Kimura, G., Silver, E.A., Blum, P., et al., 1997
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1. INTRODUCTION[1]

Shipboard Scientific Party[2]

The planet is profoundly affected by the distributions and rates of materials that enter subduction zones. The material that is accreted to the upper plate results in growth of the continental mass, and fluids squeezed out of this accreted mass have significance for biologic and geochemical processes occurring on the margins. Material that is not accreted or underplated to the margin bypasses surface residency and descends into the mantle, chemically affecting both the mantle and magmas generated therefrom. Subduction of the igneous ocean crust returns rocks to the mantle that earlier had been fractionated from it in spreading centers, along with products of chemical alteration that occur on the seafloor. Sediments that are subducted include biogenic, volcanogenic, authigenic, and terrigenous debris. These sources provide characteristic geochemical signatures that may be discerned in the erupting arc magmas and that may alter the composition and possibly the behavior of the eruptions. The partitioning between accreted and subducted sedimentary materials, along with the roughness of the subducting plate, may fundamentally affect the earthquake rupture process and tsunami generation. It is thus of primary importance to understand the nature of the partitioning between accreted and subducted sediments.

The Costa Rica Margin presents an excellent opportunity to study this partitioning process. Many subduction environments suffer from rapid fluctuations in the delivery of terrigenous debris to the trenches because of Pleistocene sea-level changes. Such fluctuations make it difficult to extrapolate the volume of incoming material back in time. Costa Rica and wide regions of the Middle America Trench have little or no turbidites, and the incoming sedimentary sections on the Cocos Plate are relatively constant. In addition, the Costa Rica Margin has been exceptionally well imaged with two-dimensional (2-D) and three-dimensional (3-D) seismic reflection data and recently with wide-angle seismic refraction data. Intensive studies of the arc volcanoes have been carried out and are continuing. Detailed submersible, heat-flow, and bathymetric observations have recently added to our store of knowledge of this margin.

REGIONAL SETTING

Costa Rica lies at the southern end of the Central American island arc system, formed by subduction of the Cocos Plate on the Pacific Margin (Fig. lA). The surface manifestation of this subduction—the Middle America Trench—has its southern end off southernmost Costa Rica, where it intersects the Panama fracture zone. The regional tectonic setting of southeastern Central America is controlled by the convergence of the Cocos, Caribbean, and South American Plates. The oceanic Cocos Plate subducts beneath the Caribbean Plate along the Middle American Trench at rates ranging from 70 mm/yr off Guatemala to nearly 90 mm/yr off southern Costa Rica (Fig. lB). The southeastern part of Central America is called the Panama Block, which includes all of Panama and southeast Costa Rica. Its northern boundary is the convergent North Panama Deformed Belt (Silver et al., 1990), which extends from the Caribbean coast of Colombia to Limon, Costa Rica. In Costa Rica, the boundary consists of a diffuse left lateral shear zone from Limon to the Middle America Trench (Ponce and Case, 1987; Jacob and Pacheco, 1991; Guendel and Pacheco, 1992; Goes et al., 1993; Fan et al., 1993; Marshall et al., 1993; Fisher et al., 1994; Protti and Schwartz, 1994). The north-trending boundary between the Cocos and Nazca Plates is the right-lateral Panama fracture zone. West of this fracture zone is the Cocos Ridge, a trace of the Galapagos Hotspot, which subducts beneath the Costa Rican segment of the Panama Block.

The Nicoya Peninsula is composed of Late Jurassic to Late Cretaceous ophiolitic rocks, and Late Cretaceous and younger sedimentary rocks (Fig. 2). The older magmatic sequence has a mid-ocean-ridge basalt (MORB) chemistry (Meschede and Frisch, 1994), suggesting an origin as oceanic crust. The younger magmatic sequence has a mixture of arc and ocean-island chemistry, which Meschede and Frisch (1994) interpret as part of a regional Cretaceous sill event that affected the whole Caribbean region. Sedimentary rocks overlying the Nicoya Complex are thin and include radiolarian cherts, black shales, pelagic limestones, sedimentary breccias, and minor sandstones. Abundant ash beds occur in the early part of the section. Several kilometers of age-equivalent strata on the northeast side of the peninsula include volcaniclastic turbidites that probably accumulated in a forearc basin (Lundberg, 1983). Overall, the strata overlying the Nicoya Complex indicates shallowing through time at irregular rates, and uplift continuing into the Holocene (Gardner et al., 1992).

Seismicity

Costa Rica is seismically very active. Shallow seismic events ($z < 40$ km) occur (1) associated with the subduction of the Cocos Plate under the Caribbean Plate and Panama Block; (2) along the Panama fracture zone; (3) as intraplate activity within the Cocos and Caribbean Plates and the Panama Block; (4) as interplate activity between the Caribbean Plate and Panama Block, both along the North Panama Deformed Belt as well as along the central Costa Rica shear zone; and (5) associated with the volcanic arc (Protti et al., 1995). Intermediate-depth earthquakes (40−220 km) occur as internal deformation of the subducted portion of the Cocos Plate (Protti et al., 1995). Since April 1984, the Costa Rica Volcanological and Seismological Observatory at the National University (OVSICORI-UNA), has been recording activity from all these seismic sources and has located, in just a decade, over 20,000 earthquakes.

The intermediate-depth seismic activity under Costa Rica reveals a tear on the subducted Cocos Plate under central Costa Rica (the Quesada Sharp Contortion [Protti et al., l995]), which is recognizable below 70 km (Fig. lB). To the northwest the Cocos Plate dips 80°, and seismicity attains depths of 220 km beneath the Nicaragua border to 135 km at the tear. To the southeast the Cocos Plate dips 60°, and seismicity does not exceed 125 km (Protti et al., 1995). The projection of the tear to the trench coincides with an abrupt change in the bathymetry of the Cocos Plate along a northeast alignment (the rough/smooth boundary of Hey [1977]). This boundary projects to the entrance of the Nicoya Gulf just southeast from Ocean Drilling Program (ODP) Site 1039. This bathymetric change marks the boundary between lithosphere of the Cocos Plate created along the

[1]Kimura, G., Silver, E., Blum, P., et al., 1997. *Proc. ODP, Init. Repts.,* 170: College Station, TX (Ocean Drilling Program).
[2]Shipboard Scientific Party is given in the list preceding the Table of Contents.

