. The plates are presently converging at 10 cm/yr across the trench.*
Key to symbols :
1-4 : Zones with continental basement : 1, andesitic volcanic zones with grandioritic plutons (western Sierra Madre, Central Colombian cordillera) ; 2, non-volcanic zones, often with flysch facies (eastern Sierra Madre, southern Sierra Madre, eastern Colombian cordillera, flysch nappes of Venezuela) ; 3, carbonate platform, folded (Texas platform, Sierra Madre de Chiapas) or non-folded (Honduras, Yucatan, Cuba, Bahamas) ; 4, molassic formations (west side of the Gulf of Mexico, Llanos of Venezuela and Colombia).
5 : Zones with oceanic sequences : cherts, radiolarites, associated with ophiolitic bodies, metamorphosed or not in the blueschist facies, overthrusted on the continental margins (caribbean nappes of the greater Antilles and Venezuela, western Colombian cordillera) or dipping under the continental margins (Franciscan of Baja California).
6 : Plio-Quaternary volcanic zones : mainly transmexican volcanic axis and volcanic cordillera of Central America.
7-10 : Tectonics : 7, normal faults, strike slip faults, transform faults ; 8, thrusting ; 9, axial dipping : A, Parras transverse zone ; B, Guatemala transverse zone ; C, Barquisimeto transverse zone ; 10, present day subduction (Middle-America trench, Antilles trench).



B

B. *(lower diagram) Seabeam bathymetric map showing detailed bathymetry around the Leg 67 sites.*

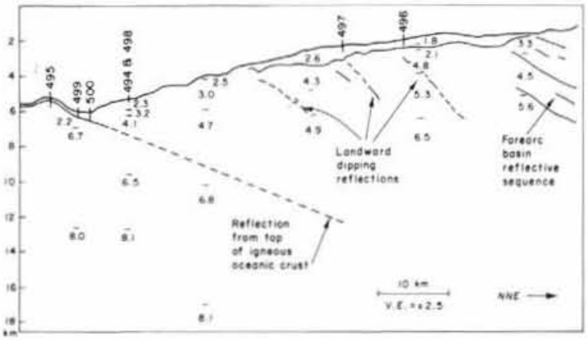


Figure 2

Summary of seismic-reflection and refraction studies showing velocity structure and major reflectors. The location of sites drilled by Glomar Challenger on Leg 67 are indicated.

SEABEAM SURVEY

During a transit from Panama to Acapulco, a Seabeam survey was made by the S.S. Jean Charcot in the Mid America trench (Renard *et al.*, 1980). The survey consisted of a continuous corridor of detailed bathymetry wide running along the foot of the continental slope. Two maps including some sites of Leg 66 and Leg 67, of about 50 km^2 and 100 km^2 respectively were made. The contour interval was 10 m and mapping was done in real time, using a system of the Centre Oceanologique de Bretagne.

The map of the Leg 67 area (Fig. 1 B) shows a system of alternating enlongated depressions and ridges on the Cocos plate. Due to the fact that the scarps are rectilinear and cross the regional bathymetry, they can be interpreted as a horst and graben tectonic structure. The common direction of these structures is N 130-N 140, parallel to the magnetic anomalies of the Cocos plate. This parallelism suggests that this faulting originated along the grain on the plate along the East Pacific rise, as observed in the Cyamex and Rise diving cruises, and that it was reactivated when the plate was flexed as it entered the trench. This faulted structure is seen in the trench to the landwall toe of the trench. As a consequence the trench appears as a succession of diamond shaped ponds, where the graben cross the trench, separated by flat swells representing the partially buried horsts.

The landward slope of the trench is perfectly rectilinear along almost 20 km, and perhaps beyond the seabeam survey ; it shows neither evidence of local or large slump blocks, nor disturbances related to the oceanic plate and trench structures. The slope is divided into rectilinear steps, which seem limited by fault scarps, identified by the fact they do not respect the detailed topography.

In conclusion, in the Leg 67 area, the Cocos plate displays its own typical structure, oriented N 130-140°, as it enters the trench, where these structures determine a succession of oblique basins and swells ; it dives under the continental slope without disturbing it. It seems that here the Cocos plate essentially falls into the subduction zone beneath the American continental margin which is itself extensively faulted parallel to the trench.

