Rapid Quaternary uplift of marine terraces: Cabo Blanco to Montezuma area, Peninsula de Nicoya, Costa Rica

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INTRODUCTION

The Nicoya Peninsula of Costa Rica, located 65 km inland of the Middle America Trench, represents an area of uplifted forearc created by the northeastward subduction of the Cocos Plate beneath the Caribbean Plate. The southern coast of the Nicoya Peninsula is located near the rough-smooth boundary which separates rough ocean floor characterized by buoyant seamounts to the south from relatively dense and smooth crust to the north. Deformation along the southern Nicoya coast is amplified by the subduction of seamounts along this boundary (Gardner and others, 1992; Marshall and Anderson, 1995). Rough crust has been subducting along this margin for the last 1-5 million years (Gardner and others, 1992; Collins and others, 1995). The purpose of this study is to examine Quaternary tectonism as evidenced by Holocene and Pleistocene marine terraces to determine rates and mechanisms of net uplift of the Nicoya Peninsula. Ages and altitudes of Holocene and Pleistocene terraces are used to calculate the local uplift rates along the coast perpendicular to the trench. These uplift rates may be compared with other study areas on either side of Cabo Blanco to determine the block rotation of the southern tip of the peninsula.

STUDY AREA

This study focuses on the southern tip of the Nicoya Peninsula, extending from Cabo Blanco along the coast for 10 km, ending at Montezuma. A significant topographic feature of this coast is an extensive low elevation, wave cut surface, referred to as the Cabuya terrace, that lies between the abandoned Cobano sea cliffs and the modern shoreline (Marshall, 1991; Marshall and Anderson, 1995). In general, the width of the Cabuya platform decreases from approximately 1 km near the village of Cabuya to less than 100 m at Montezuma. Between Cabuya and the Rio Cedro, the broad platform is cut in the Paleocene-Eocene Cabo Blanco Formation consisting of intensely folded interbedded marine mudstones and sandstones (Lundberg, 1982). From Rio Cedro to Montezuma, the platform narrows considerably and is punctuated by small arcuate beaches at the larger stream mouths. Along this stretch, the platform is cut into the more resistant basalt of the Cretaceous Nicoya Complex (Lundberg, 1982).

Cabo Blanco itself has been uplifted relative to the Cabuya surface along the El Flor fault (Marshall and Anderson, 1995). In this area, a broad and continuous Cabuya surface is virtually absent. Instead, steep sea cliffs and narrow erosional platforms replace the Cabuya surface.

METHODS

Holocene Platforms

To establish an accurate uplift history along the coast, topographic surveys were conducted along Holocene wave-cut platforms (Figure 1), and shell samples were collected for radiometric dating. Beginning at Cabo Blanco, profiles of modern abrasion platforms were taken using altimeter, transit, and hand-level surveys to compare the morphology of the active wave platform with abandoned bedrock terraces. Inner edge, outer edge and terrace tread elevations were recorded for each terrace and later correlated with adjacent sites along the coast. When possible, precise elevations of shell fragments at several sites were also recorded (Figure 2), and these shells were sampled for C-14 radiometric dating (Beta Analytic Laboratory).

The rate of uplift for each of the dated sample sites can be calculated using the following expression:

$$\text{Uplift (m/ka)} = \frac{(X1 + X2 + X3)}{X4}$$

where X1 is modern elevation, X2 is depositional elevation of the sample relative to mean sea level, X3 is paleo-sea level at the time of deposition, and X4 is calibrated 14-C age. Using a local

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tidal chart, the modern elevations were corrected for sea level using a sine equation in Kaleidagraph. Field observations were used to determine the depositional facies. All the radiometric dates from the sites that are less than 1000 years old, were not affected by the Barbados sea level curve. As a consequence, we assume that sea level has remained the same for 1000 years. Using Excel, a spreadsheet of the profile sites was compiled, and the uplift rate calculated using the equation above. These rates were examined to observe the changing rate of uplift moving northeast parallel to the coast.