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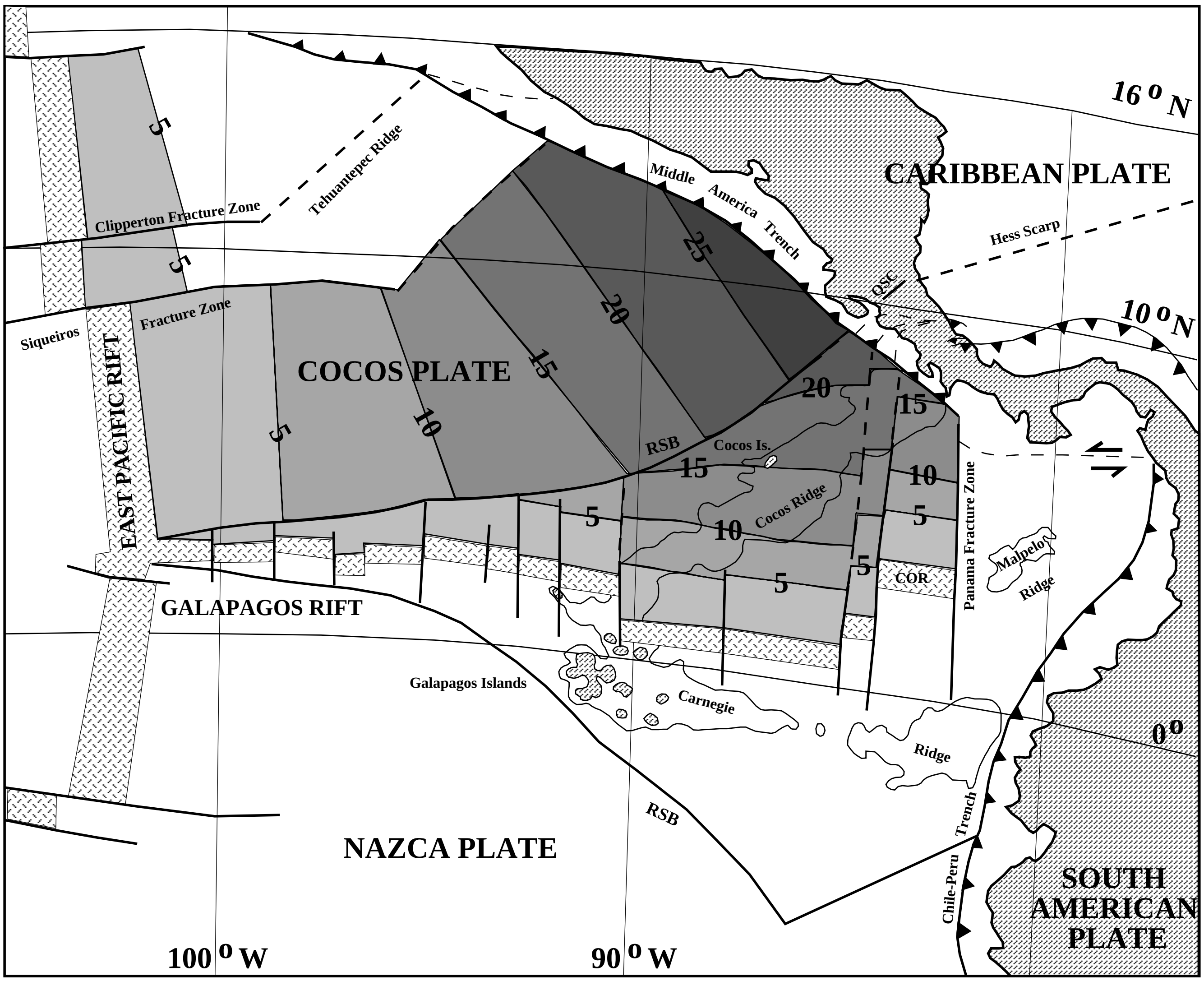

Figure 1. **A.** Regional tectonic map of southern Central America (modified from Protti et al., 1995), showing major tectonic boundaries and geographic features discussed in the text. Also shown is the distribution of lithospheric age (in Ma) of the Cocos Plate, after Hey (1977). RSB = rough/smooth boundary; QSC = Quesada Sharp Contortion of the Wadati-Benioff Zone; CRR and ECR = Costa Rica and Ecuador rifts, respectively. Darker shades of gray show greater age. **B.** Tectonic setting of southern Central America and the geometry of the top of the Wadati-Benioff Zone (from Protti et al., 1995). Isodepth contours are at 20-km intervals, from 40 km. Filled triangles = active volcanoes; and filled circles = location of large (magnitude >7.0) earthquakes that occurred in this century. Darker shades of gray show greater depth. Each shade increment is 1000 m.

East Pacific Rise and that created along the Galapagos spreading center. The northeast extension of the rough/smooth boundary, which may become the Quesada Sharp Contortion after subduction, was interpreted as a relict of the original transform fault along which the Farallon Plate broke into the Cocos and Nazca Plates either 25 Ma (Hey, 1977) or 27 Ma (Lonsdale and Klitgord, 1978). On the other hand, recent studies of the magnetic pattern in the Cocos Plate have inferred faster spreading rates than were previously recognized, so the age of the Cocos Plate subducting beneath the Nicoya Peninsula may be younger.

Earthquakes of a magnitude >7 occurred beneath the Nicoya Peninsula in 1827(?), 1853, 1900, and 1950. The 1978 Samara earthquake of magnitude 6.8 ruptured only a small portion of the Nicoya segment (Guendel, 1986). To the southeast of the Nicoya Peninsula, magnitude 7 earthquakes occurred in 1882, 1939 and 1990, whereas to the northwest off Nicaragua major quakes have been reported in 1750, 1840, 1844, 1863, 1881, 1889, 1901, 1916, 1921, 1956, and 1992. A spatial and temporal seismic gap is defined by the nonoccurrence of an important earthquake on the Nicoya segment since 1950, coupled with the occurrences of the 1990 earthquake at the entrance of the Nicoya Gulf and the 1992 earthquake off Nicaragua. A lack of seismicity in this Nicoya gap is evident at magnitudes of 2.5 or above. Based on the experience of the 1990 and 1992 earthquakes and the aftershock relocations of the 1950 earthquake (Guendel, 1986), elastic coupling begins about 15-km arcward from the trench. The potential rupture area of a future Nicoya earthquake is estimated between 3900 and 9600 km² (J.M. Protti, pers. comm, 1996).

Accumulated strain has also been recorded by repeated global positioning system (GPS) campaigns in the region. The Nicoya Peninsula moves to the northeast with respect to the rest of the Caribbean Plate at rates of up to 30 mm/yr, based on preliminary results from the 1994 and 1996 GPS campaigns. Dixon (1993) noted a convergence deficiency between Cocos Island (on the Cocos Plate) and Liberia (on the Caribbean plate just northeast from the Nicoya Pen-