DRILLING RESULTS

Cocos Plate

The oceanic Cocos Plate forms the seaward slope of the Middle America Trench off Guatemala (Fig. 1 A). Igneous ocean basement is overlain by a thin sediment blanket that is uniformly 200-300 m thick. Site 495 is on a horst about 22 km seaward of the trench axis and 1,925 m above it. The uniformly thick sediment follows topography (except where faulted), a character commonly interpreted in seismic reflection records as that of "pelagic sediment".

The sediment section penetrated at site 495 records the early and middle Miocene path of this site as it passed northward through the equatorial carbonate belt (Fig. 3) into a zone of normal slow pelagic deposition and then, during the late Miocene, into a hemipelagic environment influenced by a terrigenous source rather than the totally pelagic environment inferred from seismic records. Superimposed on this record are the effects of subsidence as the ocean

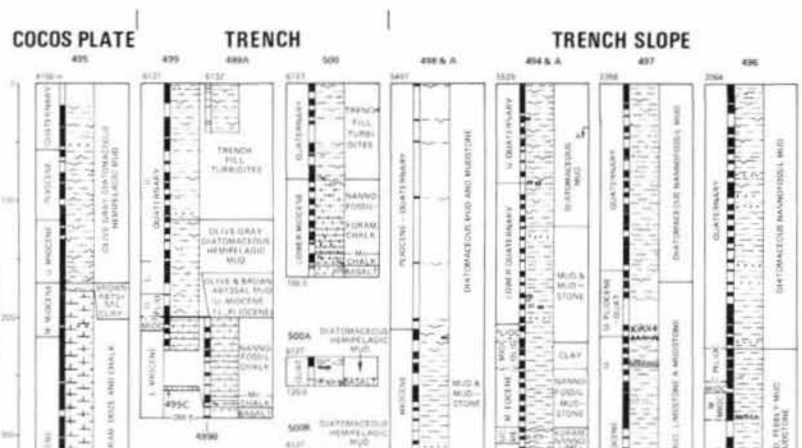


Figure 3

Simplified bio- and litho-stratigraphy of sites drilled on Leg 67.

crust grew older and moved away from the spreading East Pacific Rise. The upper hemipelagic section indicates a surprising volume of sediment transported across the trench a great distance seaward. If present rates of convergence have been constant during deposition of the hemipelagic section, the lowest beds were deposited when the site was about 900 km seaward of the trench. Such great distances of sediment transport are not seen in the present pattern of hemipelagic sedimentation as recorded at other DSDP sites in the area (van Andel *et al.*, 1973 ; Hays *et al.*, 1972).

Trench Floor

On the trench floor flat basinal areas are underlain by horizontal seismic reflectors. These reflectors represent sediment ponded in graben of the Cocos plate that are in turn underlain by weak reflectors. The lower reflectors dip gently landward and are presumed to be the deep ocean sediment section riding into the trench axis on the Cocos Plate.

Sites 499 and 500 drilled on the trench floor include seven holes, most of which bottomed in basalt or basalt rubble at various depths (Fig. 3). Site 499, near the seaward slope, is located on the southern margin of a small diamond shaped basin in the trench. Site 500, at the base of the landward slope, is located on the northern flank of a horst crossing the trench diagonally as shown by the Seabeam survey (Fig. 1 B). The trench fill, as seen in seismic records, is represented by an upper Quaternary (slightly less than 400,000-yr-old) sequence of alternating muddy and sandy turbidites with a microfossil assemblage transported from the shelf and slope. This turbidite sequence is underlain by a complete but abbreviated oceanic sequence like the one recovered at site 495 on the Cocos plate. At site 500 this section is cut by a normal fault that probably formed during the development of the horst and graben structure of the trench seaward slope. The sediment beneath the trench floor is compacted normally and shows few signs of compressional deformation even against the trench landward slope.

