

35. INTERPRETATION OF SEISMIC REFLECTION DATA OF THE MIDDLE AMERICA TRENCH OFFSHORE GUATEMALA¹

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ABSTRACT

A geophysical and geological survey conducted over the landward slope of the Middle America Trench offshore Guatemala, together with published well information from the outer shelf and Leg 67 drilling results from the toe of the slope indicate that imbricate slices of oceanic crust were emplaced in the landward slope offshore Guatemala in the Paleocene or early Eocene. Since that time, sediment apparently has accumulated on the landward slope primarily as a sediment apron blanketing an older, tectonically deformed prism of sediments and crustal slices. There is little or no evidence for continued tectonic accretion seaward of the volcanic arc during the late Tertiary.

Seismic reflection and refraction surveys have revealed landward-dipping reflections that are associated with high compressional wave velocities, large magnetic anomalies, and basic-ultrabasic rock. Multifold seismic reflection data reveal that the edge of the continental shelf is a structural high of Cretaceous and Paleocene rock against which Eocene and younger sediments of the shelf basin onlap and pinch out. The upper part of the continental slope is covered in most places by a 0.5- to 1.0-km-thick sediment apron with seismic velocities of 1.8 to 2.6 km/s. The base of the sediment apron commonly coincides with the base of a gas hydrate zone where water is 1500 to 2300 meters deep. Immediately beneath the sediment apron an irregular surface is the top of an interval with velocities greater than 4 km/s. Within this interval, landward-dipping reflections are traced to about 6 km below sea level. These reflections coincide with the top of seismic units having oceanic crust velocities and thicknesses.

The sediment apron pinches out on the lower continental slope where refraction results indicate only a few hundred meters of 2.5-km/s material lying over about a kilometer of 3.0-km/s sediment. Between the 3.0-km/s sediment and a landward continuation of ocean crust, an interval of 4.1- to 4.7-km/s material occurs that thins seaward. Near the interface between the 4+ -km/s material and oceanic crust with velocities of 6.5 to 6.8 km/s, reflection records indicate a landward-dipping horizon that can be followed about 30 km landward from the Trench axis.

Coring on the continental slope returned gravels of unweathered metamorphosed basalt, serpentine, and chert, unlike rock generally found onshore in Guatemalan drainage basins feeding the Pacific coast. These gravels, which were probably derived from local subsea outcrops, are similar to lithologies found on the Nicoya Peninsula farther south.

A canyon cut in the outer continental shelf and upper continental slope may be associated with faulting, as indicated by an offset of linear magnetic anomalies at the shelf edge.

In a general way our observations are consistent with previous suggestions that slices of rock, some of which may have oceanic crustal lithologies, are imbedded in the upper slope. However, the reflection data collected for the Deep Sea Drilling Project site survey do not show the many concave upward landward-dipping reflections that have been reported from other areas offshore Guatemala. The lower slope is probably a tectonically deformed and consolidated sediment wedge overlying oceanic crust, but it is not clear that it is organized into a series of landward thinning wedges. The structures within the landward slope may have originated during the late Paleocene to early Eocene tectonic event and may not be the result of an ongoing steady-state process of sediment accretion by sediment offscraping at the toe of the slope or by underplating of sediment at the base of the sediment wedge beneath the continental slope and shelf.

INTRODUCTION

The Middle America Trench extends southward from the Rivera Fracture Zone off the Pacific coast of Mexico to the Cocos Ridge off Costa Rica. It has been interpreted (Molnar and Sykes, 1969; Seely et al., 1974; Jordan, 1975; Karig et al., 1978) as an expression of subduction of the Cocos Plate beneath North and Central America. Structures along the continental margin and the volcanic chain and landward-dipping seismic zone that parallel the Trench for much of its length are presumably related to the underthrusting that characterizes the subduction process. Global plate kinematic descrip-

tions (Larson and Chase, 1970; Minster et al., 1974; Minster and Jordan, 1978) indicate a convergence rate of roughly 9.2 cm/yr. between the Cocos Plate to the west and the North American and Caribbean plates to the east.

The continental margin can be divided into two contrasting zones: north of the Gulf of Tehuantepec the continental shelf is narrow, the Tertiary volcanoes are 160 to 450 km from the Trench, and the Benioff zone dips about 30°. South of the Gulf of Tehuantepec there is a broad shelf underlain by a structural basin, Tertiary volcanoes are 200 km from the Trench, and the Benioff zone dips approximately 40°. Along the northern portion Paleozoic structures terminate at the continental edge, and continental truncation by oblique subduction has occurred (Karig, 1974; Karig et al., 1978) with post-Miocene accretion (Moore, Watkins et al., 1979); the southern zone, by contrast, has been interpreted as a zone of sediment accretion (Seely et al., 1974) or landward understuffing (Seely, 1979).

¹ Aubouin, J., von Huene, R., et al., *Init. Repts. DSDP, 67*: Washington (U.S. Govt. Printing Office).

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The broad continental shelf that runs along the west coast of Central America from the Gulf of Tehuantepec of southern Mexico to the Nicoya Peninsula of Costa Rica is underlain by a thick sedimentary sequence, which along much of the shelf onlaps a structural high at the seaward edge (Seely, 1979). The structural high is not well developed offshore Nicaragua but is quite pronounced to the north off El Salvador and Guatemala. An Exxon well at the seaward edge of the shelf basin offshore Guatemala bottomed in Coniacian sediment (Seely, 1979). Couch (1976), Woodcock (1975), and Couch and Woodcock (1981) have mapped a free-air gravity high over the seaward edge of the Nicoya Peninsula and over parts of the margin to the north. They have inferred its continuity along the shelf edge northward to the Gulf of Tehuantepec where it takes a sharp turn inland across the Isthmus of Tehuantepec. Modeling studies that they have done indicate that this anomaly is not merely a topographic effect but is partly a result of high-density material localized near the shelf edge.

The general continuity of this anomaly along the shelf from the Nicoya Peninsula would suggest that the same structures and lithologies that are causing the anomaly beneath the Nicoya Peninsula occur more or less continuously along the continental shelf to the Gulf of Tehuantepec, though locally they may occur at different structural levels. In fact, Woodcock (1975) found that he could successfully model the gravity and magnetic anomalies off Guatemala if he assumed that landward-dipping slabs of Nicoya-like lithology lie embedded in the upper slope off Guatemala. In this modeling he used densities and induced magnetizations for the high-density slabs that are appropriate for ocean crust and for the Nicoya Peninsula (Dengo, 1962). Woodcock interpreted the gravity and magnetic data to indicate at least two slices of Nicoya-like lithology lying within the upper slope above a landward-dipping continuation of ocean crust.

Segmentation of the Central American margin by faulting normal to the Trench axis has been proposed by Carr et al. (1974) on the basis of offsets of the volcanic chain and concentrations of earthquake energy release. They proposed that segmentation results from differing dip angles of portions of the down-going slab causing tear faults between segments.

DSDP Legs 66 and 67 as well as the geophysical surveys prior to drilling were designed to evaluate the suggested contrast in structural history between the Mexican and the Central American zones of the Middle America Trench as well as the suggested segmentation. We report the results of our geophysical and geological surveys off Guatemala on the proposed accretionary margin. Our seismic reflection and refraction data, magnetic data, and coring data suggest that landward-dipping slices of rock with oceanic affinities similar in lithology to that of the Nicoya Peninsula are embedded within the upper continental slope offshore Guatemala. Deformed sediment is inferred beneath the lower continental slope above a landward continuation of ocean crust. Offset magnetic anomaly patterns on the upper slope near a deep submarine canyon suggest that the

canyon location may be governed by faults trending normal to the Trench axis. Drilling results published by Seely (1979), together with Leg 67 Hole 494A results, suggest that continual steady-state tectonic accretion of sediment to the landward slope has not occurred. Instead, a major event occurred in the late Paleocene or early Eocene that emplaced slivers of ocean crust in the slope and uplifted the Guatemala margin. Since that time, the Trench has apparently been kept nearly free of sediment by continued subduction of trench fill, with sediments bypassing the inner slope region, or a period of tectonic erosion has occurred that removed previously accreted material from the toe of the slope.

INNER SLOPE STRUCTURE

Figure 1 shows the location of multichannel common depth point (CDP) reflection transects, seismic refraction profiles, and sediment cores on the continental margin off Guatemala. The bathymetric contours of Figures 1 and 2, constructed from our sounding data, show a deep submarine canyon, called San Jose Canyon, incised into the broad, flat continental shelf and upper continental slope. The Canyon, which is subduced on the lower slope, is important as a window into the geology beneath the apron of sediments on the upper slope. Total magnetic field values were obtained along all tracks, and Figure 3 shows contours and anomaly trends of the residual field obtained by removing the international geomagnetic reference field from our observations. Representative seismic sections are shown in Plate 1 (see back pocket, this volume).