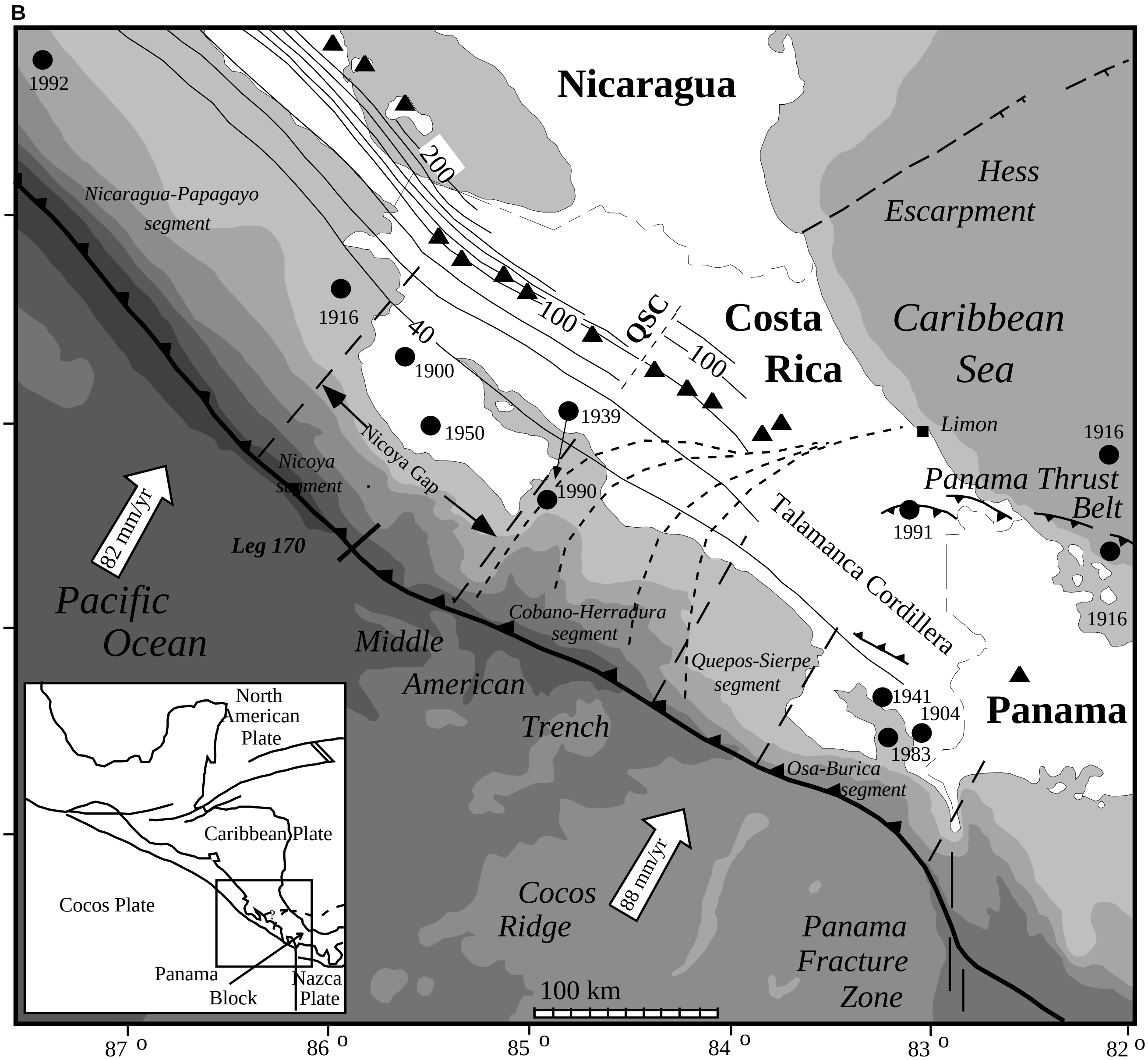

Figure 1 (continued).

insula) and modeled it as a locked interface at a depth of about 25 km below the Nicoya Peninsula.

Previous Drilling and Site-Specific Geology and Geophysics

Site 565 (Fig. 3) was drilled to a depth of 328 mbsf during International Phase of Ocean Drilling (IPOD) Leg 84, stopping prematurely in hemipelagic mud of early Pliocene or late Miocene age because of drill string sticking and the presence of gas hydrates. Detailed seismic reflection and refraction data have been recorded seaward of the Nicoya Peninsula. The results of a detailed 2-D and a more restricted 3-D seismic reflection study (Fig. 4) were reported by Shipley et al. (1992); a wide-angle refraction study, including both 2-D and 3-D coverage, was recently completed (Christeson et al., 1995; McIntosh et al., 1995); and a set of *Alvin* dives (McAdoo et al., 1996; Kahn et al., 1996), heat-flow measurements (Langseth and Silver, 1996), piston cores (Zuleger et al., 1996), and both SeaBeam (McAdoo et al., 1996) and hydrosweep (von Huene and Flüh, 1994) bathymetric mapping have recently been reported.

Seismic Reflection and Refraction Data

During April, 1987, a series of 2-D seismic reflection lines and a 3-D reflection survey were carried out on the Pacific Margin of Costa Rica, offshore of the Nicoya Peninsula. The source was a six-airgun, 1000-in^3 tuned array, recorded by a 3.3-km-long, 96-channel hydrophone streamer. Seismic data were processed at the University of Texas at Austin Institute for Geophysics (Stoffa et al., 1991; Shipley et al., 1992). One of the early findings of the 2-D data set was the fact that a major part of the incoming strata on the lower plate was underthrust beneath the toe of the margin, and this underthrust strata decreased markedly in seismic traveltime thickness within the first few kilometers landward of the trench (Fig. 5), presumably a result of significant dewatering (Shipley et al., 1990). Another primary feature of the margin illustrated by these seismic data is a high-amplitude re-

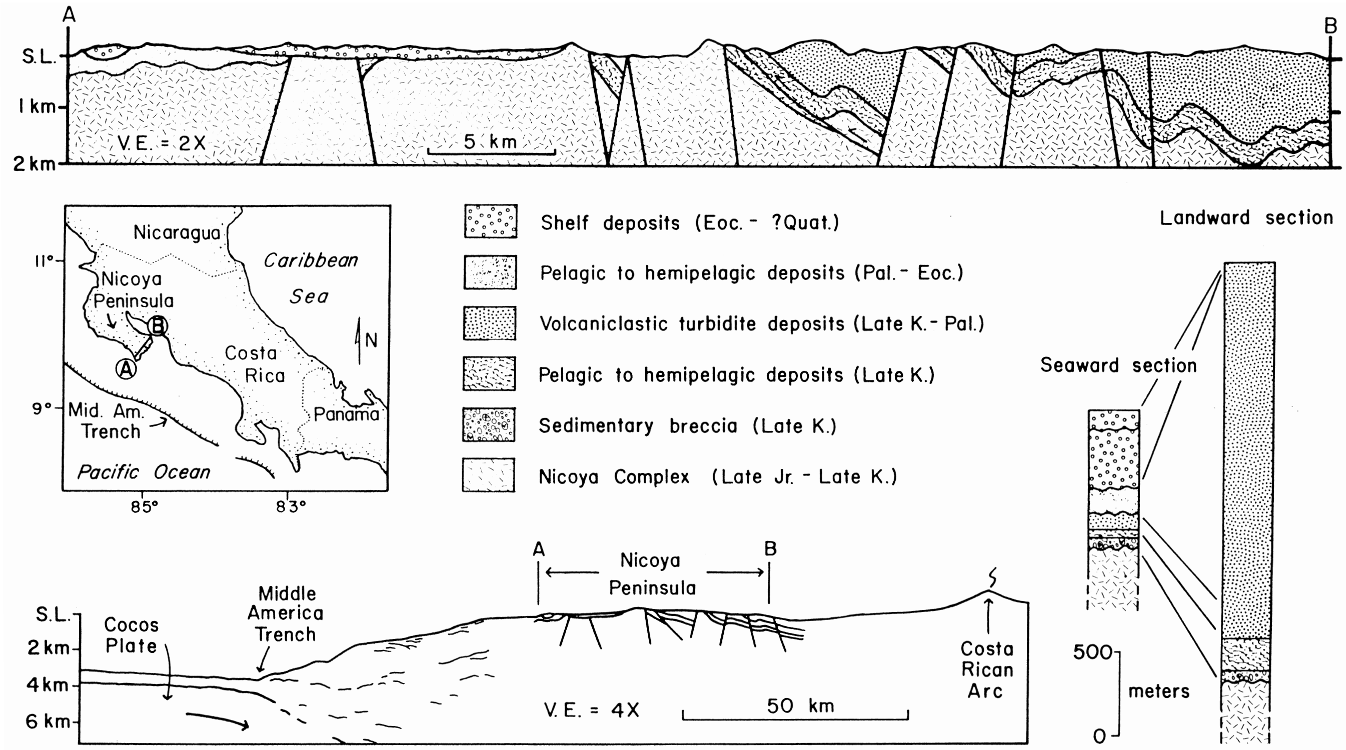

Figure 2. Generalized cross section and stratigraphic columns of the Nicoya Peninsula. Inset shows location of Line A–B on map of Costa Rica. Lower section is schematic of entire forearc. Jr. = Jurassic; K. = Cretaceous; Pal. = Paleocene; Eoc. = Eocene; V.E. = vertical exaggeration (from fig. 2 of Lundberg [1983]).

flection (Fig. 6) that separates a slope apron (~500 m thick on the lower slope and up to 2 km thick on the upper slope) from the deeper prism. The reflection extends to about 5 km from the toe of the slope, with the seawardmost 5 km of the prism apparently composed of material scraped off the incoming section. The nature of the prism beneath the high-amplitude reflection was not resolved prior to Leg 170.