The drilling results indicate that the trench is more complex than would be expected from the seismic records. Basalt and basalt rubble occur at levels consistent with the diagonal leg trending basalt basement ridge seen in the Seabeam bathymetry but not in the seismic records. The drill holes appear to be 2 km from the seismic line, a distance that could account for the absence of the ridge in seismic records. The trench fill has no pronounced lateral differences in facies transverse to the trench axis as might be expected from axial turbidity current channels (Piper *et al.*, 1973 ; von Huene, 1974).

Lower Slope of Trench

Benches on the lower slope of the trench, such as the more than 20 km lone one on which sites 494 and 498 are located (Fig. 1 A), are commonly interpreted as having been formed by the emergence of a large thrust fault at the seafloor. Such thrusts cannot be seen in seismic reflection records from the trench off Guatemala ; below the floor of the bench there is a weak sequence of nearly horizontal reflectors that are about 1,200 m thick. At site 494, only 500 m above the trench floor, we recovered a sequence of rock in normal stratigraphic succession that ranges in age from Late Cretaceous to Quaternary (Fig. 3). The Upper Cretaceous rock is about 900 m above the top of igneous oceanic crust as measured in seismic records (Fig. 2).

At site 494 upper Miocene to Quaternary slope deposits cover a sediment sequence similar to that reported by Seely (1979) from the edge of the continental shelf. The environments represented by this sequence, the nature of hiatuses, and their relation to the sequence of the shelf from young to old are interpreted as follows, in descending order :

1) a Pliocene and Quaternary deposit consisting principally of sediment transported from the shelf and upper slope to this site ;

2) an upper Miocene unconformity coincident with the widespread upper Miocene unconformity on the shelf ;

3) a sequence of distal, terrigenous, hemipelagic clay that accumulated during the early Miocene on sea floor near the carbonate compensation depth and at rates an order of magnitude less than, age-equivalent deposits on the adjacent shelf (3 m/MY versus 100 m/MY) ;

4) an upper Eocene to Oligocene hiatus that is the age equivalent of a widespread unconformity in the adjacent shelf section but of unknown origin in the section drilled ;

5) an Eocene hemipelagic clay deposited below the foraminiferal carbonate compensation depth but above the nannofossil carbonate compensation depth at rates at least five times less than age-equivalent shelf deposits ;

6) a hiatus of unknown origin but of an age that is represented by thick, widespread Paleocene sediments below the adjacent shelf ;

7) an Upper Cretaceous claystone that accumulated in an open ocean environment above the carbonate compensation depth CCD at depths about equivalent to, but at rates apparently less than age-equivalent rocks below the present shelf ;

8) a contact of unknown origin between claystone and igneous rocks ;

9) igneous rock originally of calkalkaline basaltic composition and atypical of oceanic crust ; the nature of body sampled is unknown. This sequence shows microfracturing from tectonic stress beginning with rock at the base of the Pleistocene, but there appear to be no large thrust faults cutting the drilled section.

At site 498 only the slope section (olive-gray mudstone) appears to have been penetrated. We interpret the difference in thickness of the Miocene sections of olive-gray mudstone as reflecting relief on the upper Miocene disconformity.

Middle Slope of Trench

Sites on the trench of the middle slope were positioned to penetrate the slope deposits and to sample the underlying landward dipping reflectors. We planned to test whether the reflectors are part of an imbricated stack resulting from subduction, as has been inferred by Seely *et al.*, (1974), Ladd *et al.* (1978), and Ibrahim *et al.* (1979). Drilling was terminated short of the primary objectives for safety considerations because we discovered gas hydrate. Slope deposits, as interpreted from seismic-reflection records, unconformably drape the rock that makes up the bulk of the continental margin (Fig. 2). The slope deposits thin toward the lower slope of the trench.

Site 497 was drilled in olive-gray mud with varying biogenic and vitric tuffaceous components (Fig. 3). It is in general a uniform section of mixed hemipelagic and terrigenous mud interspersed with a thin pebbly mudstone that represents mass movement. A similar litholgy was penetrated at site 496 where the upper sequence is biogenic mud of Quaternary age underlain by biogenic sandy mudstone of Pliocene and Miocene age. Sediment recovered from the mid-slope area contains volcanic ash beds, rich in terrigenous detritus, and yielded a microfossil assemblage displaced from upslope. The foraminiferal assemblage at site 496 indicates subsidence of the site in Miocene time from shelf to lower bathyal depths. This subsidence is coincident with a subsidence reported by Seely (1979) from the adjacent shelf edge.