Figure 4 is an example of a seismic line across the Trench and continental slope west of San Jose Canyon. There is a sharp shelf edge with a fairly smooth slope down to the Trench axis with only minor terraces. The most obvious characteristic of the record beneath the continental slope is the preponderance of diffraction hyperbolas and almost complete lack of planar reflections. At 8.5 s there are faint, irregular reflections that may indicate landward continuation of ocean crust beneath the toe of the slope. The upper slope is mantled by a sediment apron up to 0.5 s thick that lies on an irregular surface. The sediment apron pinches out downslope, and there is little or no sediment fill in the Trench axis. This is true both north and south of San Jose Canyon. Several sediment-free channels within the Canyon suggest recent erosion. If sediment is being channeled downslope by the Canyon, it is not accumulating as planar units on the lower slope or in the Trench axis except in small local ponds.

Figure 5, a seismic record that coincides with the axis of San Jose Canyon on the upper slope, is different from Figure 4 in showing the seaward edge of the thick sediment basin that underlies the shelf. The upper slope of Figure 5 is mantled by a sediment apron that extends to the lower slope where it blankets three terraces. This section clearly shows landward-dipping reflections in the upper slope beneath the sediment apron. At least two reflections are seen that are not as regular as the reflections from the sediments of the shelf basin (Reflections A and B, Figs. 5 and 6). In other respects the sec-

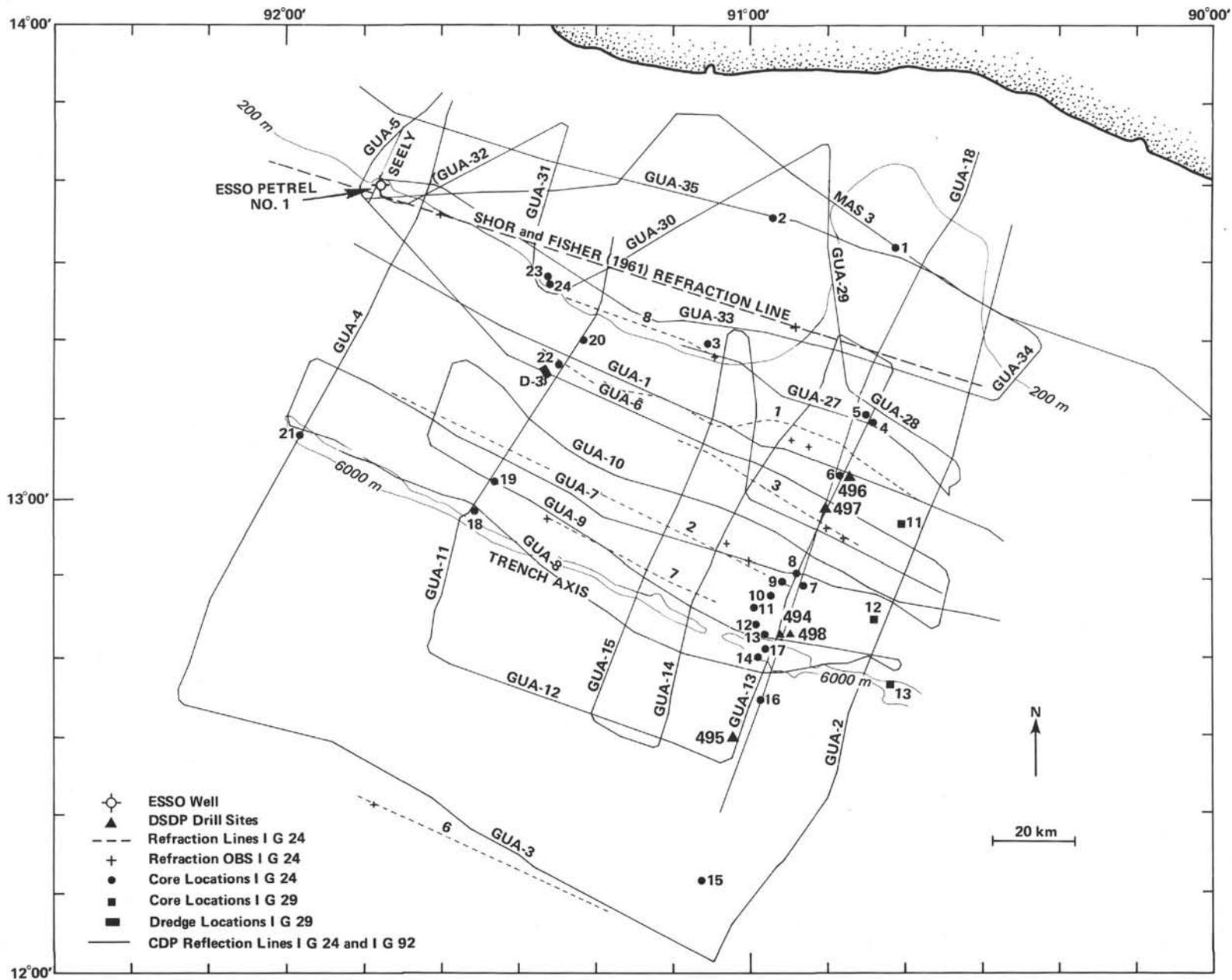


Figure 1. Track of multichannel seismic reflection survey offshore Guatemala. (Dots indicate core locations. Reflection lines are designated GUA- followed by a 1- or 2-digit number. Dashed lines are locations of refraction lines.)

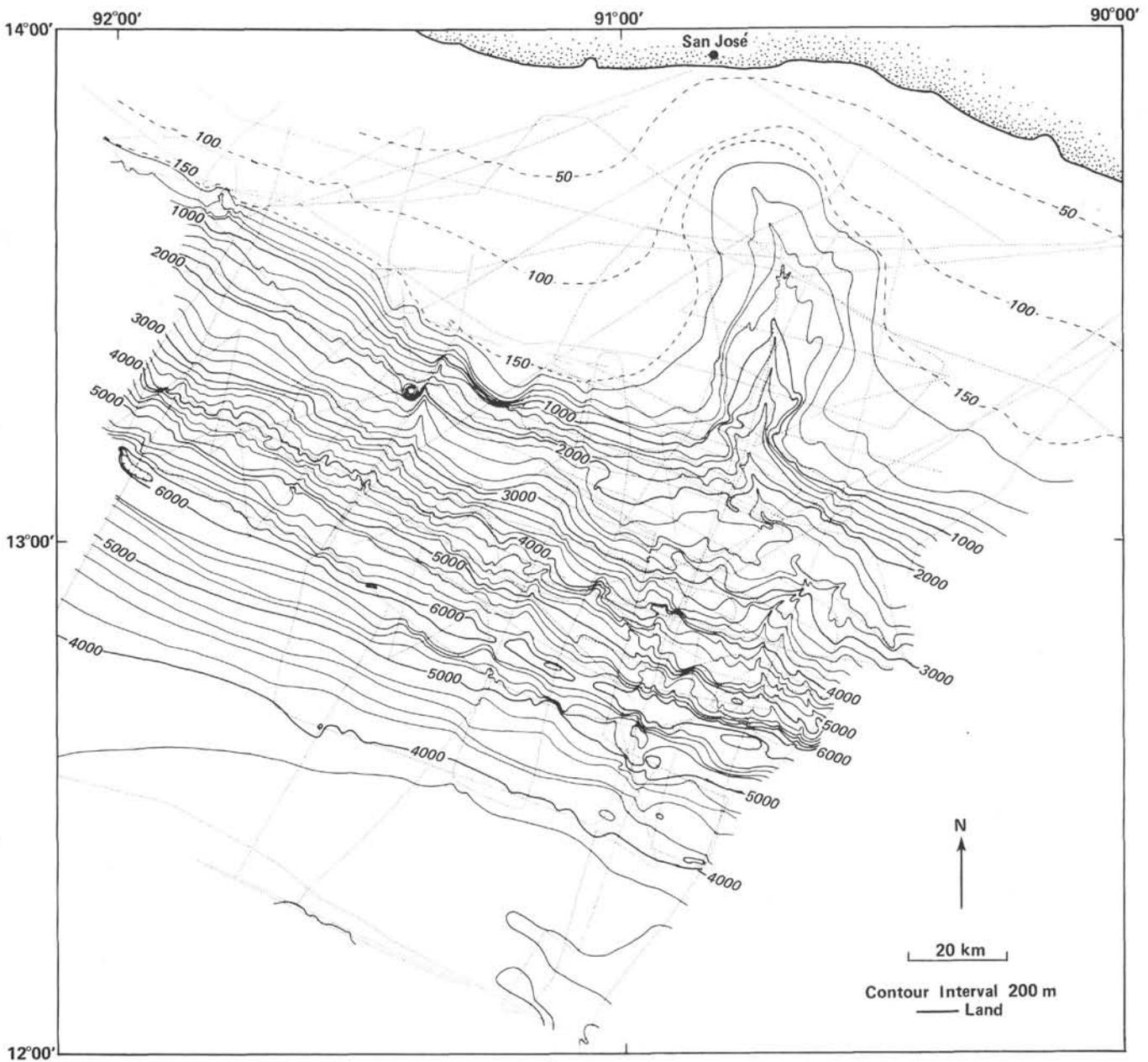


Figure 2. Bathymetry in survey area based on data collected by the *Ida Green* in 1977. (The dotted lines indicate ship tracks.)

tion of Figure 5 is like that of Figure 4, with many diffractions and few coherent reflections within the wedge of material beneath the landward slope.