An example from Site 1 at Cabo Blanco illustrates how we calculated uplift rates from radiometrically dated shell fragments. The outer edge of the tread of a low, narrow terrace remnant is at an altitude of 2.61 m above sea level. The tread is formed on a thin veneer of intertidal sediments resting upon bedrock exposed in the riser between the terrace and the modern beach. The inner edge of the terrace is buried under hillslope colluvium. In order to estimate the altitude of the bedrock inner edge of the platform, which is the closest approximation to sea level at the time of formation, we use an error bar that is equal to the modern intertidal range of 1.2 m. Therefore, the inner edge could be as high as 3.81 m or as low as 2.61 m. The radiometric date on a shell fragment from the veneer of sediment on the terrace is 333 +30/-45 ybp. Assuming that paleo-sea level at that time was little different than today, the resultant uplift rate is 6.0 +3.8/-2.7 m/ka.

Pleistocene Platforms

An altimeter survey was conducted to measure elevations of discrete terraces within the Pleistocene Cobano surface above the town of Cabuya. Because of the greater ages of the higher terraces, a different technique was used to determine the longer-term uplift rate. Two altimeters were used, one to record elevations of sea level and the terraces, and the other which remained stationary to record changing barometric pressure during the 3-hour survey. After correcting for sea level and barometric pressure, the elevations of terraces were correlated with individual highstands of a Pleistocene sea level curve. After selecting the best fit sea level curve, an inferred uplift rate diagram was plotted to determine the average long-term uplift rate (Figure 3).

RESULTS

Holocene Uplift-Rate Calculations

Holocene terraces were surveyed at 12 sites along the coast of Peninsula de Nicoya between Cabo Blanco and Montezuma (Figure 1). Figure 2 is a coast-parallel projection of the sites, with altitudes of the outer and inner edges of each terrace and of points along the tread between the outer and inner edges (Figure 2). The eight southernmost sites are in the Cabo Blanco area. In the Cabuya area, we combine our survey at Site 9 with radiometric dates and survey data from Marshall (1991). At sites with radiometric dates, we calculated uplift rates from the altitudes of specific terraces and the radiometric ages of the samples. In general, uplift rates are highest at the southeastern end of the Peninsula, at Cabo Blanco, and decrease northeastward toward Montezuma.

Using this procedure to estimate altitudes of bedrock inner edges that are buried beneath terrace treads, we obtain the following results. In the Cabo Blanco area, uplift rates vary from 6.0 +3.8/-2.7 m/ka at Site 1, to 5.4 +1.6/-1.3 m/ka at Site 5, to 5.6 m/ka at Site 7. The error bars for each of these rates overlap; the three rates have in common a range in uplift rate from 4.1 to 7 m/ka. At Cabuya, Marshall (1991) dated 8 radiometric samples on two extensive, well-preserved terraces. For the lower terrace, radiometric ages ranged from 498 to 2378 ybp (increasing age with higher altitude along the terrace), yielding uplift rates that ranged from 3.3 to 4.0 m/ka. For the higher terrace, radiometric samples ranged in age from 4338 to 5273 ybp, yielding uplift rates that range from 3.4 to 3.9 m/ka. Both terraces yield similar uplift rates that are all less than the range of values from Cabo Blanco.

At Rio Lajas, two surveys identified at least 5, and perhaps 6, terraces. The greater number of terraces than at Cabuya might be the result of river erosion by Rio Lajas, so some of the terraces might be fluvial. Another possibility is that terrace preservation is better at Rio Lajas, and that individual surfaces cannot be discerned as easily at Cabuya. This possibility is more likely, considering the wide range in age estimates obtained by Marshall (1991) for the two easily discerned surfaces at Cabuya. Radiometric samples from the two lowest terraces at Rio Lajas are

378 and 808 ybp, yielding uplift rates of 4.8 and 4.9 m/ka. Although these rates are slightly higher than those at Cabuya, our correlation of terraces along the coast suggests that terraces are tilted down to the northeast, and that uplift rates should decrease in that direction.