CONCLUSIONS

Geophysical data from the Middle America trench transect off Guatemala contain nothing unusual when compared with geophysical data from other convergent margins although the records do not resolve much structure at depth along the landward slope of the trench, as is seen, for instance, along the companion transect off Mexico (Moore *et al.*, 1979). The results from drilling off Guatemala also reveal nothing unexpected in the post-middle Miocene sediment. The unexpected results occur in the one drill hole that sampled roçk below the cover of slope deposits, rock that is much older than that anticipated from previous geophysical work. Perhaps another unexpected aspect is the scant evidence for compressional deformation. However, it is difficult geophysically to detect structure that is smaller than a few hundred meters in very deep water, and structure is not well defined from the study of an isolated drill core.

The ocean crust entering the middle-America trench off Guatemala has a Miocene section that clearly records northward passage of the Cocos plate first beneath the equatorial carbonate belt and then into proximity of an upper Miocene to Holocene terrigenous source. The distance from land where the terrigenous sediment first reached the area of site 495 is problematical but is certainly hundreds of kilometers away if plate reconstructions for this area are correct. As the crust was flexed down into the trench, the crust was tensionally faulted into horst and graben that persist beneath the trench until hidden from view under the landward slope of the trench.

The diagonal trend of structures in the downflexed ocean crust is interpreted as reactivation of the planes of weakness imparted to the crust during generation along the East Pacific Rise. Bathymetric coverage is not sufficient to show the beginning of horst and graben structure, but because the overlying sediment cover does not seem to be draped over fault scarps, the faulting must have been relatively recent.

The trench floor is distinguished from the seaward slope of the trench by the ponded turbidites. The ponded sediment contains a microfauna less than 400,000 years old, attesting to the youth of the present trench floor. The youthful sediment and recent tectonism, together with active seismicity and volcanism, are strong evidence for rapid convergence of oceanic and continental crusts. Nonetheless, the failure to find any increase in compressional structure or even initial tectonic consolidation of trench fill and underlying oceanic sediment at the foot of the landward slope is puzzling. In fact, the drilling and geophysical data indicate little tectonism other than the horst and graben of the ocean crust.

On the landward slope of the trench, a cover of hemipelagic sediment of middle Miocene to Holocene age disconformably drapes the underlying continental framework, which is generally obscured in seismic-reflection records. Few DSDP holes have penetrated deeply beneath this disconformity so commonly observed in seismic-reflection records across convergent margins. In seismic-reflection records, the discontinuity consists of reflections paralleling the seafloor overlying landward dipping reflectors (see, for instance, Moore *et al.*, 1979). The slope deposits reveal more small-scale deformation at depths of about 200 m than was seen at site 500 almost at the landward slope of the trench. Thus, in contrast to the trench floor, sediment draped over the slope shows some effects of tectonism.

At site 494, only 3 km landward from the trench floor, we penetrated the slope deposits and found rock that is surprisingly old and overconsolidated. The sedimentary rock here was deposited in water shallower than the carbonate compensation depth and has distal continental affinities. From the shipboard studies we are unable to ascertain the original environments of deposition except to infer that they are of a lower continental slope to shallow ocean provenance. The Miocene section beneath site 494 originated seaward of those deposits recovered from the mid-slope at sites 496 and 497. The section at site 494 deposited close enough to land, or entirely at latitudes north of the carbonate zone of high productivity, not to be inundated by carbonate ooze.

TECTONIC INTERPRETATION

An interpretation of our shipboard data in the context of previous geologic studies is difficult because the data, particularly thoses from site 494, do not fit the commonly applied steady-state model of tectonic accretion (Fig. 4) nor do any of the less often invoked models seem to apply without difficulty. Three end-member models or explanations, all of which may apply in part, include the slumping of a large block, subduction of sediment without accretion, or tectonic erosion.

