TECTONICS OF THE MIDDLE AMERICA TRENCH

OFFSHORE GUATEMALA

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ABSTRACT

A geophysical and geological survey conducted over the landward slope of the Middle America Trench offshore Guatemala has revealed landward-dipping reflectors which 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 on which Cretaceous 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/sec. Immediately beneath the sediment apron an irregular surface is the top of an interval with velocities of 4.3 to 4,7 km/sec. Within this interval landward-dipping reflections are traced to about 6 km below sea level. Above this zone of dipping reflectors two positive magnetic anomalies are observed as well as a positive free-air gravity anomaly reported by other workers.

The sediment apron pinches out on the lower continental slope where refraction results indicate only a few hundred meters of 2.5 km/sec material lying over about a kilometer of 3.0 km/sec sediment. Between the 3.0 km/sec sediment and a landward continuation of ocean crust an interval of 4.1 to 4.7 km/sec material occurs which thins seaward. Near the interface between the 4+ km/sec material and oceanic crust with velocities of 6.5 to 6.8 km/sec, 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 found onshore in Guatemala. These gravels, which were probably derived from local subsea outcrops, are similar to Nicoya lithologies.

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

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Our observations are consistent with previous suggestions that slices of rock similar to Nicoya lithology are imbedded in the upper slope. The lower slope is probably a tectonically deformed and consolidated sediment wedge overlying ocean crust.

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 descriptions (Larson and Chase, 1970; Minster et al, 1974; Minster and Jordan, 1978) indicate a convergence rate between the Cocos plate to the west and the North American and Caribbean plates to the east of roughly 10 cm/yr.

The continental margin can be divided into two contrasting zones: North of the Gulf of Tehuantepec the continental shelf is narrow, the Tertiary volcanos 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 volcanos 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 or oblique subduction has occurred (Karig, 1974; Karig et al, 1978); the southern zone, by contrast, has been interpreted as a zone of sediment accretion (Seely et al, 1974).

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 onlaps a structural high at the seaward shelf edge (Seely, 1978). The Nicoya Peninsula is the seaward edge of a structural basin that is a southeastward continuation of the shelf basin. An Exxon well at the seaward edge of the shelf basin offshore Guatemala bottomed in Coniacian sediment (Seely, 1978). Couch (1976) and Woodcock (1975) have mapped a free-air gravity high over the seaward edge of the Nicoya Peninsula and have traced it continually along the shelf edge northward to the Gulf of Tehuantepec where it takes a sharp turn inland across the Isthmus of Tehuantepec. The continuity of this anomaly along the shelf from the Nicoya Peninsula suggests that the same structures and lithologies that are causing the anomaly beneath the Nicoya Peninsula occur continuously along the continental shelf to the Gulf of Tehuantepec. 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) based on offsets of the volcanic chain and concentrations of earthquake energy release. They proposed that segmentation is due to differing dip angles of portions of the downgoing slab causing tear faults between segments.

We undertook detailed geological and geophysical surveys along portions of each of the two zones in order 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. In this paper we report the results from our survey 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 lithology similar 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 topographic canyon suggest that the canyon location may be governed by these fault traces.

DATA

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 incised into the broad, flat continental shelf and upper continental slope. The canyon, which is subdued on the lower slope, is important as a window into the geology beneath the apron of sediments on the upper slope. We call this canyon San Jose Canyon. Total magnetic field values were obtained along all track, and Figure 3 shows the residual field obtained by removing the international geomagnetic reference field from our observations.

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 sec there are faint, irregular reflections which 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 sec 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 which 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 which are not as regular as the reflections from the sediments of the shelf basin (Figure 6). In other respects the section 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 sec two-way travel time which can be traced horizontally in the time section about 30 km landward from the trench axis (Figure 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 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 there are not extensive coherent reflectors within this wedge.

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 (in preparation). Note particularly the velocities in excess of 4 km/sec 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/sec interface the reflection observed at 8 sec in several records can be traced within the 4.1 to 4.9 km/sec field almost 30 km landward of the trench axis. The depth of this 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 sec 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 velocity 5+ km/sec 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) observed layer 2 with a velocity of 5.7 at station 5 but not at station 5'.