On several lines, however, a strong reflection is recorded at about 8 s of two-way travel time, which can be traced horizontally in the time section about 30 km landward from the Trench axis (Fig. 7). This reflection is strongest on lines GUA-2 and GUA-4. This reflection is not only important for indicating a possible landward continuation of oceanic crust, but it also indicates that we are transmitting seismic energy down to this level through the overlying wedge of material. The overlying wedge, which shows only scattered indications of reflections with a predominance of diffractions, is not opaque to our sonic energy. We are not seeing coherent reflections, because no extensive coherent reflectors exist with-

in this wedge or the impedance contrast between reflecting units is too small.

Figure 8 is a depth section derived from Figure 5 with seismic refraction and coring results superimposed. The refraction data are described by Ibrahim et al. (1979). Note particularly the velocities in excess of 4 km/s within a large part of the inner slope wedge. The three seawardmost refraction lines indicate igneous ocean-crust velocities and thicknesses extending landward of the Trench about 17 km. Slightly shallower than the top of the 6.5 to 6.8 km/s interface the reflection observed at 8 s in several records can be traced within the 4.1 to 4.9 km/s field almost 30 km landward of the trench axis. The depth of the reflection shown in Figure 8 is based on velocities observed at refraction lines MSI-7 and MSI-2. It is puzzling that the strong reflection seen at 8 s

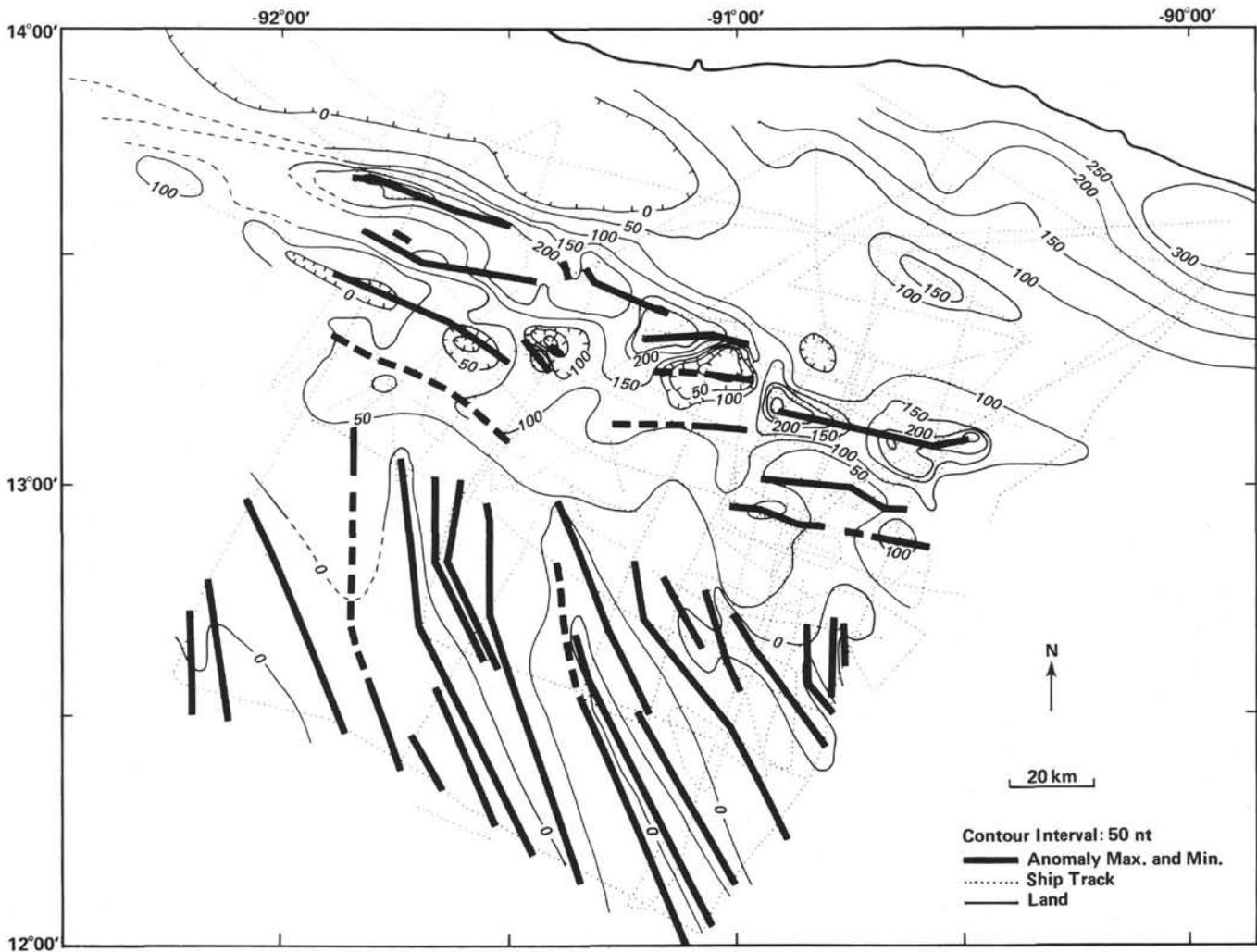


Figure 3. Magnetic contour chart based on data from 1977 survey of *Ida Green*. (The north-south trending magnetic anomalies are Miocene sea-floor-spreading anomalies. The east-west trending anomalies beneath the shelf edge and upper slope reflect buried structures related to development of this margin.)

does not coincide with an observed refraction horizon. One solution to this problem may be that the reflection is from the top of a thin layer of 5+ km/s velocity not observed in the refraction experiments. Shor et al. (1971) point out that Layer 2 in the Pacific is observed in refraction experiments over only a short distance, if at all. Shor and Fisher (1961) computed a velocity of 5.7 km/s at Station 5 and identified it as Layer 2 but found no such interval on reverse shooting. When interpreting the refraction information shown in Figure 8, we have ignored the anomalously shallow mantle velocity at the toe of the slope at Station 7. We have attributed this shallow interface to errors in picking the first arrivals of head waves from this interface or shallower ones. Preliminary analysis of refraction data from ocean-bottom seismometers of the Hawaii Institute of Geophysics indicates that a layer of velocity 5+ km/s does indeed exist at Station 7, and mantle is at depths in agreement with Shor and Fisher Station 5 and our Station 2 (E. L. Ambose, personal communication, 1981).

The upper slope refraction lines MSI-8 and Shor and Fisher line 4 indicate the top of a 5+ km/s layer dipping landward parallel to reflections. On refraction line MSI-1 the interface between 4.8 km/s and 5.4 km/s falls on a dipping reflection indicating that the velocity interface coincides with the reflection and does not dip more gently landward to connect with the 4.5- to 5.6-km/s interface of refraction line 8. The velocities of 5.3+ km/s and 6.5+ km/s are appropriate for ocean-crust Layers 2 and 3. The combination of reflections and refraction velocities suggests that there are two separate landward-dipping blocks of oceanic crust within the upper slope. The coring results as well as the magnetic and gravity modeling of Woodcock (1975) and Couch (1976) lend further support to this conclusion. The material with velocities of 5 km/s and greater was the primary target for Holes 496 and 497.