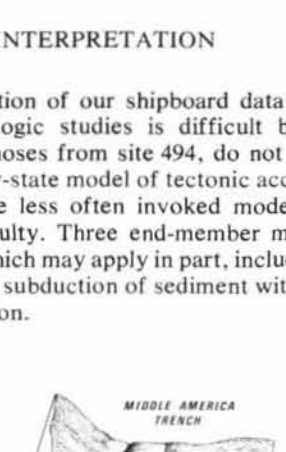


Figure 4

Diagram of subsurface geology across the Middle-America Trench off Guatemala based on geophysics and Leg 67 drilling.

From considerations of sedimentary facies, a slump that displaced the large bench on which site 494 was drilled must have originated in an environment seaward of the shelf edge (Seely, 1979) and of sites 496 and 497. A pre-Pliocene age seems to be required by the blanket of Miocene to Quaternary slope deposits, which has no slump scars as large as the proposed slump block, and also by the mid-Miocene discontinuity between slope deposits and the unexpected site 494 section. Although a slump block would alleviate the problematical absence of compressional structure at the foot of the slope and provide a means of transporting an older accreted section from upslope to the present trench floor, the Seabeam survey shows no scar nor does the perfectly linear and more than 20 km long base of the slope have the characteristic lumpy morphology of a slump. Slumping does not explain the absence of accretion in the Pliocene and Quaternary and the slump explanation requires considerable subduction of sediment.

The concept of sediment subduction since Miocene time implies disposal of a great amount of sediment somewhere down the Benioff zone since the present convergence began (early to mid-Miocene). Perhaps the rather surprising section at site 494 is an anomalous accreted block brought in on the ocean plate, but as in the slumping model the block would have been accreted in the pre-middle Miocene.

It is possible that the pre-Miocene sequence at site 494 originated close to the continental margin, of Guatemala, beginning in the Late Cretaceous. This sequence was deposited contemporaneous with the top of the Nicoya complex that crops out on the continental shelf of Costa Rica. In the Santa Elena peninsula, peridotites are overlain by a sequence beginning exactly at the same time (Upper Campanian-Maestrichtian) as the sequence above igneous rocks at site 494. Because an Upper Cretaceous sequence of sediment is a general feature on the Pacific side of Central America, it seems more realistic to associate the pre-Miocene sequence at site 494 with these late Cretaceous sequences of Central America, instead of a hypothetic terrane rafted on the ocean plate that was incorporated into the continental framework during some ancient collision.

So, if we accept the concept of sediment subduction, we must accept that there is no accretion at the base of the continental margin of Middle America trench. Some subduction of sediment is required to explain the lack of accretion in the site 494 area, however sediment subduction was probably not the only process involved. If a block from the ocean plate was incorporated just prior to the Miocene, all the post Miocene sediment would have to be subducted rather than accreted ; if the pre-Neogene section at 494 was always part of the margin, all post Cretaceous sediment would have been subducted. Periodic sediment subduction seems reasonable but continuous sediment subduction since the Cretaceous does not. Thus there must be another explanation for the lack of accretion since at least Miocene and probably Cretaceous time.

Tectonic erosion is a third concept that might be applied to explain the drill data. Because the vector of plate convergence is normal to the trench axis, little transport in a lateral direction seems appropriate, and tectonic erosion would require subduction of continental fragments, a difficult concept. Tectonic erosion however is an efficient way to truncate the base of the slope despite the conceptional problems of stuffing rock of less density beneath that of greater density or the abrasion of the continental framework on a massive scale. This mechanism has been applied to explain the Neogene truncation of the convergent margin off northern Honshu (von Huene *et al.*, 1980).

As problematical as these explanations may seem, they are briefly discussed here to provide some focus for subsequent study. It seems paradoxical to find more evidence for a passive structural setting than for active tectonism along a margin with such high rates of plate convergence, but this paradox might be a matter of the depths of drilling and the resolution of geophysical data.

REFERENCES

Aubouin J., Tardy M., 1980. L'Amérique alpine : le domaine caraïbe et ses liaisons avec les cordillières nord et sud-américaines : introduction, *26e Inter. Geol. Congr., Paris, Colloq. C5*, 14-17.