Holocene Terrace Correlation

In addition to calculating uplift rates at sites with radiometric dates, we combined information on terrace elevations and radiometric dates in order to correlate terraces between Cabo Blanco and Montezuma (Figure 2). Although remnants of as many as 7 different terraces are preserved among the 12 sites and some terraces can be correlated over distances of several km, only two surfaces are extensive enough to be correlated along nearly the entire 10-km length of the Cabo Blanco to Montezuma coastline (see the lines correlating terrace inner edges for two terraces on Figure 2). Just as Holocene uplift rates decrease to the northeast, so too do the inner-edge elevations of these two terraces. The higher surface has the greatest relief, ranging in altitude from 17 m near Cabo Blanco to 13 m near Montezuma. The lower surface has an inner edge altitude of 8.5 m Cabo Blanco and of 7.5 m at Montezuma. The higher terrace is tilted a greater amount to the northeast because it is older (on the order of 5000 years, and has been tilted and raised over a greater period of time than the lower terrace, which is only about 800 to 1500 years old.

CONCLUSIONS

The varying uplift rates along the coast are most likely due to the northeastward subduction of the Cocos Plate seamounts and rough topography under the Caribbean Plate. As these seamounts move under Nicoya, they cause the peninsula to tilt in a northeastwardly direction, uplifting highest at the southeastern tip.

Although it is difficult to examine net uplift mechanisms of the Nicoya peninsula using only the data presented here, a correlation of other uplift rates along either side of this study area supports the these mechanisms for the tectonism occurring along the Nicoyan coast. It is evident from Cook's data (this volume) that uplift rates decrease in a northwest direction.

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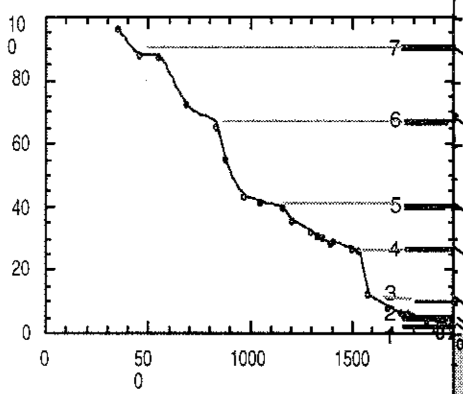
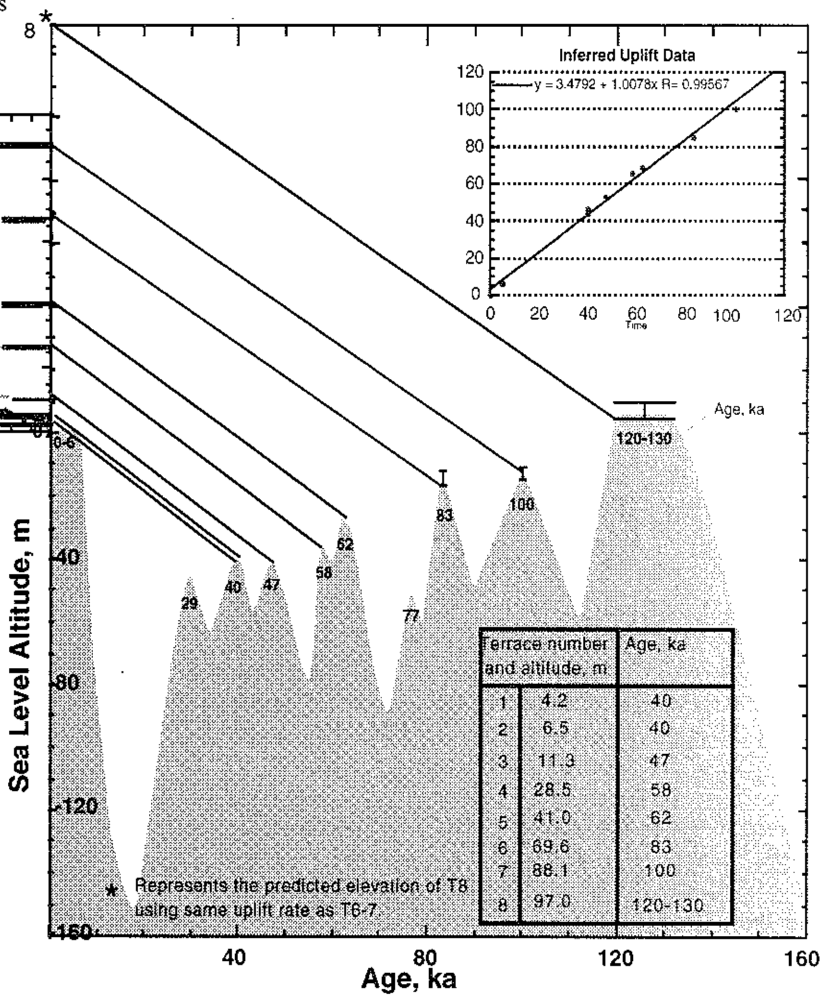
Figure 3. (left and below)
Terrace altitudes corresponding to Pleistocene sea-level high stands. Insert shows inferred uplift vs inferred age of Pleistocene terraces. Figure modified from Merritts and Bull, 1989.