Refraction lines MSI-3 and MSI-5 in the midslope region indicate relative high velocities immediately beneath the slope sediment apron. Marked by numerous diffrac-

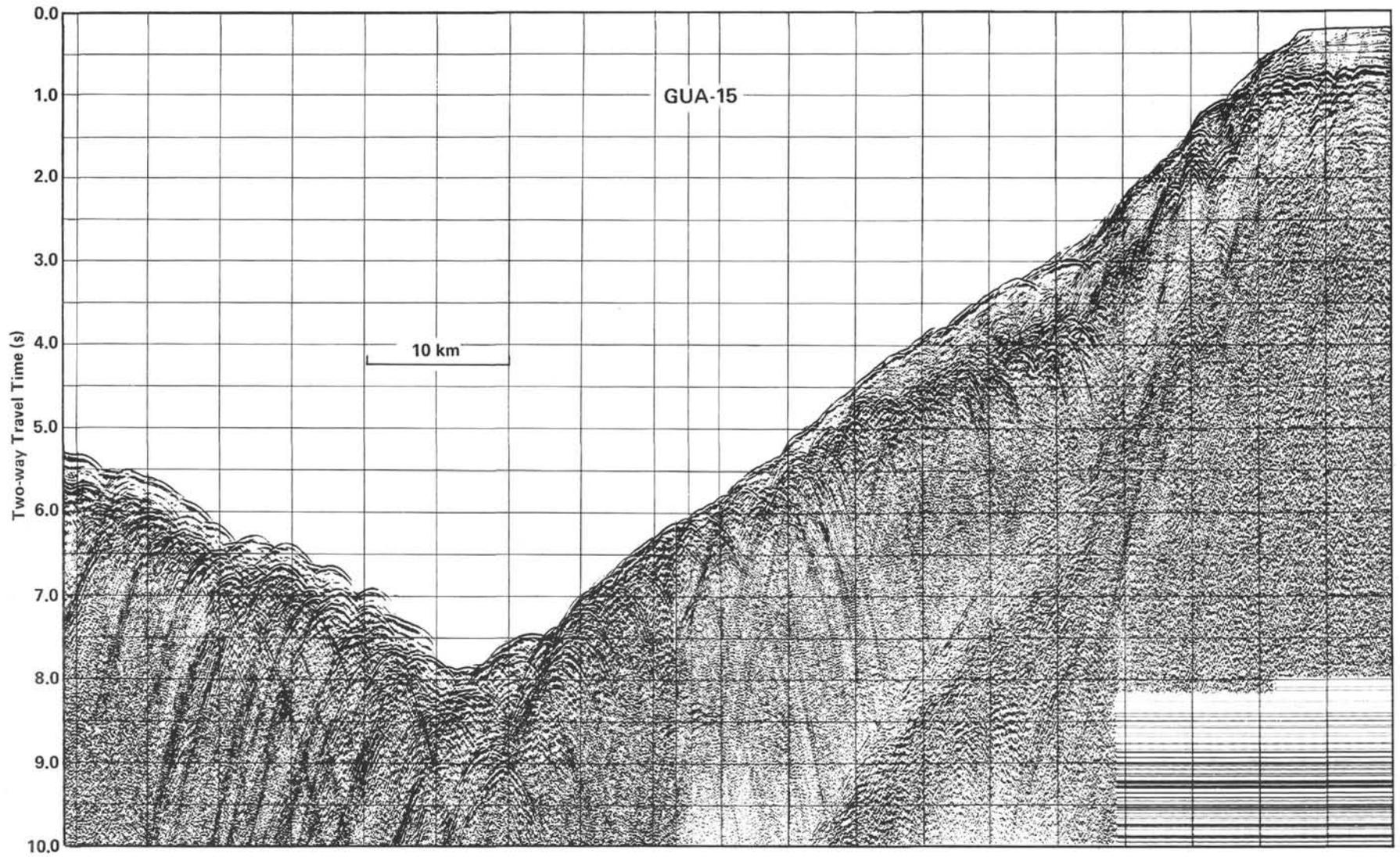


Figure 4. Seismic reflection section GUA-15. (Its location away from the large canyon is indicated in Fig. 1. Note the sharp shelf edge at the right-hand edge of the figure and the lack of turbidite fill in the trench. Horizontal lines are separated by 0.5 s of two-way travel time.)

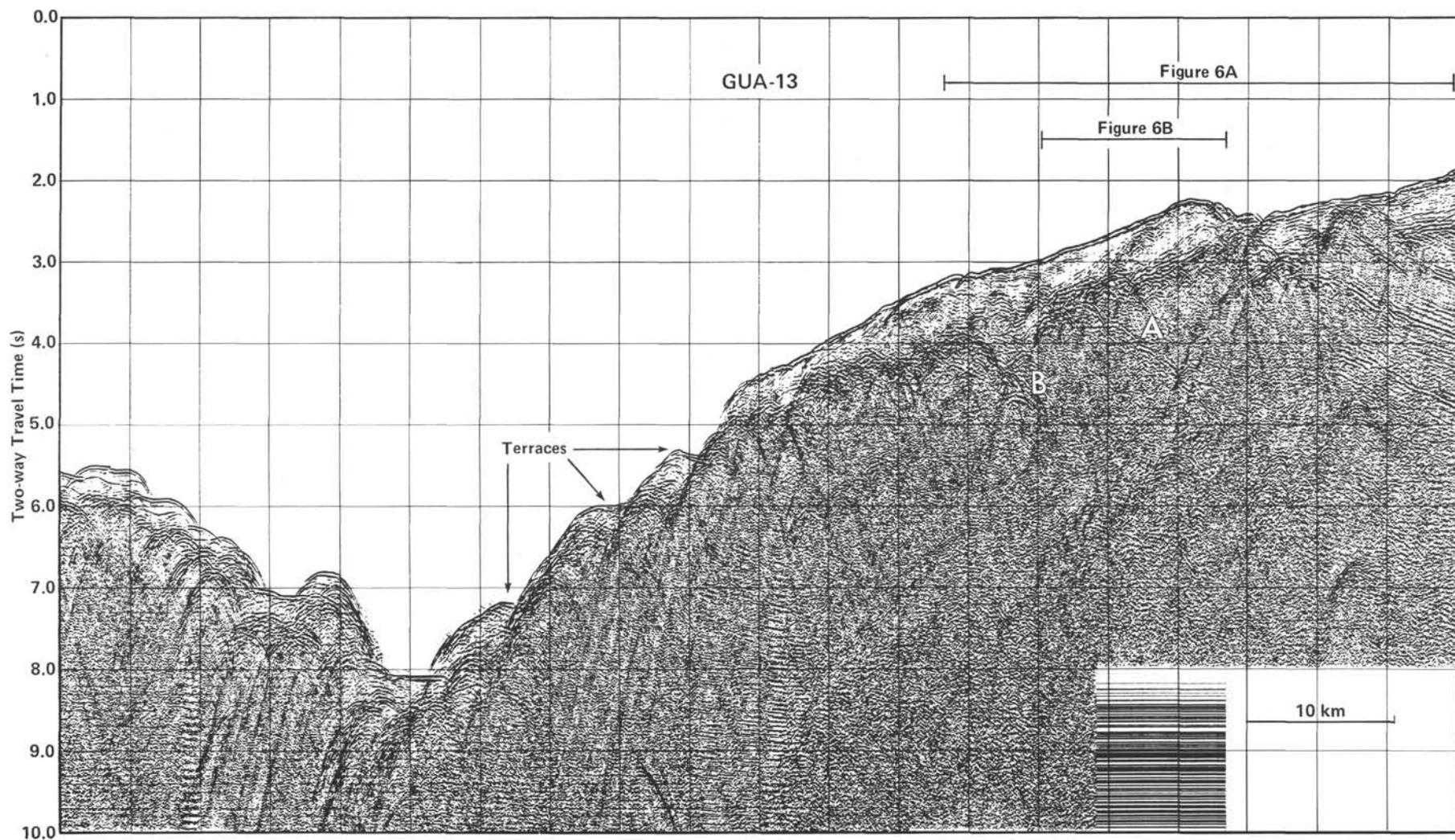
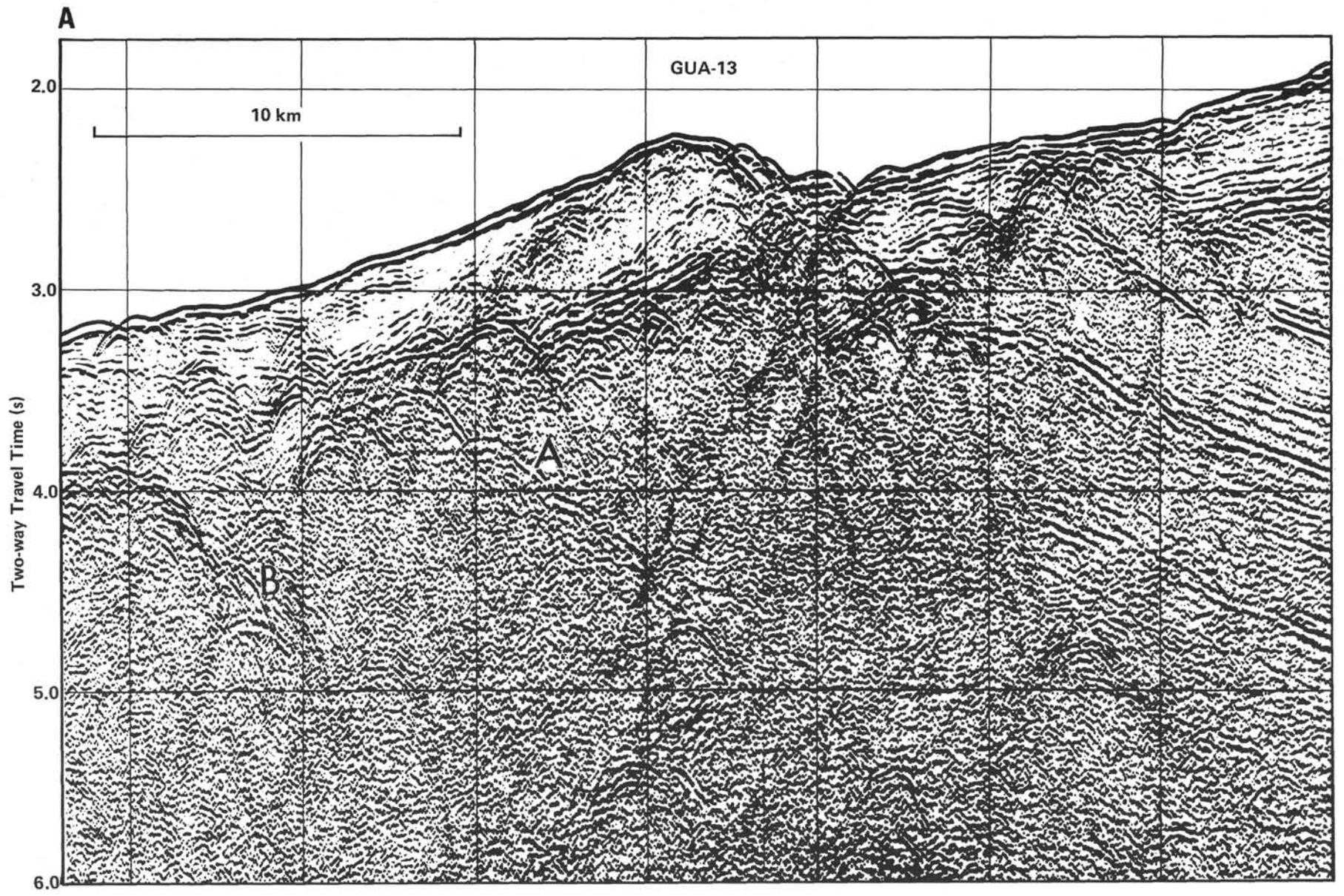


