UPLIFT OF MARINE TERRACES ALONG THE SAN ANDREAS FAULT: FORT BRAGG REGION, NORTHERN CALIFORNIA

SARAH LEIBSON
Carleton College
Sponsor: Mary Savina

INTRODUCTION

Marine terraces are prominent landforms along the Pacific coast of northern California. These terraces are the result of Quaternary sea level high-stands superimposed on a tectonically uplifting coast (c.f Lajoie, 1986). Regional tectonic uplift is the result of the seismically active plate boundary between the North American and Pacific plates, known as the San Andreas Fault. The study of these marine terraces helps to provide an understanding of rates of tectonic uplift and deformation. This survey of the marine terraces around the Fort Bragg region contributes to a larger database that is collectively aiding in the understanding of crustal deformation along this major plate-bounding strike-slip fault.

Methods

In order to calculate uplift, one must determine the number and elevation of marine terraces in a region, as well as the age and magnitude of each sea-level high-stands to which they correspond.

Determining Terrace Location and Elevation

After identifying marine terraces from large-scale color aerial photos and field reconnaissance, the primary method of estimating the terrace elevations relied upon a Trimble pathfinder PRORX Global Positioning System, with real time differential correction, to collect data points throughout the region. Nine transects were surveyed roughly perpendicular to the coast along the fifteen kilometer section of coast between Kibesillah Rock and the mouth of Jug Handle Creek.

Multiple data points were recorded at the outer edge, inner edge, tread and riser of each identifiable terrace (Fig. 1). Notes were made about the estimated depth to bedrock at each point. When bedrock inner edges were not visible, estimations were made by projecting the terrace slope back from a bedrock outer edge, or by subtracting a rough estimation of sediment cover.

This dataset was then superimposed on digital orthophoto quadrangles of the region. Additionally, large-scale stereoscopic photographs were examined in an attempt to estimate the location of the inner edge of the

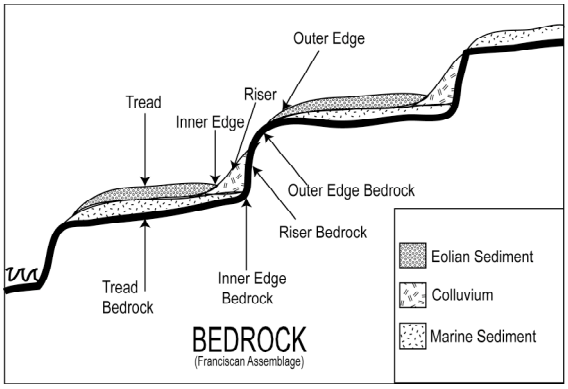

Figure 1. Schematic cross section of a flight of marine terraces, showing types of sediment cover and terminology of terrace elements. The elevation of the inner edge bedrock is the most valuable because it is the best approximation of mean sea-level during a high-stand.

terraces, by noting significant changes in elevation. Information from the stereo-scope analysis and the GPS data were compared and compiled to determine the exact location of the terrace inner edges and their elevations.

Eventually, all of the inner edge bedrock elevations (both surveyed in the field and estimated in the lab) were analyzed, and best fit lines were matched to the points to laterally correlate the terraces.

Determining Terrace Age

Once the number, location, and elevation of each terrace was determined, it was essential to assign an age to each terrace. In order to find corals suitable for uranium thorium dating, marine sediment from various locations throughout the field area was sieved. This proved unsuccessful at all sites except for a fossiliferous cove, in the lowest terrace, at the southern tip of Mac Kerricher State Park. At this location, two small fossil corals, believed to be *Balanophyllia elegans*, were uncovered. These two corals are scheduled to be subject to uranium thorium dating in March of 2004. An accurate date from these corals would be extremely valuable because it would be only the second marine terrace locality with a uranium series date in the 1,207 kilometers between Cayucos, California and Bandon Oregon (Muhs et al., 1994).

In lieu of a U-series date for the lowest terrace, the age assignment for this terrace was based on a study by Kennedy et al. (1982), in which he conducted amino acid racemization and faunal analysis on samples from the same Mac Kerricher State Park fossil site.

The assumption of uniform uplift rate was used to extrapolate the ages of the successively higher terraces. The sea-level curve compiled by Darter (2000) was used to pinpoint high-stand ages and magnitudes.