Shipley et al. (1992) considered several options involving sediment underplating and offscraping to explain the complex and variable internal prism structure visible in the 2-D and 3-D seismic images. These models assumed that the prism was composed largely of accreted sediment consistent with the imaged internal structure. Although the 3-D data were depth migrated after stack to produce good images, no independent velocity data were available to ensure accurate vertical positioning or to suggest the lithology of the unsampled prism. However, since 1991, three wide-angle seismic data sets have been acquired off western Costa Rica, including two transects across the Leg 170 drilling area. A key result of the refraction work is that the seismic velocity of the trench slope is significantly higher than previously estimated for the seismic migration processing. For example, just beneath the slope apron near midslope, the migration velocity was 2.4 km/s, whereas the refraction modeling indicates a velocity of ~4.5 km/s. On the basis of initial refraction results, von Huene and Flüh (1994) inferred that Nicoya Complex ophiolitic rocks extended from onshore and are present beneath much of the trench slope. However, because of overlapping velocity/lithology fields, the velocities alone are insufficient to determine the nature of the Costa Rica accretionary prism.

In addition to the frontal offscraping and the enigmatic high-amplitude reflection, the 2-D and 3-D seismic data imaged structures diagnostic of sediment underplating and a number of long reflections within the prism, some of which continue to the seafloor, that are interpreted as out-of-sequence thrust faults. The sedimentary apron in the lower slope region is heavily dissected by many of these out-of-sequence thrusts. Farther inland, cutting the upper-slope region, is a wide area of normal faults that also cut the apron (McIntosh et al., 1993). Between these two zones of differing apparent stress state are four mud diapirs, whose source appears to be the base of the sedimentary apron, although a deeper influence, such as fluids expelled from the prism or underthrust strata, also appears likely (Shipley et al., 1992).

Heat Flow

The Cocos Plate west of the Nicoya Peninsula is part of a wide region of anomalously low heat flow (von Herzen and Uyeda, 1963; Vacquier et al., 1967). A detailed suite of heat-flow stations taken seaward of the Nicoya Peninsula (Fig. 7) showed an average value of 13.5 mW/m^2 in the trench seaward of the frontal thrust (Langseth and Silver, 1996). Heat flow increased to 23.5 mW/m^2 just landward of the frontal thrust, and again to about 30 mW/m^2 farther upslope. The measured heat flow stayed relatively constant at the latter value farther upslope, which is itself anomalous because heat flow generally decreases upslope in subduction environments, as distance from the source of nonconductive mantle heat increases.

The reason for the anomalously low heat flow in the trench is not understood (expected heat flow for crust of late Oligocene to early Miocene age would be ~80 mW/m^2, and for late early Miocene age it would be ~100 mW/m^2). One explanation proposed by Yamano and Uyeda (1990) for anomalously low heat flow off the Peru Margin is refrigeration by circulating seawater, probably in the uppermost part of the oceanic crust. Seawater circulation in the uppermost crust was documented for a distance of kilometers on the flank of the Juan de Fuca ridge by Davis and Fisher (1994), and for tens of kilometers by Fisher et al. (in press). Off the Nicoya Peninsula, the sudden increase in heat flow just beyond the frontal thrust and the near uniformity of

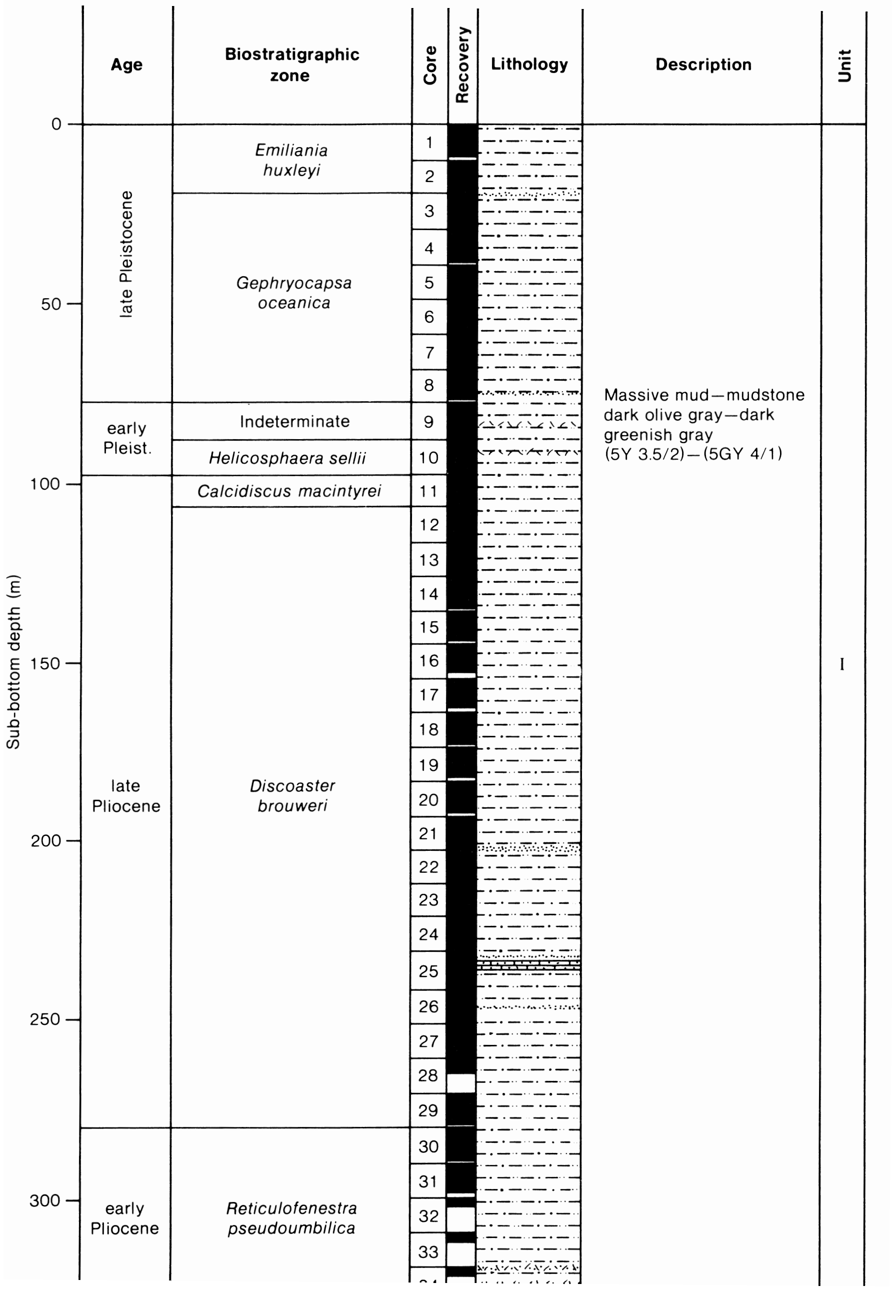

Figure 3. Stratigraphic section of DSDP Leg 84, Site 565.

heat flow farther upslope are considered by Langseth and Silver (1996) to be consistent with a model of heat advection through prism dewatering, but not with a model of shear heating.

Alvin Dives

In an attempt to understand the distribution of fluid flow across this margin, a set of 20 *Alvin* dives (Fig. 8) was made during February, 1994 (Silver, 1996). One of the objectives of the dive program was to investigate the distribution of fluid vents at the frontal thrust and farther upslope, identifying locations of communities of chemosynthetic clams and tubeworms, or regions of authigenic carbonates, all of which had been very effective elsewhere for similar purposes (e.g., Barbados, Japan, and Oregon). Five dives were devoted to searching the frontal thrust for signs of chemosynthetic organisms, and the rest were distributed farther upslope. One of the mud diapirs had four large, active vents with abundant clams and tubeworms and widespread authigenic carbonate crusts and slabs (Kahn et al., 1996). Of the other diapirs, one had a pock mark, but no other signs of venting. The region of outcropping out-of-sequence thrusts showed abundant, small clusters of vent communities, suggesting fracture control of fluid venting. Kahn et al. (1996) interpreted the absence of vent communities at and near the frontal thrust, in conjunction with the heat-flow evidence of fluid flow in this region, as indicating distributed flow rather than highly focused flow. The latter has been shown to characterize fluid-vent systems elsewhere (e.g., Le Pichon et al., 1990; Fisher and Hounslow, 1990). Farther upslope, the flow through the prism appears to be controlled by fracture permeability. Direct knowledge of the process of fluid flow through the prism must await drilling.