Refraction line MSI-1 on the upper slope indicates a transition from 4.8 km/sec to 5.3 km/sec coinciding with a landward-dipping reflection. A similar transition is seen on refraction line MSI-8 farther upslope where the transition from 4.5 km/sec to 5.6 km/sec lies on a strong reflection. If this reflection were projected landward, it would intersect the transition from 4.4 km/sec to 5.8 km/sec observed by Shor and Fisher (1961). The coincidence of refraction velocity transitions with reflections in the upper slope indicates strongly that the velocity transitions lie along landward-dipping horizons. Velocity transitions should not be lineally interpolated along straight lines connecting observed velocity transitions except where two observations of the velocity transition lie along the same reflection.

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 linear and 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.

Gravels were cored at several locations on the inner slope. Three of the locations are indicated in Figure 8 where clean, coarse, angular fragments of serpentine, chert, mudstone, and basalt were obtained.

INTERPRETATION

The geological and geophysical evidence that we have assembled as well as other published data are consistent with a model in which one or more landward-dipping slabs of ocean crust underlies 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. This model is not too different from that of Seely et al (1974), Couch (1976), or Seely (1978).

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 anything reported from the subaerial geology of southern Guatemala or El Salvador which is dominated by andesitic volcanics in the drainage basins of rivers emptying sediment into the Pacific. Presumably, then, 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 anomaly at the shelf edge if a slice of this material were emplaced in the upper slope.

Within the upper slope, landward-dipping reflections are probably caused by the velocity contrasts along the surfaces of landward-dipping slabs. Beneath the toe of the slope a reflection at about 8.0 sec two-way travel time that extends as much as 30 km landward has a gentle landward dip and is probably related to a landward continuation of oceanic crust.

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, indicate a landward-dipping zone with velocities and thickness appropriate for a landward continuation of ocean crust. The 6.5 km/sec velocity is appropriate for oceanic layer 3, and the 8.0 km/sec is appropriate for mantle (Shor et al, 1971). Above the 6.5 km/sec horizon is material with velocities of 4+ km/sec. 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 of 4+ km/sec 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/sec 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, 1974).

The upper slope refraction lines MSI-8 and Shor and Fisher line 4 indicate the top of a 5+ km/sec layer dipping landward parallel to reflections. On refraction line MSI-1 the interface between 4.8 km/sec and 5.3 km/sec 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/sec interface of line 8. The velocities of 5.3+ km/sec and 6.5+ km/sec 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 and Couch lend further support to this conclusion.

Refraction lines MSI-3 and MSI-5 in the midslope region indicate relatively high velocities immediately beneath the slope sediment apron. The irregular surface, marked by numerous diffraction hyperbolas, that underlies the sediment apron is the top of a unit with velocities of 4.7 km/sec which again may be tectonically consolidated sediment or may include slices of rock. In the midslope area reflections from within this 4.7 km/sec material indicate landward-dipping units.

The reduction in size or termination of San Jose Canyon and several other upper- to midslope canyons in the lower slope suggests that tectonic deformation in this region is counteracting the effects of canyon formation. Also, tectonic deformation of the lower slope may be responsible for the lack of extensive turbidite fill in the trench because lower slope sediment may become involved in the tectonic zone and be folded into the lower slope.

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.

Our magnetic data shows right-lateral offset of a linear anomaly associated with the upper slope. The offset near the large canyon suggests faulting perpendicular to the trench axis which may be related to a right-lateral offset of the Guatemalan volcanic chain noted by Carr et al (1974).

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FIGURE CAPTIONS

FIGURE 1. Track of multichannel seismic reflection survey offshore Guatemala. Large 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 R/V *Ida Green* in 1977. There is more track with bathymetric data than shown in Figure 1.

FIGURE 3. Magnetic contour chart based on data from 1977 survey of R/V *Ida Green*.

FIGURE 4. Seismic reflection section GUA-15. Its location away from large canyon is indicated on Figure 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 sec of two-way travel time.

FIGURE 5. Seismic reflection section GUA-13. Its location is shown in Figure 1 within the large canyon which 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 reflection about 25 km from the right-hand edge of the figure is shown in detail in Figure 6 and indicates landward-dipping units within the upper slope.