RESULTS AND DISCUSSION

Analysis of the GPS data and aerial photo mapping shows that the area contains three relatively continuous broad terraces (Fig 2) with elevations of ~25m, ~43m, and ~59m.

The elevation of the inner edge of individual terraces varies up to nine meters at different

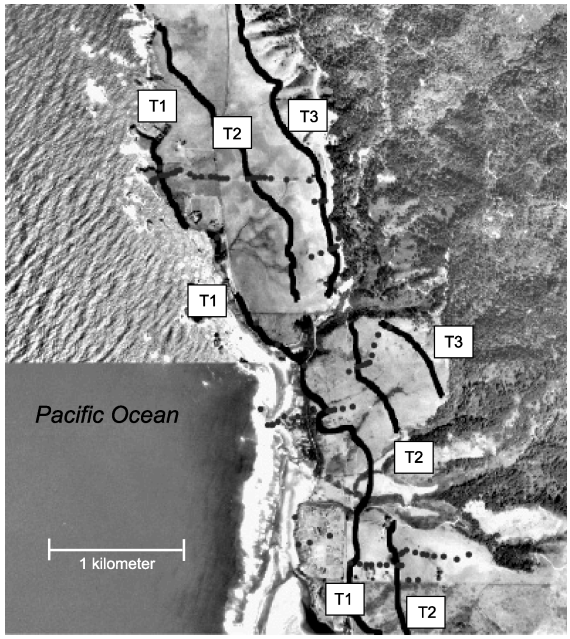

Figure 2. Location of marine terrace inner edges (T1, T2, and T3) overlain upon an aerial photograph of the coast from the mouth of Ten Mile River to Kibesillah Rock. Dots indicate GPS data points.

points along the coast, but there is no general trend of increasing or decreasing uplift rates in one direction along the coast (Fig 3).

Two transects (4 and 8) included miscellaneous inner-edge points around 30 m and 48 m (Fig. 3); however, the classification of these points as inner-edge points was tentative. Rare inner-edge points were also identified above 70 m, but lack of bedrock points, due to the large amount of colluvium and the high level of erosion from stream cutting made it extremely difficult to determine an accurate elevation for these potential higher terraces.

On Transect 7 we identified a possible inner-edge at ~12 m (Fig 3). An inner edge at this elevation was not visible anywhere else in the field area, and consequently was disregarded as being representative of a major terrace. However, the possibility that this inner edge point represents an elsewhere eroded or covered terrace would have significant implications for the correlation of the terraces to sea-level high stands and would greatly affect the calculated regional uplift rate.

The terrace elevations of ~25 m, ~43 m, and ~59 m likely correspond to the sea-level high-stands of ~83 ka, ~108 ka, and 122 ka