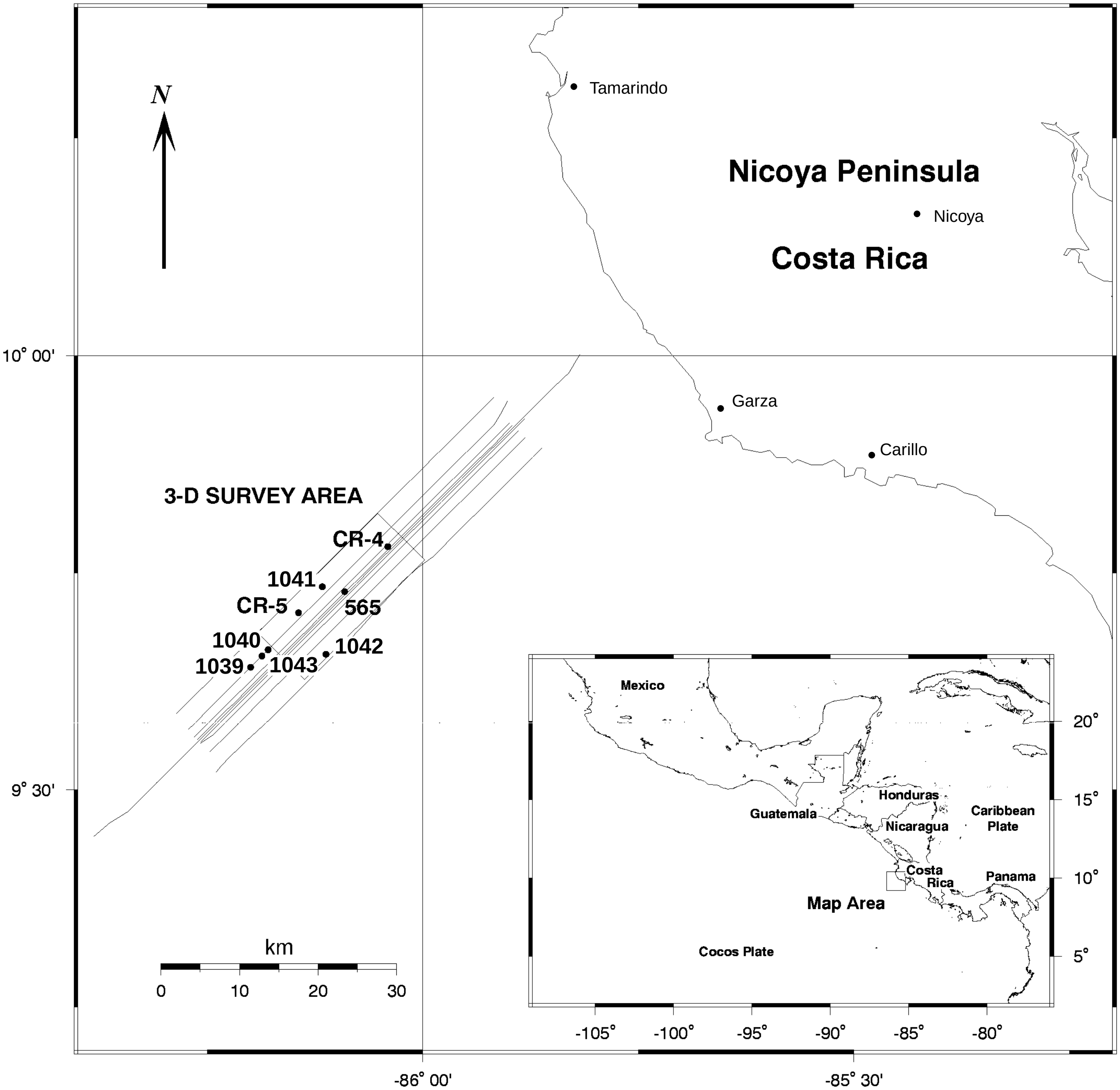

Figure 4. 2-D and 3-D seismic reflection surveys carried out offshore of the Nicoya Peninsula. 2-D lines are shown as lines. 3-D data set is within the rectangular area. Location of the area is shown in the inset. Site 565 is from IPOD Leg 84. Site 1039 = proposed site CR-1; Site 1040 = proposed site CR-2; Site 1041 = proposed site CR-3; Site 1042 = proposed site CR-7; and Site 1043 = proposed site CR-6. Proposed sites CR-4 and CR-5 are shown for reference purposes.

DSDP Site 565

The only previous drilling on the Costa Rica Margin was at Site 565 on Deep Sea Drilling Project (DSDP) Leg 84. As indicated above, the presence of gas hydrates and the stickiness of the mud in the upper part of the section combined to end this site before the primary objective (sampling the high-amplitude reflection below the sedimentary apron) could be accomplished. Gas hydrates were recovered at 285 and 318 mbsf. Benthic foraminiferal faunas indicated a gradual uplift from abyssal depths (4000 m) in the lowest part of the section to lower middle bathyal depths (1500–2000 m) in the late Pleistocene, and possibly subsidence or downslope movement to the present depth of 3100 m. Folds were observed in the upper (Pleistocene) part of the section, but not in the deeper part, suggesting a normal stratigraphic age-depth, so downslope movement of the uppermost strata is a possibility (Baltuck et al., 1985). Sedimentation rates are highest in the late Pleistocene (165 m/m.y.), somewhat lower in the early to late Pliocene (125 m/m.y.), and very slow in the early Pleistocene (no greater than 13 m/m.y.), although the latter may indicate the presence of an unconformity.

Geochemistry

Chemical mass balance calculations measure the percentage of subducted sediment-hosted elements that are recycled in arc volcanism, and, therefore, permit minimum estimates of the amount of sed-

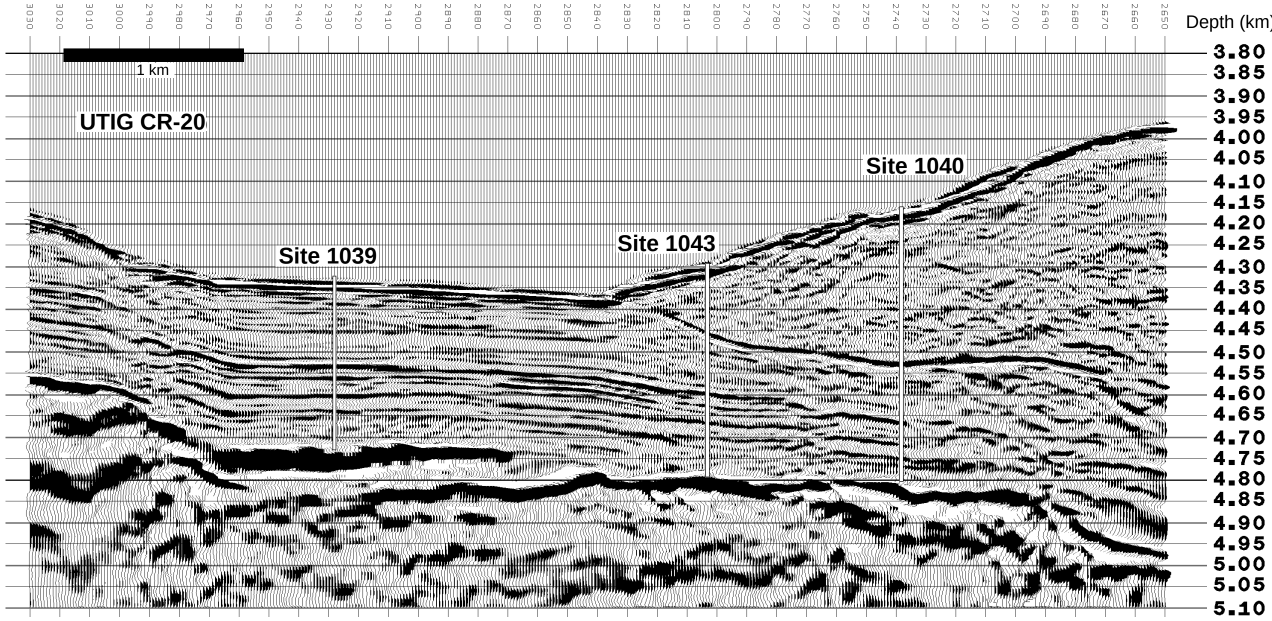

Figure 5. Depth migrated seismic Line CR-20; the location is shown in Figure 11. Locations of Sites 1039, 1043, and 1040 are shown.