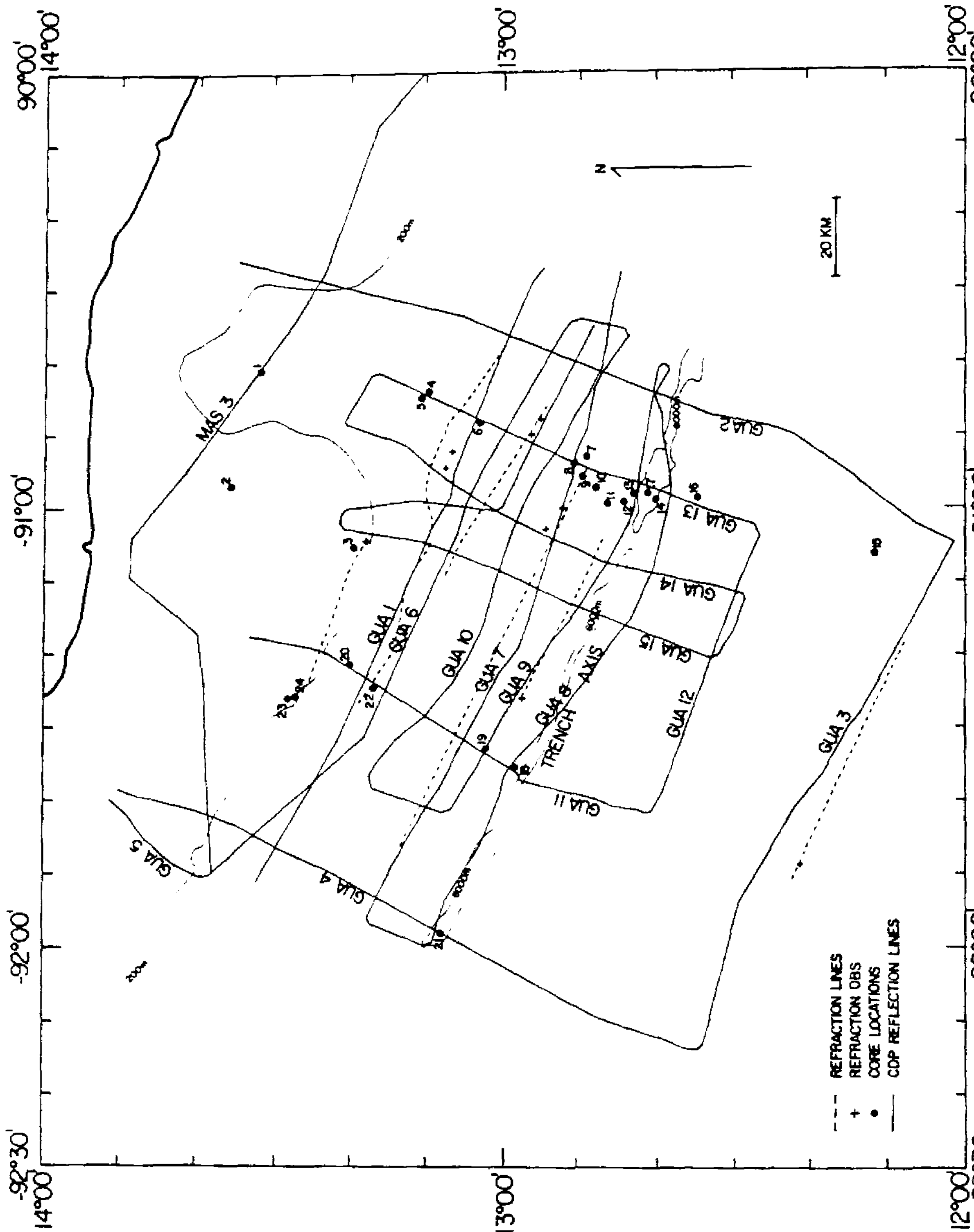
FIGURE 6a. Closeup of right-hand end of Figure 5 showing landward-dipping units of shelf basin and upper slope.

FIGURE 6b. Closeup of landward-dipping reflection in upper slope from Figure 5.

FIGURE 7. Toe of slope on line GUA-2 whose location is indicated in Figure 1.

FIGURE 8. Depth section of line GUA-13. For location see Figure 1. A magnetic profile is drawn above the line drawing of reflections seen on line GUA-13. The 2-digit numbers below the line of the seafloor are refraction velocities from our data (indicated above the line of the seafloor by MSI-) and the data of Shor and Fisher (1961) (indicated by S & F). The locations of our refraction lines are indicated on Figure 1. The designations sbcm and b 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 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.