Figure 5. Seismic reflection section GUA-13. (Its location is shown in Fig. 1 within the large canyon that has cut away the shelf edge. Note the landward-dipping reflections extending about 10 km from the right-hand edge of the figure. They indicate the seaward edge of the sedimentary basin underlying the shelf. The landward-dipping reflections about 25 km from the right-hand edge of the figure are shown in detail in Fig. 6 and indicate landward-dipping units within the upper slope. The lowermost terrace northwest of the Trench axis is the terrace surveyed by Seabeam [Aubouin et al., Seabeam Survey, this volume] and drilled at Sites 494 and 498.)



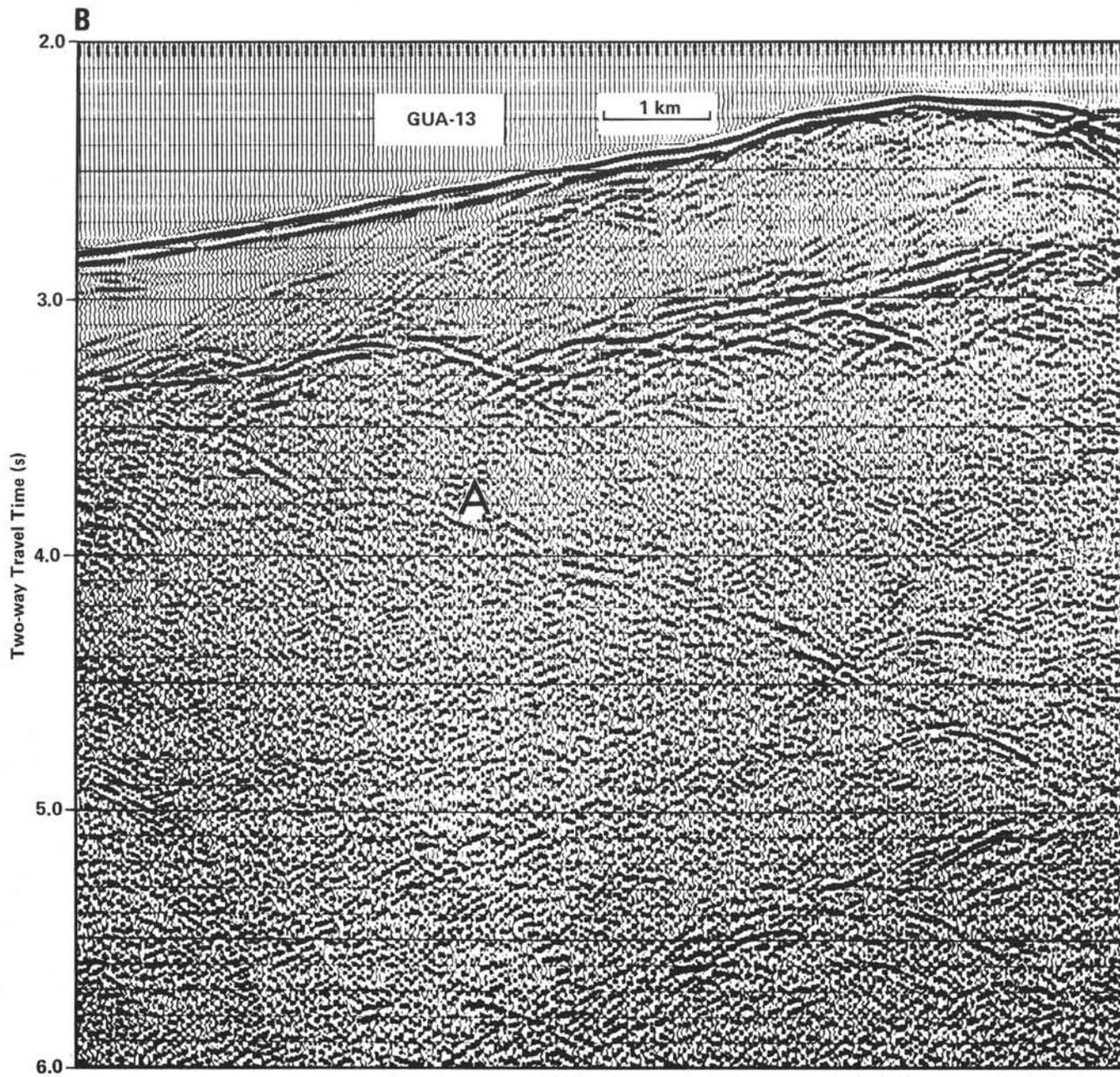


Figure 6. A. Close-up of right-hand end of Figure 5 showing landward-dipping units of shelf basin and upper slope. (Vertical exaggeration is 7:1).
B. Close-up of landward-dipping reflection in upper slope in Figure 5. (Vertical exaggeration is 3:1).

