The Effects of Seamount Subduction on Fore Arc Kinematics and Origin of the Nicoya Complex, Pacific Coast, Costa Rica

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INTRODUCTION

Along the Pacific coast of Costa Rica, nearly orthogonal convergence is occurring at the rapid rate of 10 cm/yr as the Cocos plate subducts beneath the Caribbean plate at the Middle America Trench (Figure 1). The Cocos plate is characterized by pronounced, linear ridges of seamounts that rise a thousand meters above the sea floor (Figure 2). Subduction of these rough elements has profound effects on seismicity (Protti et al., 1995) and deformation (Gardner et al., 1992) of the thinly sedimented accretionary prism along the Pacific coast. For example, subducting seamounts can produce rapid rates of fore arc deformation (Marshall and Anderson, 1995; Fisher et al., 1998). Collision of the seamounts weakens the upper plate and results in frontal erosion due to gravitational failure of the trench. Thus, at the toe of accretionary prisms, there are often trench embayments around incoming seamounts. The extent to which seamounts are subducted and possibly underplated well landward of the toe of the accretionary prism has important implications for the style and distribution of deformation and seismicity along the plate boundary and within the upper plate.

During June and July, 1998, twelve students (named later) and four faculty, representing a total of eight Keck Consortium colleges and universities, one Costa Rican institution and one minority school came together to examine fore arc deformation along the Pacific Coast of Costa Rica. We were joined by a doctoral student at Penn State, Jeff Marshall, who did his Masters thesis in the area and who is currently completing his dissertation on deformation along the Pacific coast of Coast Rica.

Together, we hypothesized that fore arc deformation along this thinly sedimented margin is characterized by differential uplift in the upper plate controlled by the roughness of incoming seamounts. To address this hypothesis we undertook an integrated study utilizing geomorphology, Quaternary geology, structural geology, geochemisrty, paleomagnetism and geophysics. Our field area, the southern tip of the Nicoya Peninsula (Figures 2 and 3), is directly inboard of a line of subducting seamounts, has large historic earthquakes, a spectacular set of Holocene marine terraces, and beautiful bedrock exposures on marine abrasion platforms. It is a superb location to evaluate our hypothesis.

As a second goal we attempted to discover the origin of the crust on the upper plate (Kuijpers, 1980; Bourgois et al., 1984; Frisch et al., 1992; Donnelly, 1994; DiMarco et al., 1995; Stinton, 1997; Meschede and Frisch, 1998). Specifically, did the basaltic crust of the Caribbean plate originate in the Southern Hemisphere and move northward during the early Tertiary to "dock" at its present location on the Nicoya Peninsula? Conversely, did it form at its present location as an inherent part of the Caribbean plate?