FIGURE 1



90°00' 14°00'
13°00'
12°00' -90°00'
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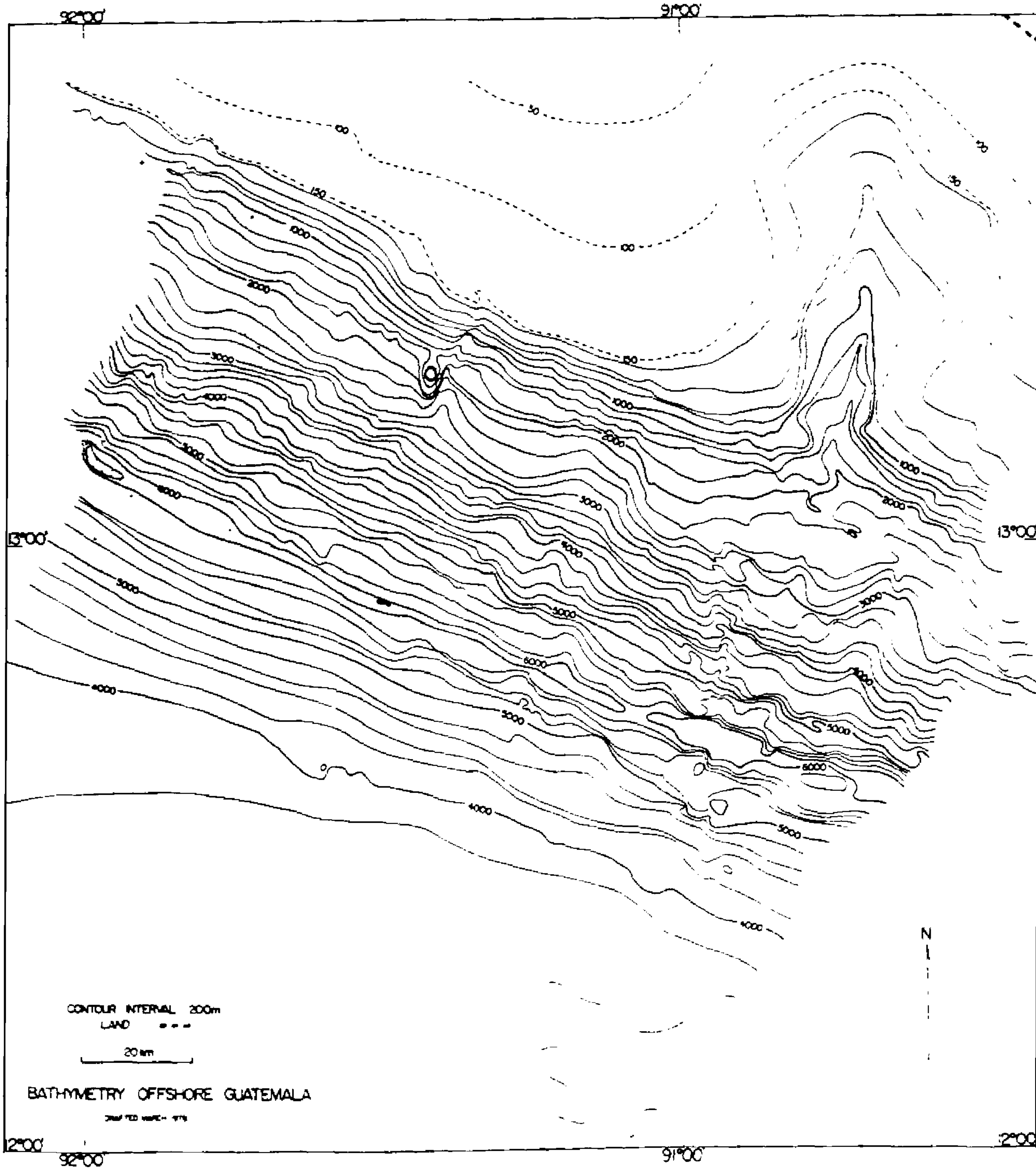
GUA 3
GUA 4
GUA 5
GUA 6
GUA 7
GUA 8
GUA 9
GUA 10
GUA 11
GUA 12
GUA 13
GUA 14
GUA 15
TRENCH AXIS
REFRACTION LINES
REFRACTION OBS
CORE LOCATIONS
CDP REFLECTION LINES