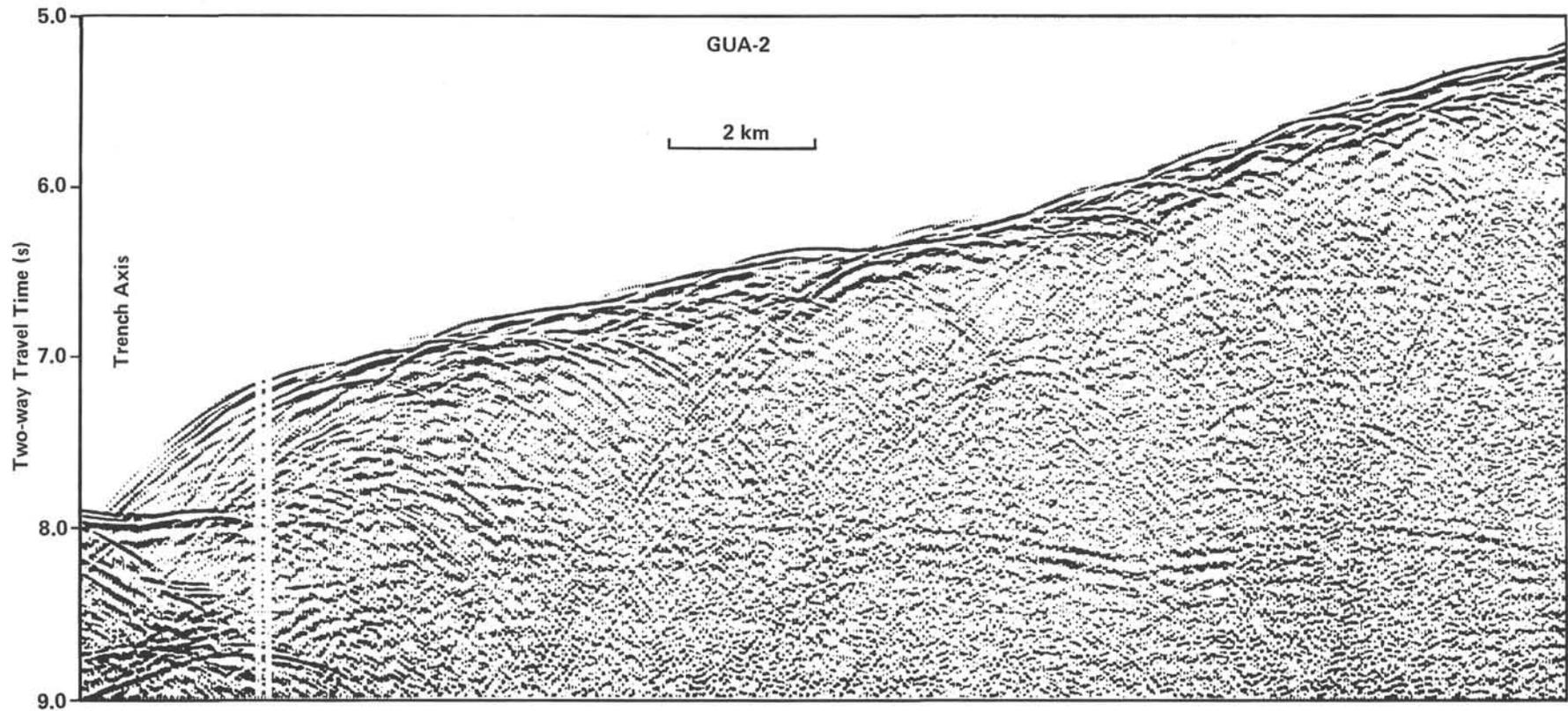


Figure 7. Toe of slope on line GUA-2, the location of which is indicated in Figure 1. (The strong reflection at 8 s is the landward continuation of oceanic crust beneath the sediment wedge at the base of the landward slope.)

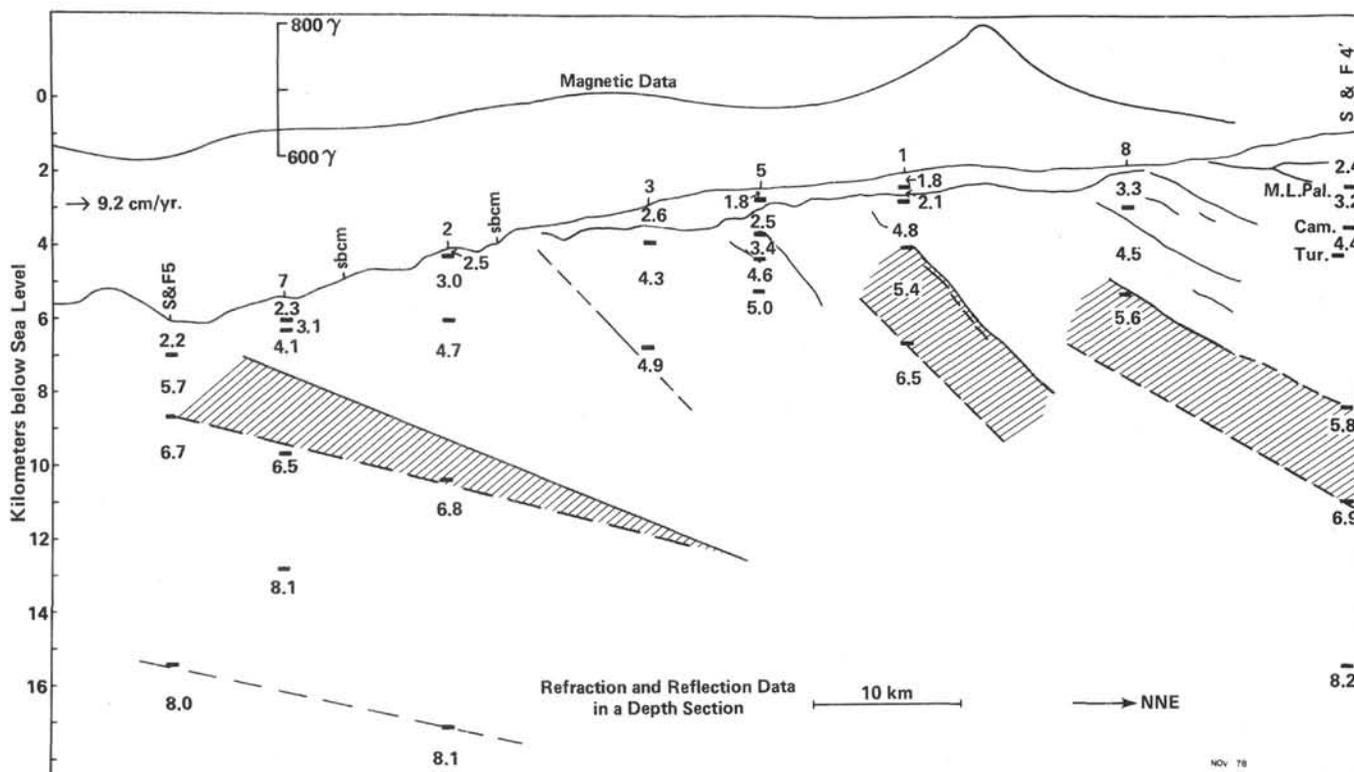


Figure 8. Depth section of line GUA-13. (For location, see Fig. 1. A magnetic profile is drawn above the line drawing of reflections seen on line GUA-13. The two-digit numbers below the line of the seafloor are refraction velocities of our data [refraction line indicated above the line of the seafloor by a single-digit number] and the data of Shor and Fisher [1961] [refraction line indicated by S&F]. The locations of our refraction lines are indicated on Fig. 1. The sbcm designations above the line of the seafloor are core locations where gravels of serpentine, chert, and mudstone were obtained. The convergence rate of 9.2 cm/yr. for the Cocos Plate with respect to North America as given by Minster et al. [1974] for this area is indicated at the left of the figure. Vertical exaggeration is $\times 2.5$. Age of the shelf section determined from Exxon drilling is indicated by M.L. Pal. [mid-lower Paleocene], Cam. [Campanian], and Tur. [Turonian].)

tion hyperbolas, the irregular surface that underlies the sediment apron is the top of a unit with velocities of 4+ km/s, which may be tectonically consolidated sediment or may include slices of igneous rock. In the midslope area, reflections from within this 4+ km/s material indicate landward-dipping units. Leg 67 drilling probably did not reach any of this material at Sites 496 and 497.

Our refraction results, together with the results of Shor and Fisher (1961), are consistent with the presence of landward-dipping slabs of rock within the upper slope and with tectonic consolidation of the lower slope. Beneath the lower slope two of our refraction lines, together with a line from Shor and Fisher (1961), indicate a landward-dipping zone with velocities and thicknesses appropriate for a landward continuation of ocean crust. The 6.5-km/s velocity is appropriate for oceanic Layer 3 and the 8.0-km/s velocity is appropriate for mantle (Shor et al., 1971). Above the 6.5-km/s horizon is material with velocities of 4+ km/s. Such velocities are possibly low for oceanic Layer 2 velocities (Shor et al., 1971; Houtz and Ewing, 1976) but high for terrigenous sediment at the observed depth of burial (Nafe and Drake, 1957). The material with velocities of 4+ km/s may be either tectonically dewatered sediment (Carson et al., 1974) or highly fractured basaltic Layer 2, or a mixture of the two. Velocities of 4+ km/s have been observed within the inner slopes of other trenches (Ewing et al., 1960; Ludwig et al., 1966; Shor and von

Huene, 1972; Yoshii et al., 1973; Hussong et al., 1975, 1976; Kieckhefer et al., 1980).

In Figure 8 the plot of observed magnetic anomalies shows a strong positive anomaly above the upper slope and a smaller anomaly above the midslope region. Figure 3 shows that these magnetic anomalies are roughly linear and generally parallel the shelf edge throughout the survey area. The strong positive anomaly above the upper slope is offset downslope near the western edge of San Jose Canyon.

Our piston cores recovered angular, unweathered gravels in canyons on the lower slope off Guatemala, suggesting the existence of rock of Nicoya-like lithology within the upper slope. These gravels contain serpentine, chert, and basalt, which are lithologies similar to those found on the Nicoya Peninsula but *unlike* lithologies generally reported from onshore southern Guatemala or El Salvador, which is dominated by andesitic volcanics in the drainage basins or rivers emptying sediment into the Pacific. Presumably the gravels originated in local subsea outcrops exposed by erosion or faulting in canyons. The lithologies of these gravels could give rise to the observed magnetic and gravity anomalies at the shelf edge if a slice of this material were emplaced in the upper slope.