Terrace number and altitude, m		Age, ka
1	4.2	40
2	6.5	40
3	11.3	47
4	28.5	58
5	41.0	62
6	69.6	83
7	88.1	100
8	97.0	120-130

Figure 1. (below)
Profiles of Cabo Blanco Sites showing modern platforms and lower uplifted terraces. Zero on y-axis denotes sea level.

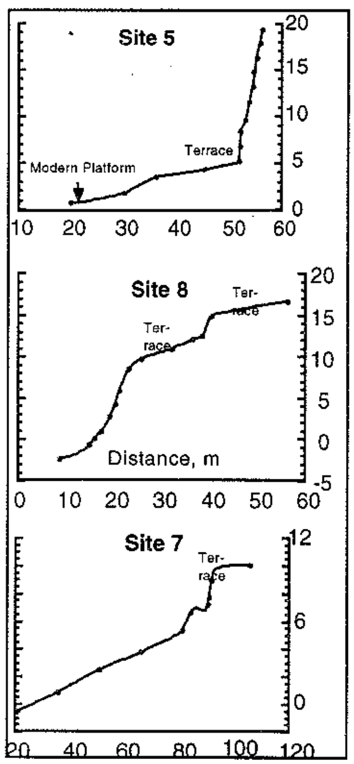
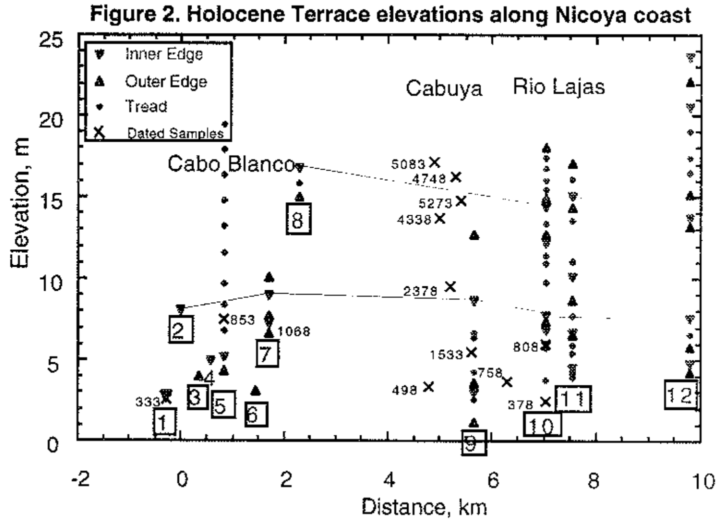


Figure 2. Holocene Terrace elevations along Nicoya coast



Rate and style of Holocene uplift in response to subducting seamounts, Malpaís area, Península de Nicoya, Costa Rica