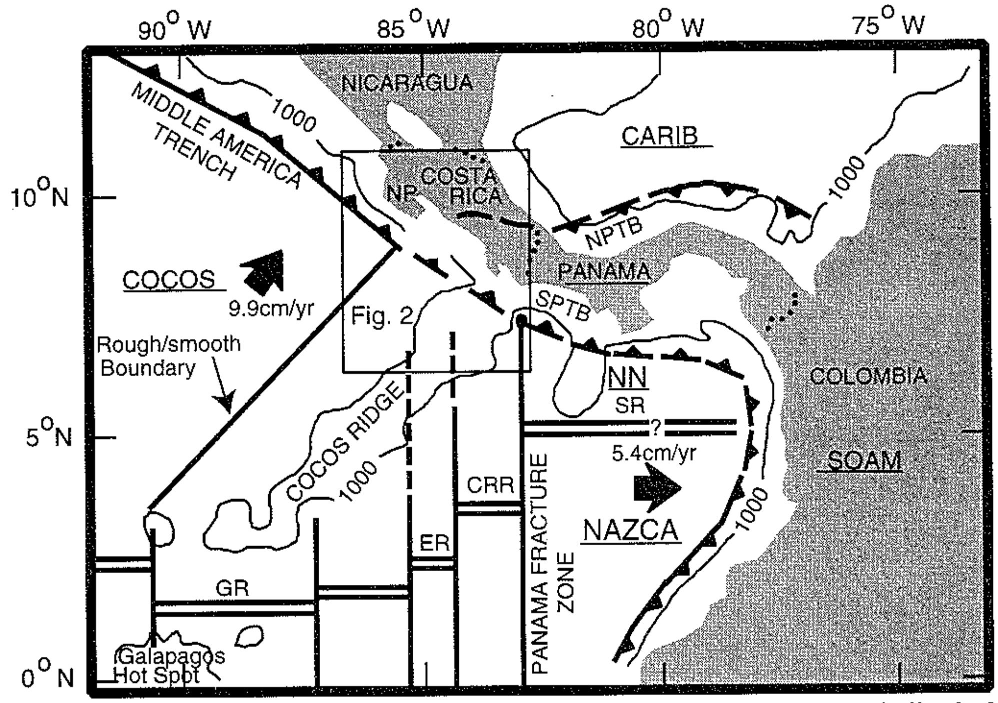

Figure 1. Major plate tectonic features of Central America. Principle plates are underlined. NN, North Nazca; SOAM, South America; GR, Galapagos Rift; ER, Ecuador Rift, CRR, Costa Rica Rift; SR, Sandra Rift; NP, Nicoya Peninsula; SPTB South Panama Thrust Belt; NPTB, North Panama Thrust Belt. Inset box shows location of Figure 2. Major tectonic features are compiled from Van Andel and others (1971), Lonsdale and Klitgord (1978), de Boer and others (1988), Mackay and Moore, (1990), and Silver and others (1990). Modern RM2 plate motions for the equatorial Pacific are from Minster and Jordan, 1978. Depth contour is in meters.

As a third goal we investigated the response of fluvial systems to the known deformation that we were calculating in the marine terrace studies. Specifically, we were interested in the rates of fluvial incision into bedrock as knickpoints retreat headward.

STUDENT PROJECTS

To answer these intriguing questions, students and faculty systematically examined coastal, stream bed, and quarry exposures along two, forty kilometer sections of the coast that are nearly orthogonal to each other (Figure 3). Five students, Bhavani Bee (Franklin and Marshall), Reed Burgette (Whitman), Emily Burton (Carleton), Jenny Cook (Trinity), and Natalie Kehrwald (Colorado College, Eric Leonard sponsor and project visitor), studied marine terraces. Over 30 shell samples were collected for radiocarbon dating. All samples yielded internally consistent ages ranging from about 500yBP to 7000yBP as we had hypothesized. Elevations of all samples were measured by either transit, hand level or altimeter surveys. Additionally, numerous topographic surveys were completed along the terraces to facilitate terrace correlation along the coast. These data, together with a paleo sea level curve, were used to determine uplift rates along the coast using the equation

$$Z\ (m/ky) = \frac{X1\ (m) + X2\ (m) + X3\ (m)}{X4\ (ky)},$$

where X1 is modern elevation above mean sea level, X2 is depositional depth determined from modern facies reconstructions, X3 is paleo sea level as determined from 3 different paleo sea level curves, and X4 is sample age. We produced an exceptional spatial distribution of values, given the right angle bend of the peninsula. With these data we accurately characterized Holocene, upper plate deformation directly inboard of the Fisher and Christmas seamount chain (Figure 2). By combining all uplift data, we modeled deformation as block tilting by calculating the axis of