Aubouin J., von Huene R., Azéma J., Coulbourn W. T., Cowan D. S., Curiale J. A., Dengo C. A., Faas R. W., Harrison W., Hesse R., Ladd J. W., Muzilev N., Shiki T., Thompson P. R., Westberg J., 1979. Premiers résultats des forages profonds dans le Pacifique au niveau de la fosse du Guatemala (fosse d'Amérique centrale), *C. R. Acad. Sci., Paris, sér. d*, **289,** 1215-1220.

Azéma J., Tournon J., 1980. La péninsule de Santa Elena, Costa Rica : un massif ultrabasique charrié en marge pacifique de l'Amérique centrale, *C. R. Acad. Sci., Paris, sér. D*, **290,** 9-12.

Hays J. S., Cook III H. E., Jenkyns D. G., Cook F. M., Fuller J. T., Goll R. M., Milow E. D., Orr W. N., 1972. *Initial Reports of the Deep Sea Drilling Project, Washington, US Gov. Print. Off.*, **9,** 1 205 p.

Ibrahim A. K., Latham G. V., Ladd J., 1979. Seismic refraction and reflection measurements in the Middle America Trench offshore Guatemala, *J. Geophys. Res.*, **84,** B10, 5643-5649.

Jordan T. H., 1975. The present day motions of the Caribbean Plate, *J. Geophys. Res.*, **80,** 32, 4433-4439.

Ladd J. W., Ibrahim A. K., McMillen K. J., Latham G. V., von Huene R. E., Watkins J. E., Moore J. C., Worzel J. L., 1978. Tectonics of the Middle America Trench offshore Guatemala, *Inter. Symp. Guatemala February 4 Earthquake and Reconstruction Process, Guatemala City, May 1978.*

Minster J. B., Jordan T. H., 1978. Present-day plate motions, *J. Geophys. Res.*, **83,** 5331-5334.

Molnar P., Sykes L. R., 1969. Tectonics of the Caribbean and Middle America regions from focal mechanisms and seismicity, Geol. Soc. Am. Bull., **80,** 1639-1684.

Moore J. C., Watkins J., Bachman S. B., Beghtel F. W., Butt A., Didyk B. M., Leggett J., Lundberg N., McMillen K. J., Niitsuma N., Shepard L. E., Shipley T. H., Stephan J. F., Stradner H., 1979. The Middle America Trench off Mexico, *Geotimes*, **24,** 9, 20-22.

Piper D. J. W., von Huene R. E., Duncan J. R., 1973. Late Quaternary sedimentation in the active Eastern Aleutian Trench, *Geology*, **1,** 1, 19-22.

Renard V., Aubouin J., Lonsdale P., Stephan J. F., 1980. Premiers résultats d'une étude de la fosse d'Amérique centrale au sondeur multifaisceaux (Seabeam), *C.R. Acad. Sci., Paris, sér. D*, **291,** 137-142.

Seely D. R., 1979. Geophysical investigations of continental slopes and rises, in : Geological and geophysical investigation of continental margins, Tulsa, Oklahoma, edited by J. S. Watkins and L. Montadert, *Am. Assoc. Petrol. Geol. Mem.*, **51,** Tulsa.

Seely D. R., Vail P. R., Walton G. G., 1974. Trench slope model, in : *Geology of continental margins*, edited by C. A. Burk and C. L. Drake, Springer-Verlag, New York, 261-283.

van Andel T. H., Heath G. R., Bennet R. H., Bubry J. D., Charleston S., Cronan D. S., Dinkelman M. G., Kaneps A. G., Kelvin S. R., Yeats R. S., 1973. *Initial Reports of the Deep Sea Drilling Project*, Washington, US Gov. Print. Off., **16,** 949 p.

von Huene R. E., 1974. Modern trench sediments, in : *The Geology of continental margins*, edited by C. A. Burk and C. L. Drake, Springer-Verlag, New York, 1 009 p.

von Huene R., Aubouin J., Azema J., Blackinton G., Carter J. A., Coulbourn W. T., Cowan D. S., Curiale J. A., Dengo C. A., Faas R. W., Harrison W., Hesse R., Hussong D. M., Laad J. W., Muzilev N., Shiki T., Thompson P. R., Westberg J., 1980. Leg 67, The Deep Sea Drilling Project Middle America Trench transect off Guatemala, *Geol. Soc. Am. Bull.*, **91,** 421-432.