Critical to the combined interpretation of the DSDP Leg 67 drilling results and the geophysical surveys is the Seabeam survey conducted by Renard et al. (1980)

and Renard et al. (this volume). This multibeam echosounder survey at the toe of the slope in the vicinity of Site 494 revealed that drilling at this site occurred on a terrace that is continuous for 15 nautical miles (n.m.) parallel to the Trench axis and that rises gently to the northwest and southeast away from a canyon near Site 494. This morphology supports the possibility that a terrace seen between 7.0 s and 7.5 s on seismic lines 13, 14, 15, and 18 may be a continuous feature that runs at least 30 n.m. along the lower slope landward of the Trench axis. A terrace at similar depths is seen to the northwest on lines 4 and 11, which even suggests that the terrace might be 75 n.m. in lateral extent. This feature seems too large (in length) to be the surface of a slump block. Instead, the terrace appears to be the upper surface of a tectonic unit of Cretaceous and Tertiary lithologies.

GAS HYDRATES

The drilling on Leg 67 encountered evidence of gas hydrates on the inner slope at Sites 496, 497, 498. This was unexpected because the seismic data in the vicinity of these holes did not seem to indicate the presence of a bottom simulating reflection (BSR) that usually is associated with the base of a hydrate zone (Shipley et al., 1979). The closest obvious indication of hydrate in the Guatemala slope region was on seismic line GUA-14 (Fig. 9) about 10 n.m. west of the drilling transect. On that line, in water depths ranging from 2 to 3 s, a reflection subparallel to the water bottom appears to cut across a sediment basin in midslope. Seaward of this midslope basin the BSR becomes coincident with the base of the sediment apron that blankets the upper slope. This raises the possibility of the coincidence of a BSR with the base of the slope apron on other lines.

Subsequently to encountering the gas hydrate in drill holes, we have looked more carefully at our seismic data and conclude that along several lines in water depths of 2 to 3 s patches of gas hydrate horizon appear. The obvious hydrate BSR on line GUA-14 was investigated by playing out the seismic traces at a greatly enlarged scale. It then became apparent that the polarity of the BSR was opposite to the water-bottom polarity (Fig. 10), the expected relationship for a high-impedance hydrate zone overlying a low-impedance free-gas zone (Shipley et al., 1979). We see this same polarity relationship in a strong BSR on line GUA-6 where it crosses GUA-14. On GUA-6 the BSR coincides with a series of diffractions that mark the base of the sediment apron. It is difficult to trace the reversed-polarity relationship throughout the region because of numerous diffractions. Strong planar reflections similar in appearance to the reflections with confirmed polarity reversal extend throughout the region in water depths of 2 to 3 s; however, they are not ubiquitous. Perhaps the poor definition of reflections in the sediment apron is in part due to the presence of hydrates. A similar situation was noticed by Shipley et al. (1979) off the east coast of the United States on the Blake outer ridges.

As pointed out by Shipley et al. (1979), the position of the base of a hydrate zone is governed by pressure and temperature conditions, which in turn govern the

position of the phase boundary between hydrate and free methane. The thermal gradient in the top 300 meters of section in Hole 494A and in the Exxon well drilled at the shelf edge agree within a factor of 2. Exxon data show a decreasing thermal gradient with depth below 300 meters (von Huene et al., this volume). The base of hydrate observed on seismic sections in the Guatemala area lies about 0.65 s sub-bottom. Interval velocities calculated from semblance statistics are about 1.7 km/s, which indicates that 1.1 km of sediment lie above the base of the hydrate. This sediment overburden plus about 2 km of water indicate that the pressure at the BSR is about 400 atm. The phase diagram of Shipley et al. (1979) indicates that at that pressure the base of hydrate should be at about 20°C to 25°C.

The thermal gradient determined at Site 494, if applicable elsewhere on the slope, indicates a temperature of about 33°C at 1.1 km sub-bottom. However, if the Exxon results can be generalized, i.e., a lower gradient below 300 meters, then the expected temperature at the BSR based on phase considerations is in general agreement with the observed temperatures.

CONCLUSIONS

The geological and geophysical evidence that we have assembled as well as other published data suggest that one or more landward-dipping slabs of ocean crust underlie the upper continental slope structurally above an extension of oceanic crust landward from the Trench axis. The wedge of material above the extension of oceanic crust below the lower slope could be folded and dewatered sediment derived primarily from downslope movement of material from the shelf and upper slope or it could be sediments and oceanic crustal slices tectonically accreted to the margin at some time in the past.

The focal mechanisms of Molnar and Sykes (1969) and the plate motions of Minster and Jordan (1978) indicate convergence of two lithospheric plates in the region of the Middle America Trench. This convergence in all likelihood contributes in an important way to the development of the structures that we see within the inner slope of the Middle America Trench. The earthquake focal mechanisms indicate thrusting; and thrusting is a simple mechanism to emplace landward-dipping slices of ocean crust into the upper slope. The compressional regime associated with thrusting may be responsible for compaction and deformation of lower slope sediments. However, the drilling results of Leg 67 together with the drilling results presented by Seely (1979) and the Seabeam survey of the area around Sites 494 and 498 suggest that accretion of sediment and oceanic crustal slices to the continental slope is not a steady-state process but instead may have happened at one time in the Paleocene and to no appreciable extent since.

The discovery of lower Miocene sediments overlying oceanic basement at Site 495 22 km seaward of the Trench axis indicates that with any reasonable spreading rate, the age of crust at the Trench axis is going to be early Miocene as well. Yet drilling at Site 494 recovered Cretaceous rock from a terrace that the Seabeam survey showed to extend for some 40 km along the Trench—too

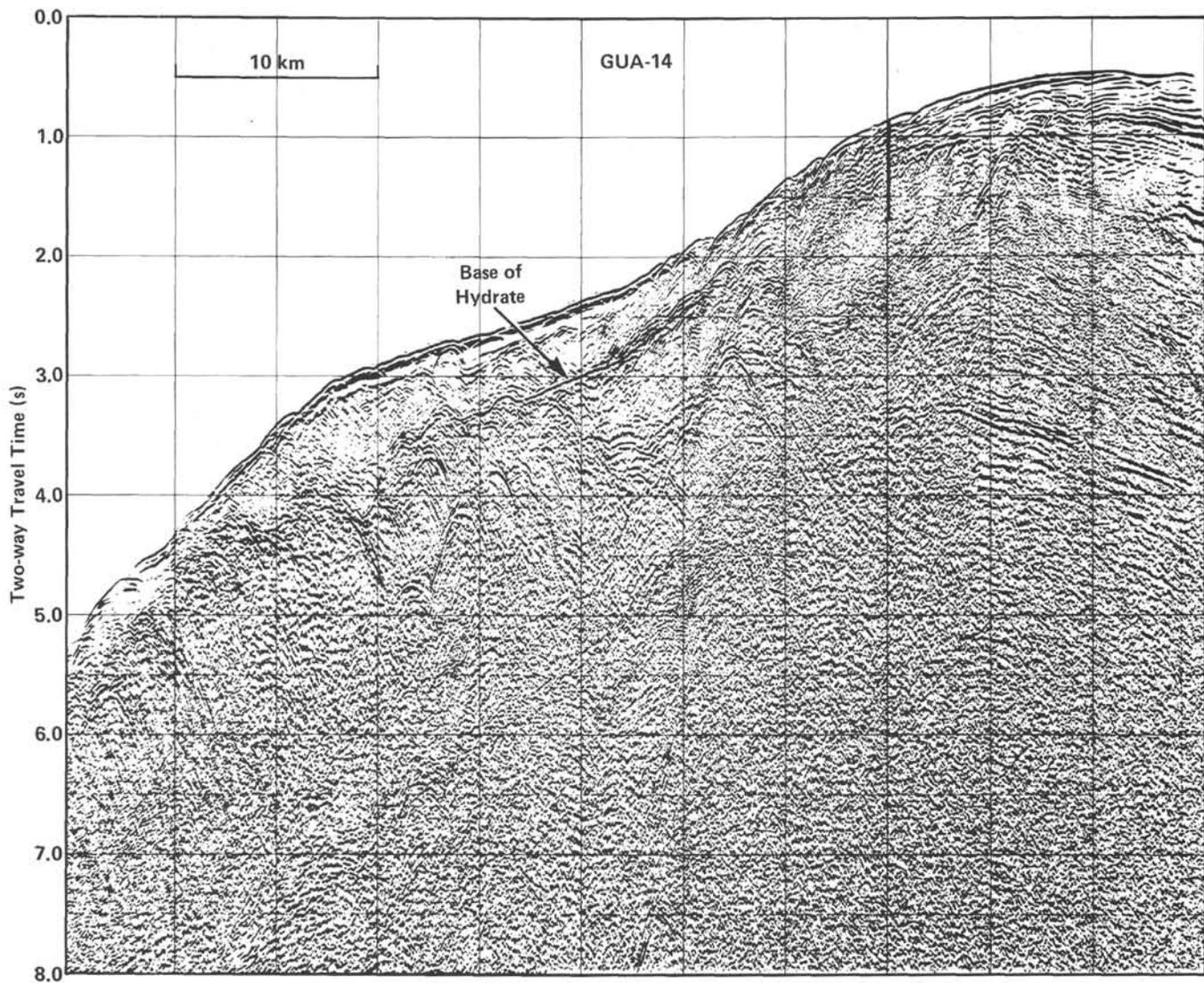


Figure 9. Part of line GUA-14 showing the most obvious expression in the area of a bottom simulating reflector (BSR) indicating the base of a gas hydrate.