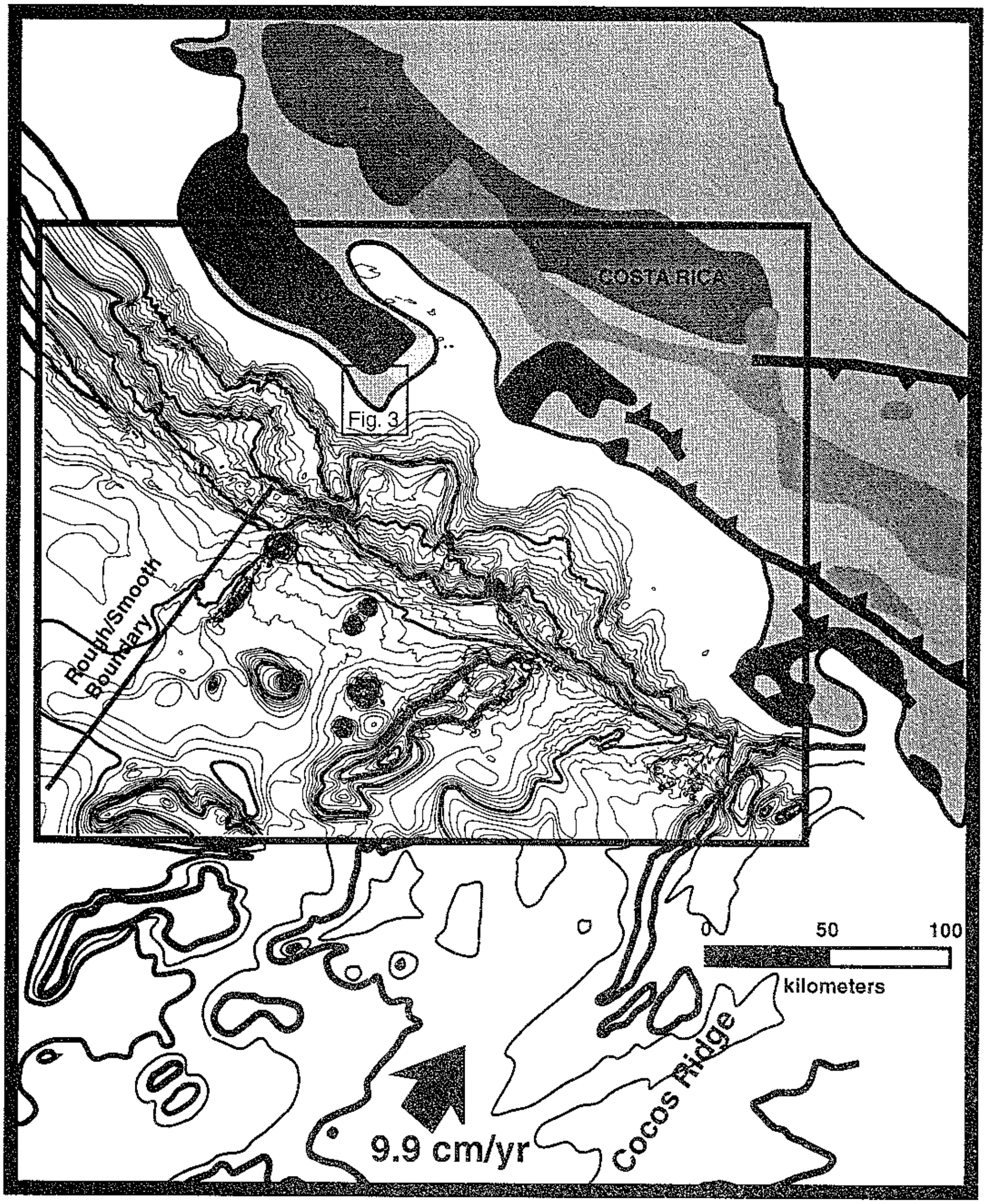

Figure 2: Generalized geologic map of Costa Rica, bathymetry of the Cocos Plate, and location of study area on Peninsula de Nicoya. Geologic units: Nicoya Complex-darkest gray; Active-arc volcanic rocks-dark gray; Extinct-arc volcanic rocks-light gray; fluvial to marine clastic and volcaniclastic rocks-lightest gray. Bathymetric data from von Huene and Fluh (1994) and von Huene et al. (1995). Bold contour interval is 1000 meters.

block rotation and it's angular velocity. Emily Burton further expanded her marine terrace study to include Holocene pedogenesis and chronosequence development. Natalie Kehrwald and Bhavani Bee extended their Holocene marine terrace studies to include terraces from older, Pleistocene, marine highstands.

One student, Erin Krall (Washington and Lee), examined the response of fluvial systems to uplift. Specifically, she examined the rate of bedrock incision and the rate of knickpoint retreat for several streams on different rock types and with different uplift rates. In this study she wanted to compare incision rates as a function of rock type and uplift rate. The superb, datable marine terraces which make the knickpoints on these streams and