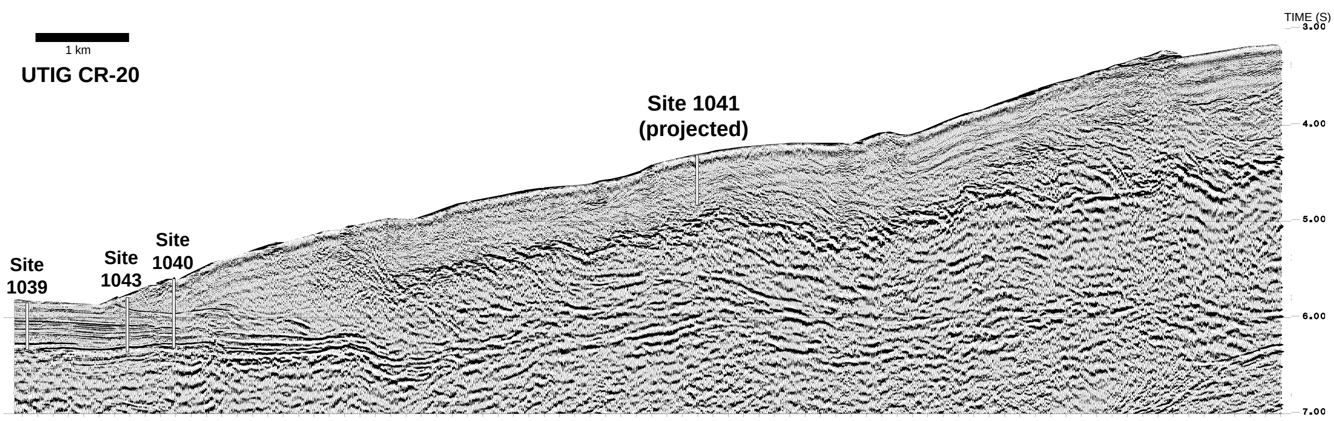

Figure 6. 2-D seismic reflection Profile CR-20, showing the locations of Sites 1039, 1040, 1041 (projected), and 1043. Site 1041 was projected to drill through the apron into the deeper prism material below. Note the high amplitude of the top-of-prism reflection. Vertical scale in two-way traveltime.

iment bypassing the deformed margin altogether. Assuming steady-state conditions, cosmogenic ^{10}Be is particularly useful in partitioning the incoming sediments into those accreted, underplated, diluted by erosion, or deeply subducted. ^{10}Be is created from cosmic rays in the atmosphere, is strongly adsorptive on settling sediment particles in the oceans, has a 1.5-m.y. half-life, and tags only the uppermost part of the sediment column (Lal and Peters, 1967; Anderson et al., 1990; Yiou and Raisbeck, 1972). It is important to note that erosion of old material from the deep prism will dilute the ^{10}Be in the oceanic column; therefore the presence of ^{10}Be in the volcanoes may also place limits on the amount of permissible subduction erosion.

In Costa Rica, the arc volcanoes do not have measurable quantities of ^{10}Be. Measurement of ^{10}Be in Site 1039 will provide a detailed picture of the ^{10}Be distribution in the sediment column, which can be combined with physical mass balance models and the absence of recycled ^{10}Be to further quantify estimates of accretion and underplating. This situation is sketched in Figure 9, where the expected age/depth/lithology relations are shown. Sites 1040 and 1041 provide opportunities to assess the amount of ^{10}Be stored in the forearc, and episodic accretion or erosion is indicated if sediments that are too old to contain ^{10}Be (>12–15 Ma) are recovered at these sites. The ^{10}Be distribution may help to distinguish between different proposed origins for the coherent intraprism reflections seen near this site. For any of these approaches to work, ^{10}Be in the sediment column cannot be significantly redistributed by diagenesis or fluid flow. Experimental studies in simple water-sediment systems suggest that ^{10}Be is relatively immobile (Nyffeler et al., 1984; You et al., 1989). However, recent results (You et al., 1989) indicate that this question should be investigated carefully in natural systems, which can be done in the context of fluid flow and chemical studies in the Leg 170 drill sites.

The geochemical stratigraphy of the incoming sediment column may be an important aid in constraining the accretionary processes. Like ^{10}Be, elements can also be traced through the subduction zone (Plank and Langmuir, 1993), and because elements do not decay like ^{10}Be, they can potentially tell us about processes affecting the entire sedimentary column. For example, although northern Costa Rican volcanics have no ^{10}Be, they have roughly the same enrichment in Ba as Guatemalan volcanics (Fig. 10). Because Ba in Central American volcanics appears to originate in subducted sediment, similarity in the volcanics suggests similar mass fluxes of subducted Ba.

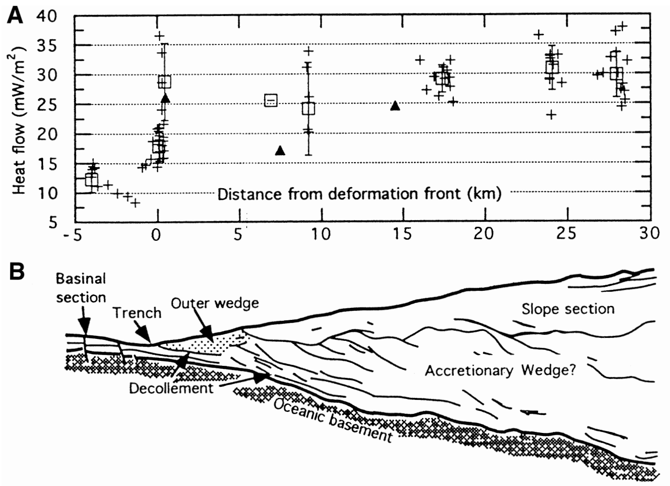

Figure 7. **A.** Heat flow vs. distance from deformation front. + = individual values; squares = group means, error bars = standard deviation; and triangles = *Alvin* probe. **B.** Schematic of structure of Costa Rica Margin (from Langseth and Silver [1996]).

The subducted sedimentary Ba flux for Costa Rica is calculated from the composition and density of the sedimentary column at Site 495, off Guatemala. The arrow in Figure 10 shows the effect of frontal accretion on the subducted flux, where increasing amounts of the upper hemipelagic mud unit are removed (total meters of sediment subducted as indicated). Fifty meters of off-scraping would bring the Ba flux for Costa Rica in line with the global trend. This is an illustrative example of how chemical fluxes might help to constrain accretionary processes. Accurate estimates require better control of the global trend (from improved constraints on the accretionary dynamics at other subduction zones) and Ba data on the incoming sedimentary column off Costa Rica (e.g., Site 1039).