large, it seems, to be a slump block. The conclusion is that no appreciable material has been scraped off the oceanic plate and accreted to the toe of the continental slope since the time when the Cretaceous limestone was emplaced. The best guess as to when this material was accreted and when the crustal slices detected in the upper slope were emplaced is the late Paleocene or early Eocene, as suggested by the uplift of the shelf edge at that time (Seely, 1979). According to Seely (1979, fig. 10), no significant uplift of the shelf edge has occurred since, although it is surprising that the most angular of the unconformities shown on Seely's figure 9 is at the base of the lower Miocene, not at the base of the Eocene. There has been little or no accretion beneath or seaward of the Cretaceous rocks at the toe of the slope. Apparently any sediments that may have accumulated in the Trench axis as well as all oceanic sediments from seaward of the Trench axis carried in on the oceanic plate have been consumed in the subduction process, bypassing the slope region. This conclusion was also

reached by the scientific staff of Leg 67 (von Huene, Aubouin, et al., 1980).

In order to determine how much crust has been consumed at the Trench since the probable emplacement of thrust slices in the late Paleocene, one needs to extrapolate back through the Eocene the half-rate of 68 mm/yr. determined for the Oligocene proto-East Pacific Rise (Handschar, 1976). This spreading rate indicates that during the 30 m.y. from the end of the Paleocene to the end of the Oligocene, 200 km of crust were generated that have now disappeared down the Trench.

A period of tectonic erosion may have removed previously accreted material from the base of the inner wedge and from the toe of the slope seaward of Site 494 in the middle Miocene. The evidence for removal lies in the mid-Miocene subsidence of the shelf edge indicated by the Exxon well (Seely, 1979) and the subsidence of the mid-slope from shelf to lower bathyal depths indicated by Miocene benthic fauna at Site 496 (von Huene, Aubouin, et al., 1980).

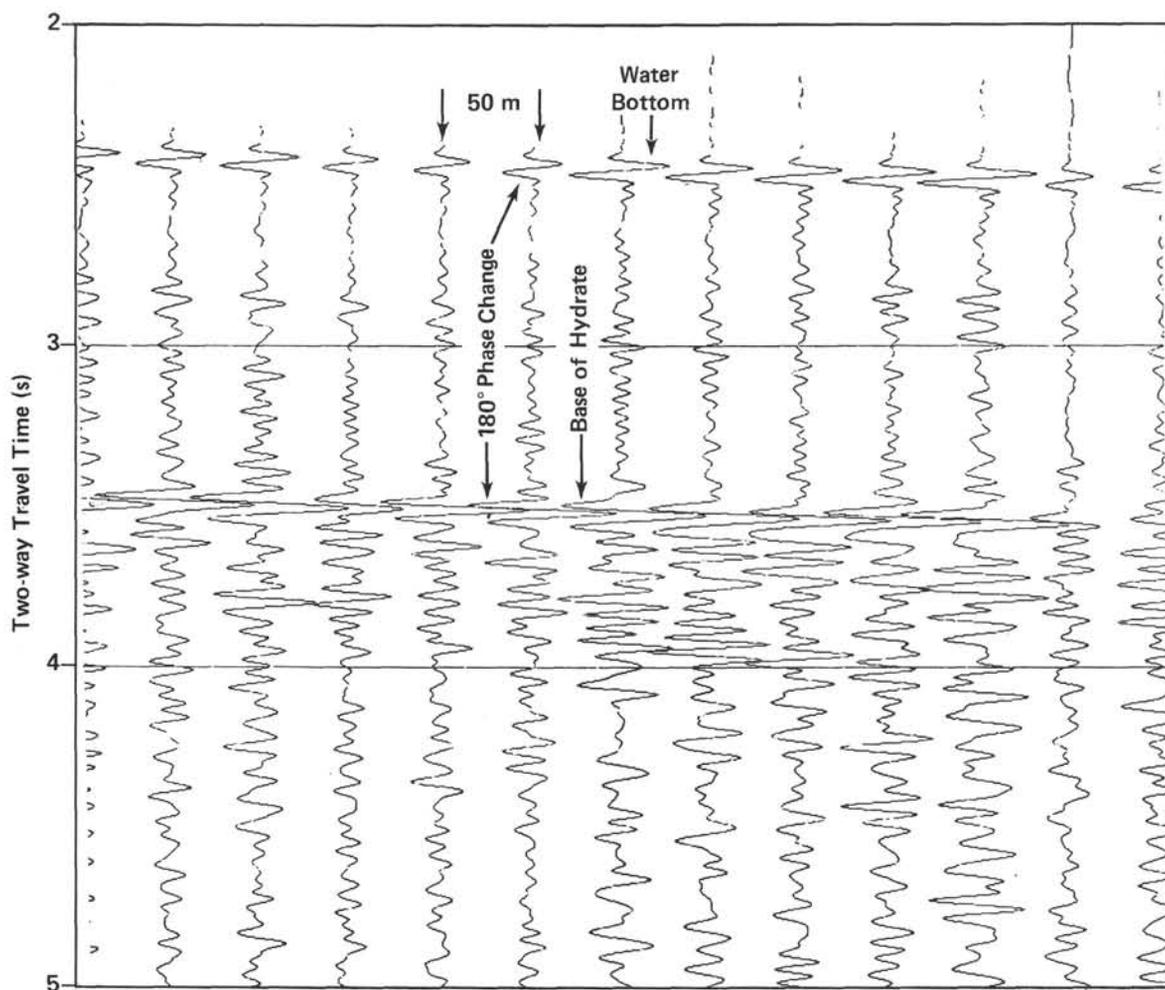


Figure 10. An expanded display of the near trace of several CDP's from line GUA-14 in the region of the obvious bottom simulating reflection (BSR) showing the reversal of pulse polarity between the water bottom and the BSR.

In summary it appears that through time the continental margin off Guatemala has been the site of tectonic accretion, sediment bypassing or subduction, and tectonic erosion at different times at the base of the continental slope.

The regional significance of the late Paleocene-early Eocene uplift of the Guatemala shelf is unclear. Did this event coincide with the initiation of subduction along the Middle America Trench in the present-day configuration? Recent paleomagnetic results (Gose and Swartz, 1977; Gose et al., 1980) suggest that the present relationships among various Central American terrains were not established before the end of the Cretaceous. Lundberg (in press; personal communication, 1981) refers to an Eocene uplift of the Nicoya Peninsula of Costa Rica "from below the CCD (abyssal environment) to at most shelfal depths (neritic environment)." This Nicoya uplift is presumably correlative with the late Paleocene-early Eocene uplift offshore Guatemala. Lundberg, however, also refers to a Campanian uplift of the Nicoya Peninsula and associated Late Cretaceous volcanoclastic deposits representing an eroded intermediate volcanic terrain, which suggests a Late Cretaceous volcanic arc in

Costa Rica. Cretaceous volcanic rocks are also reported from northern Central America (McBirney and Williams, 1965; Williams and McBirney, 1969; Weyl, 1980), but the Cretaceous volcanism in various parts of Central America is generally related to Cretaceous tectonic elements that trend more easterly than Tertiary tectonic elements and may be related to suturing of several terrains before the inception of the present Middle America Trench (de Boer, 1979). The paleomagnetic evidence suggesting the mobility of terrains in the Cretaceous, the apparent synchronicity of the late Paleocene-early Eocene uplift of the Central America shelf off Guatemala and Costa Rica and the initiation of the Tertiary volcanic provinces that parallel the Middle America Trench, argue for an early Tertiary inception of subduction along something similar to the present Middle America Trench. The emplacement of slices of oceanic crust within the upper slope offshore Guatemala may have accompanied the late Paleocene uplift of the shelf and may be related to an initial rupturing of the oceanic crust that led to the development of the Middle America Trench.

The sediments that have accumulated over time beneath the landward slope have generated methane, and

structures have developed that have permitted this methane to migrate toward the seabed/water interface in sufficient quantities to develop a gas hydrate locally.

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