FIGURE 2


92°00'
91°00'
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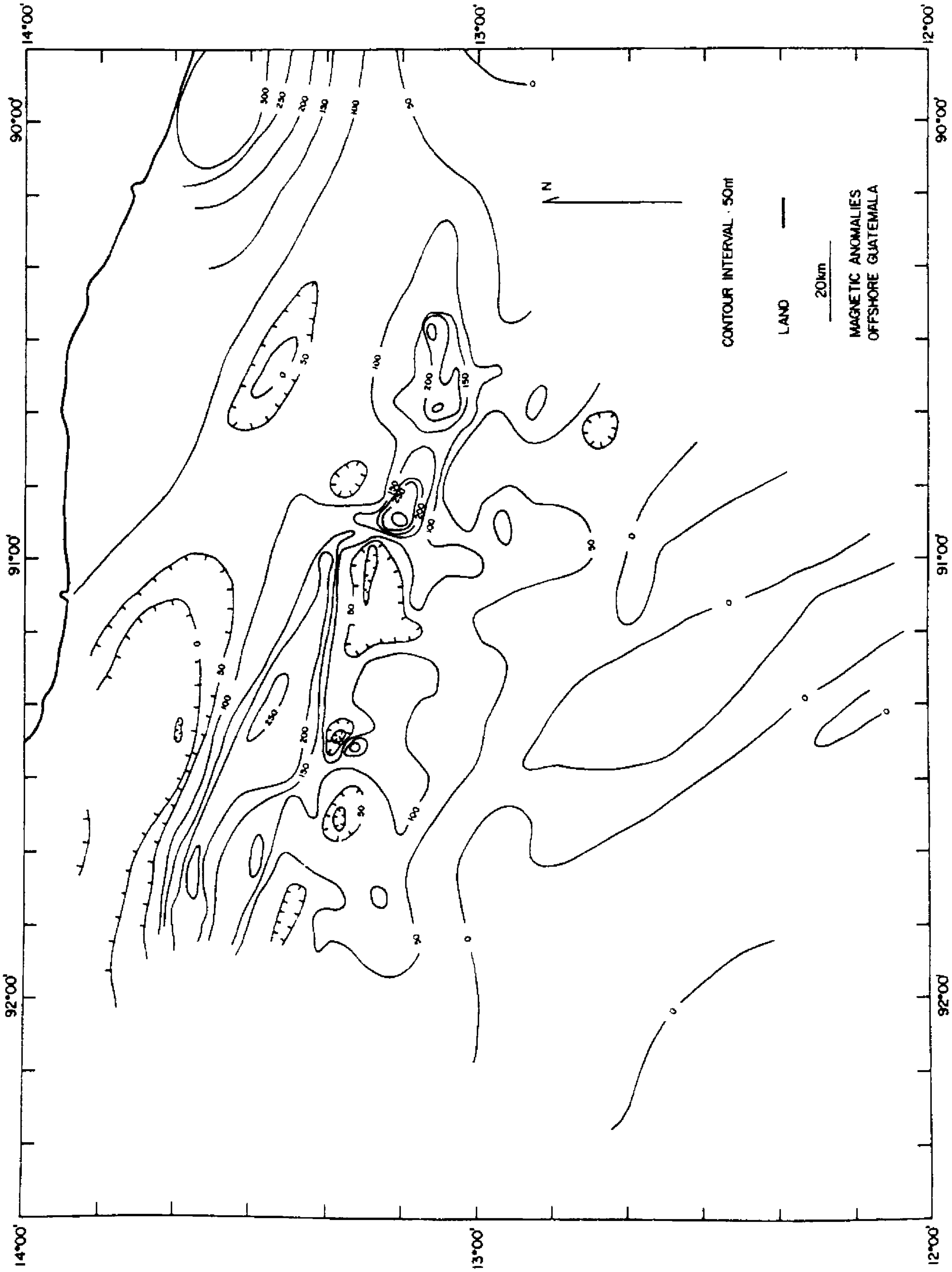
N
CONTOUR INTERVAL 200m
LAND
20 km
BATHYMETRY OFFSHORE GUATEMALA

FIGURE 3



CONTOUR INTERVAL · 50nT
LAND
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MAGNETIC ANOMALIES
OFFSHORE GUATEMALA
N
14°00'
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12°00'
90°00'
91°00'
92°00'

FIGURE 4