SCIENTIFIC OBJECTIVES

The main focus of Leg 170 is to determine mass- and fluid-flow paths through a well-constrained accretionary complex to calculate mass and fluid balances. Drilling data will facilitate an integrated effort to understand these processes using structural data and the physical and chemical properties of both the sediments and their pore fluids. The general objectives of the leg are (1) to determine the sediment, chemical, and fluid mass balances within the accretionary

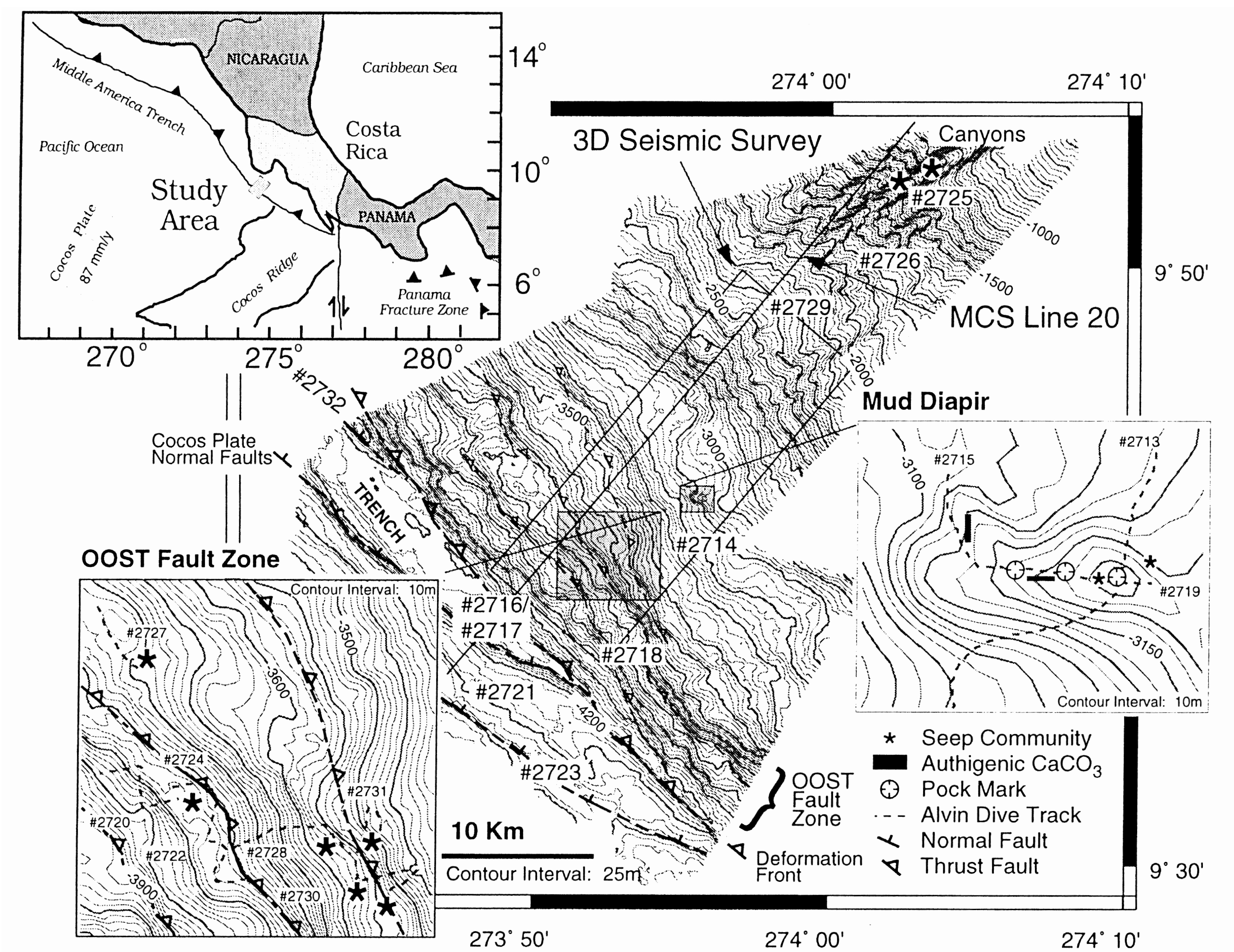

Figure 8. SeaBeam map of the seafloor across the Middle America Trench off the Nicoya Peninsula, showing the locations of *Alvin* dives. Insets show detail of the regions of high concentrations of fluid vents (from McAdoo et al., 1996).

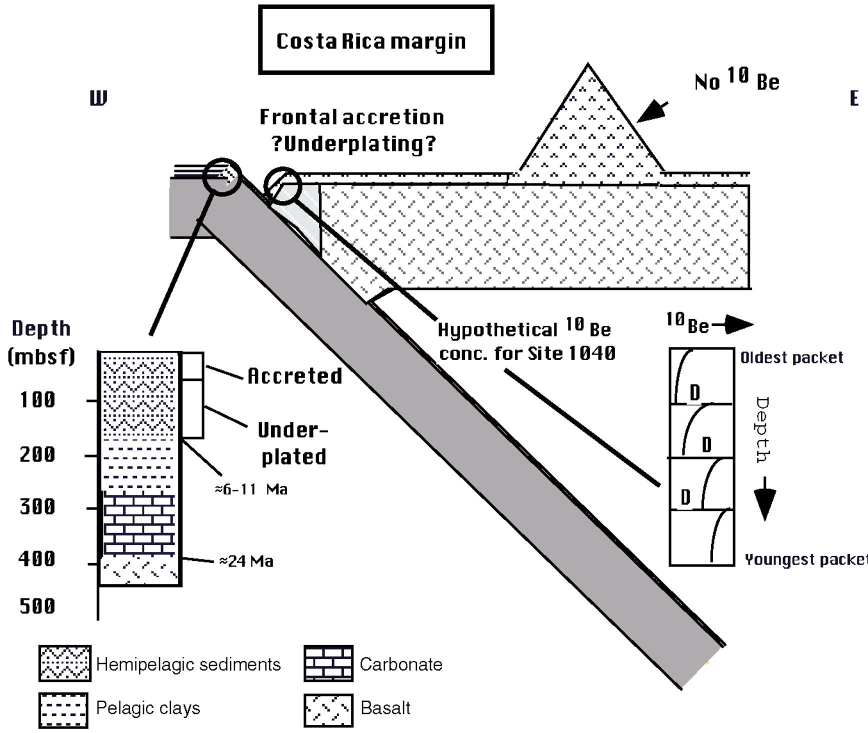

Figure 9. Lithology and ^{10}Be (half-life = 1.5 m.y.) concentrations vs. depth for Costa Rica, showing the approximate age/depth/lithology relations in the incoming sediment column. The absence of ^{10}Be in the volcanoes indicates that this uppermost part is accreted and/or underplated. The column labeled "hypothetical ^{10}Be conc. for Site 1040" shows the distribution of ^{10}Be with depth to be expected if the intraprism reflectors are older, gently folded décollements (labeled D), separating a younging-downward sequence of sedimentary packets, each packet of which is youngest at the top. ^{10}Be concentrations will be at measurable levels if younger than about 12 Ma. An absence of ^{10}Be at Site 1040 implies older ages, consistent with episodic erosion or subduction erosion.