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INTRODUCTION

Crustal flexure due to Cocos Ridge subduction that controls much of Pacific Costa Rican tectonics is predicted to cause negligible uplift on the Península de Nicoya (Gardner et al., 1992; Gardner, this volume, fig. 1). However, high Holocene uplift rates have been reported from the southern Península de Nicoya, suggesting deformation from a different source. A terrace study by Marshall (1991) of the trench-perpendicular coast between Cabuya and Montezuma (Gardner, this volume, fig. 3) shows that uplift rates decrease arcward from 4.5 m/k.y. to 1.7 m/k.y. These data and evidence of subsidence in the Golfo de Nicoya to the east indicate an arcward rotation rate of 0.01-0.02°/k.y. Marshall (1991) suggests that this deformation of the southern Península de Nicoya may be caused by subduction of the Fisher Seamount chain. Bathymetric analysis of the continental slope offshore of Cabo Blanco, the southern tip of the Península de Nicoya, suggests that other seamounts in the Fisher Seamount chain are currently subducting below the forearc (von Huene et al., 1995; Gardner this volume, fig. 2). The uplift is likely produced by crustal thickening from seamount underplating.

This geomorphic study examines the style and rate of uplift along the trench-parallel coast of the Malpaís area. The high angle of intersection between the Malpaís coast and the trench-perpendicular coast data set of Marshall (1991) allows a more three dimensional analysis of the style of forearc deformation. Marine terraces developed around the southern tip of the Península de Nicoya represent an initially horizontal datum plane that has been exposed to the effects of differential uplift.

METHODS

Terrace Elevation and Age. Holocene marine terraces were identified in the Malpaís area on the southwestern coast of the Península de Nicoya between Cabo Blanco and the town of Carmen. This transect of coastline is 9 km as expressed on a coast-parallel projection line (Figure 1). Marine terraces were identified on the basis of geomorphology, i.e. relatively flat treads separated by coast-parallel risers, and the presence of marine sediment. Elevation of the inner edge of marine abrasion platforms were used to calculate uplift. The inner edge between a gently sloping marine abrasion platform and its adjacent sea cliff is the singular geomorphic feature of a marine terrace with a well-constrained elevation. The shoreline inner edge defines an originally horizontal datum that is laterally continuous over the extent of the terrace. Additionally, elevation of bedrock abrasion platforms were used to correlate terraces along the coast. Terraces were dated using shell samples collected from marine sediments on abrasion platforms as discussed in (4) below.

Uplift Rate. Uplift rates were calculated for 6 dated samples along the 9 km transect from Cabo Blanco to Carmen (Figure 1). Data are reported in Table 1.

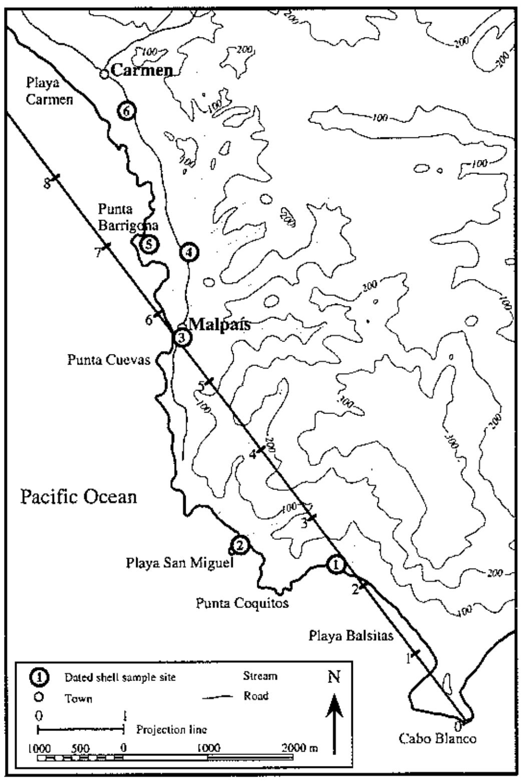

Figure 1. Map of the Malpaís area of the trench-parallel southwestern coast of the Península de Nicoya.