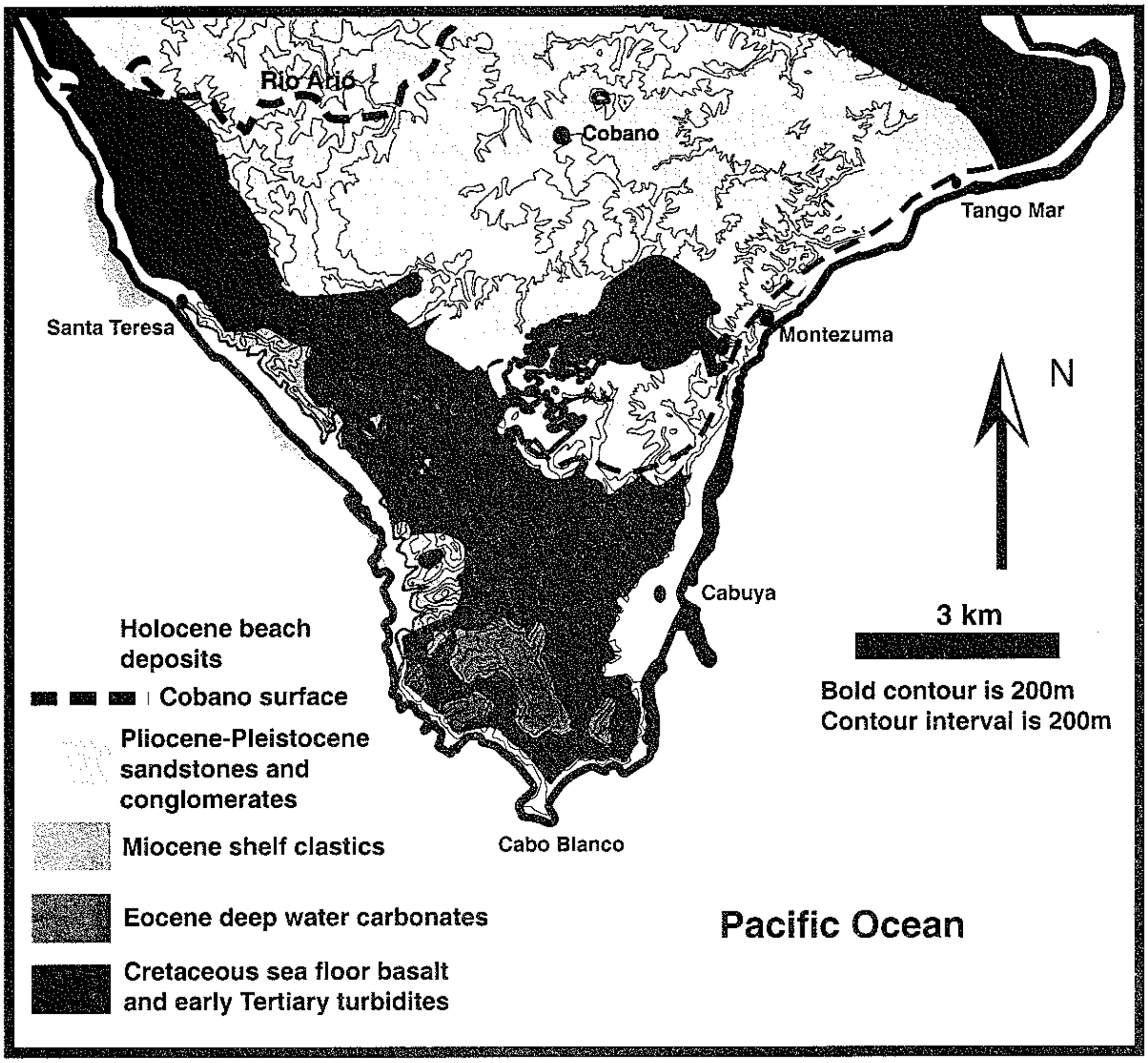

Figure 3. Generalized geology of the southeastern tip of the Nicoyan Peninsula. Geology after Lundberg (1982), Chinchilla (1983), Baumgarter et al. (1984), and Mora (1985). Heavy line along the coast marks approximate mean sea level.

the known initial positions of knickpoints and stream beds gave this study the potential to fundamentally increase our understanding of rates and mechanisms of fluvial incision into bedrock in active tectonic areas.

Two students, Alix Krull (Pomona), and Alex Claypool (Franklin and Marshall), investigated mesoscale faults which are well exposed in Tertiary rocks on marine abrasion platforms. The Tertiary rocks have a complex history of deformation. Many hours of data collection on the HOT abrasion platforms at low tide helped unravel the sequence of tectonic events. These studies discovered the nature and style of deformation in the fore arc inboard of the subducting seamounts.

Another student, Anna Reeves (Mississippi State), drilled and collected rock core from those same Tertiary rocks for paleomagnetic studies. Core samples were processed at Bruce Panuska's (Anna's sponsor and project visitor) paleomag lab at Mississippi State.

Becky Stamski (Amherst) collected samples of basaltic seafloor for geochemical analyses. She traveled far and wide at all times of day and night to find unweathered Nicoya basalt. Becky worked closely with Tekla Harms, her sponsor and project visitor. Becky's geochemical work was done at Amherst and Oregon. One intriguing and provocative question that she addressed concerned the nature of the basaltic "basement". Is it *in-situ* and thus part of the local Caribbean plate that is deforming in response to seamount subduction? Or is it allocthonous, having moved from the Southern Hemisphere into its present position during the early Tertiary. The paleomagnetism and geochemical studies helped resolve those questions.

Finally, two students, Todd Shearer (Whitman) and Enrique Hernandez (Universidad Nacional Autonomous) recorded earthquake activity (and Jeep Verde travels) during the project and reoccupied a 1950 topographic survey line across the peninsula using sophisticated, leveling and GPS equipment. From those studies they looked at historic deformation and compared it to the magnitudes and rates of deformation we determined from the Holocene, marine terrace record.

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