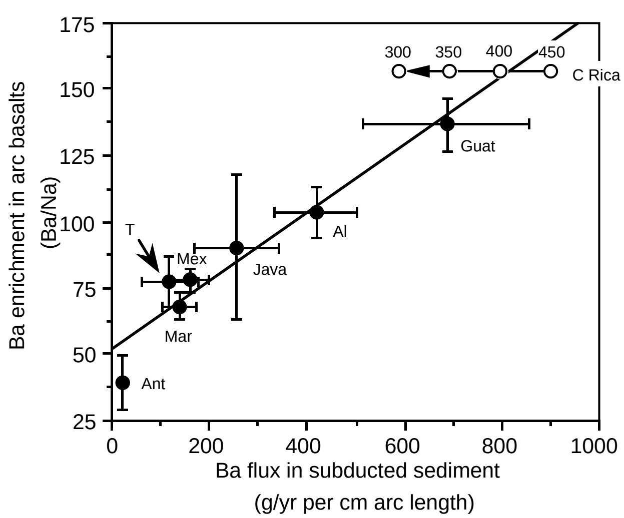

Figure 10. Correlation between Ba flux in subducted sediment and Ba enrichment of arc basalts, for the Northern Antilles, Marianas, Tonga, Mexico, Java, Aleutians, and Guatemala arcs (after Plank and Langmuir, 1993). These types of correlations, which are present for other elements as well, suggest that volcanic output is linked to sediment input in subduction zones. Line is best fit of solid points; vertical error bars are ± 1 standard deviation of the mean of volcanoes within each arc; horizontal error bars represent uncertainties in the thickness of sediment being subducted because of variable supply, underplating, and erosion (generally ± 100 m). Input fluxes do not include accreted material, however (see Plank and Langmuir, 1993). Open circles are for the Costa Rica subduction zone. Ba/Na values are for Arenal and Rincon volcanoes (data from Carr and Rose, 1987), which are the closest of the Costa Rican volcanoes to the proposed drilling transect.

prism and the larger subduction system (including the volcanic arc); (2) to test whether or not the prism is developing in equilibrium with the incoming sedimentary material and, if so, to quantify the partitioning of material into offscraped, underplated, internally shortened, and subducted volumes; and (3) to determine the effects of fluids on prism deformation.

Specific objectives of the program will focus on

1. The age and nature of the prism beneath the slope apron;
2. The source material and ages of the offscraped material in the deformed wedge;
3. The nature of the lower part of the apron and time sequence of formation;
4. The physical properties of the material above, within, and below the top-prism reflection;
5. Comparison of the reference section in the trench with the underthrust section beneath the décollement and with the material in the wedge;
6. The relative importance of underplating vs. out-of-sequence faulting; and
7. Evidence of fluid stratigraphy and flow distribution within the wedge materials.

DRILLING PLAN AND STRATEGY

Determination of mass, chemical, and fluid flow into the accretionary wedge and the partitioning of accreted and subducted material is the focus of Sites 1039, 1040, and 1043 (Figs. 5, 11). Site 1039 was designed to obtain a complete stratigraphy of the incoming material on the lower plate, characterizing the distribution of ages, lithologies, chemistry, and physical properties of the cores and pore waters. In addition, we planned to sample the basaltic crust of the Cocos Plate for lithology, physical properties, and chemistry. Site 1040 was designed to drill through the accretionary wedge, the décollement, and the underthrust sedimentary section to basement. The objective was to determine the portion of the incoming section that is

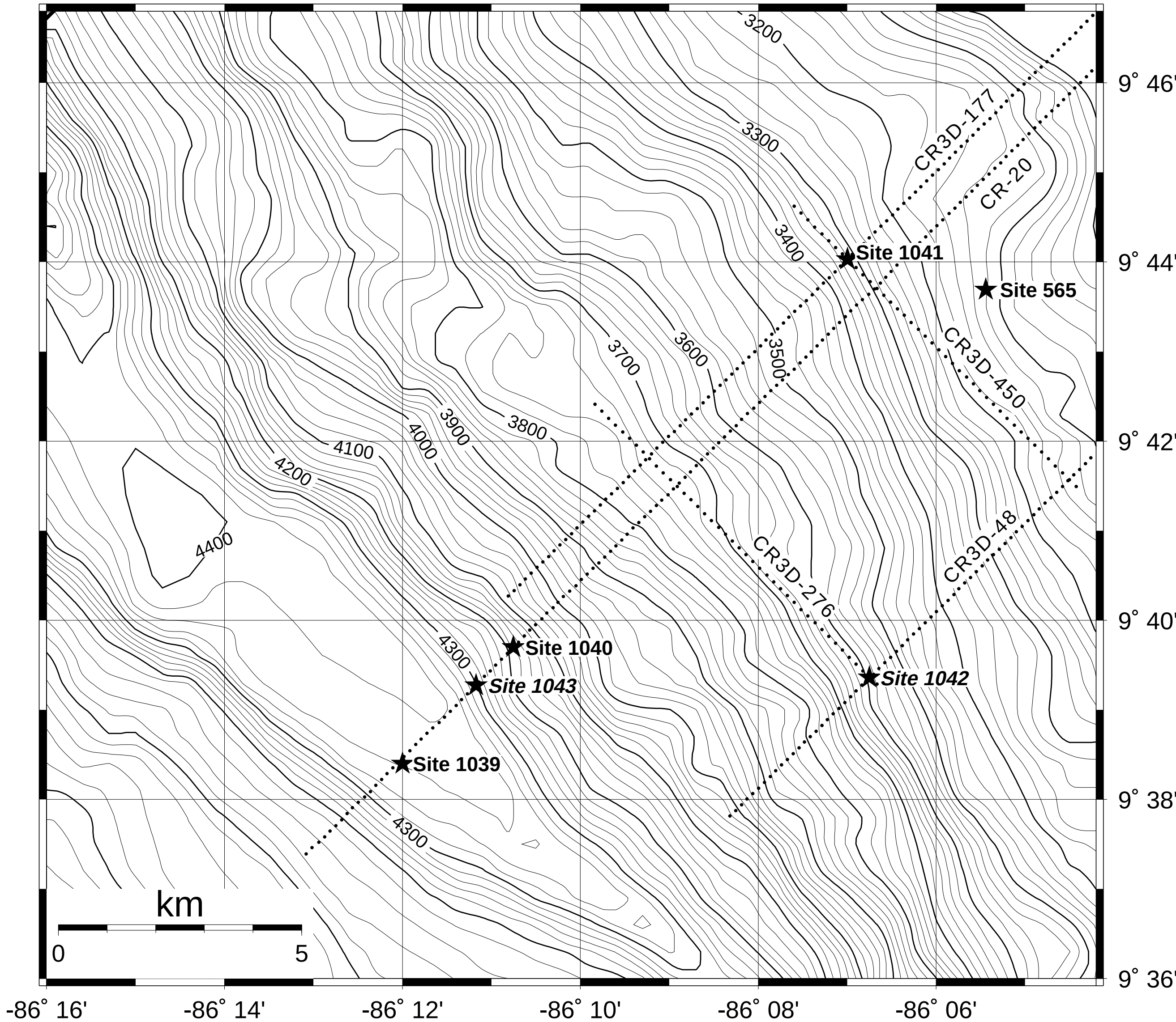

Figure 11. Bathymetric map of the Middle America Trench and lower continental slope region off the Nicoya Peninsula, Costa Rica. Dotted lines show the locations of 2-D seismic Line CR-20, on which Sites 1039, 1040, and 1043 are positioned, and 3-D lines and cross lines locating Sites 1041 and 1042. Bathymetry is from Hydrosweep data, shown with permission of R. von Huene (unpubl. data). Contour interval is 20 m.

accreted, the structure and physical properties of the accreted materials, the fluid distributions and composition, and the changes in chemistry and physical properties between the underthrust sedimentary and basaltic rocks and those of the reference section. Site 1043 had the objective of an additional crossing through the décollement and a complete logging profile of the décollement using the logging-while-drilling technique.

The objectives at Sites 1041 and 1042 (Figs. 6, 11) were to determine the distribution of material properties through the apron and finally learn the composition of the material beneath the high-amplitude reflection that represents the top of the prism. Initially, we had hoped to drill into this prism material deep enough to penetrate through a prominent reflector, interpreted to be an out-of-sequence thrust fault. With new seismic velocities from detailed wide-angle refraction studies, this reflection was seen to be too deep to penetrate. Logging while drilling in all three sites allowed us to measure the properties of newly drilled strata, including fractures and fine-scale density and porosity excursions.

Postcruise analysis of the drilling results will provide information on the input of material into the subduction zone and will give significant constraints on the partitioning of subducted vs. accreted material. It will also provide input on the compositions and partitioning of the fluids associated with initial subduction. These input parameters can then be compared with geochemical indicators in the arc volcanics to determine the ultimate partitioning between the Earth's surface and the mantle, as sampled at the volcanic arc.

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