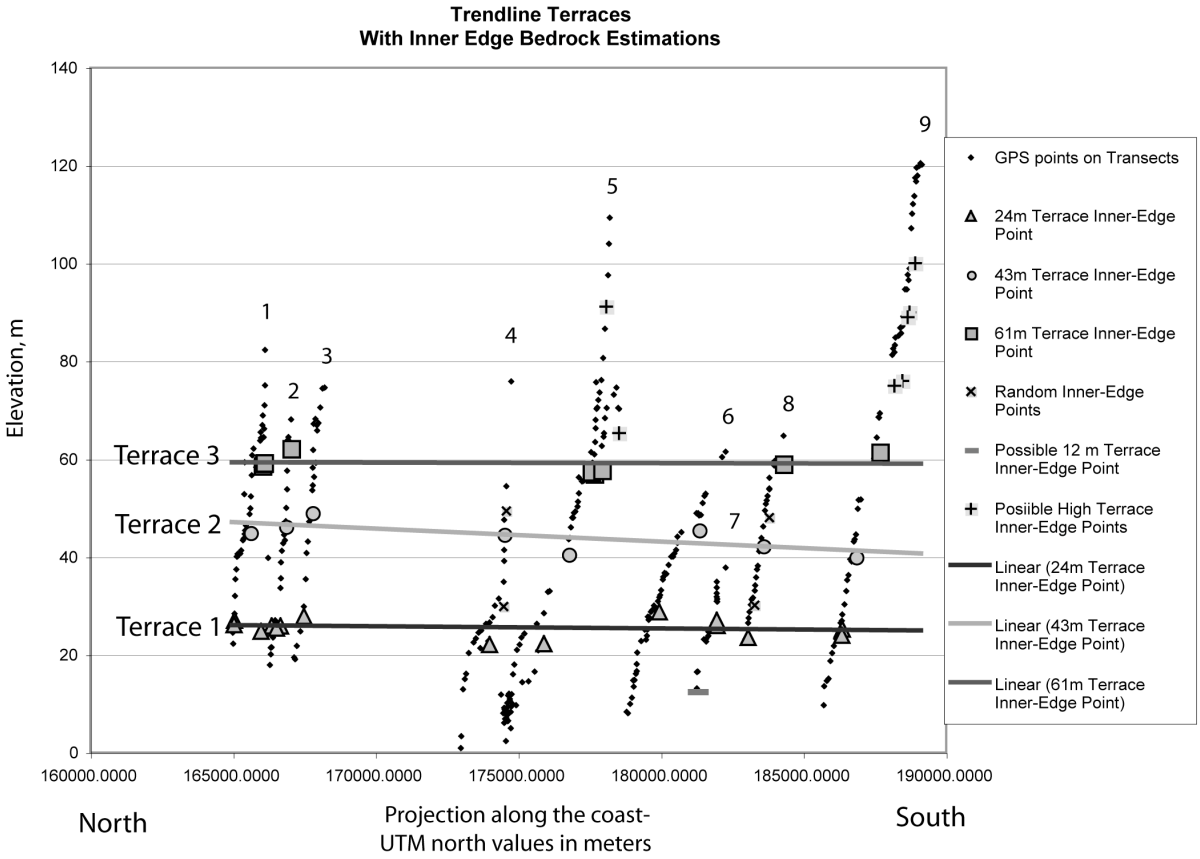

Figure 3. Plot of transects 1-9 along the coast with estimated inner-edge bedrock points highlighted. Best fit lines indicate the general elevation of the three terraces. The slight rise in elevation of Terrace 2 towards the north is likely due to local faulting in the area of transects 1, 2, and 3.

respectively. These correlations provide an average uplift rate of 0.5 m/ka (Fig 4).These age correlations are based on the following lines of reasoning:

Kennedy et al. (1982) conducted amino acid racemization and faunal analysis on samples from the fossil site on the southern point (Laguna Point) of Mac Kerricher State Park. He concluded that the fossils were deposited during either the ~83ka or ~108ka high-stand due in large part to the cool water aspect of the fauna (Kennedy et al., 1982). This fossil site is at the outer-edge of a terrace that is most likely part of the terrace with an inner-edge elevation of ~25 m. The 83 ka date for this terrace is favored over the 108ka date for multiple reasons. First, this is the lowest visible terrace and it most likely represents the more recent of the major high-stands. Second, along the California coast the ~108 ka high-stand is rarely preserved, or only partially preserved (Muhs et al., 1994; Orme, 1998); further increasing the likelihood that the ~25 m terrace (the broadest and most continuous in the Fort Bragg region) corresponds to the 83ka date. Third, a ~23 m terrace mapped 61 km south of Fort Bragg, at Point Arena, contained two *Balanophyllia* coral that produced U-series ages of 76,000 ± 4000yr and 88,000 ± 2000yr (Muhs et al., 1994). This ~23 m terrace at Point Arena was correlated to the ~83ka high-stand on the basis of faunal and amino acid data (Kennedy, 1982).

The two higher terraces of elevation ~43 m and ~59 m were assigned to the sea-level high-stands of 108 ka and 122 ka based on the assumption that uplift in the region has remained relatively constant during that time period.

CONCLUSION

The region around Fort Bragg contains a valuable record of Quaternary tectonics, sea-level changes, and geomorphic processes. The 15-km section of coast spanning from Kibesillah Rock to the Mouth of Jug Handle

Creek contains three relatively undeformed, marine terraces of elevations ~25 m, ~43 m, and ~59 m. While the age assignments to these terraces remain somewhat tentative while awaiting the completion of U-series dating of coral from the lowest terrace, there is strong evidence to support correlation of the three terraces with the ~83 ka, ~108 ka, and ~122 ka sea-level high-stands, thus implying an average uplift for the region of ~0.5 m/ka

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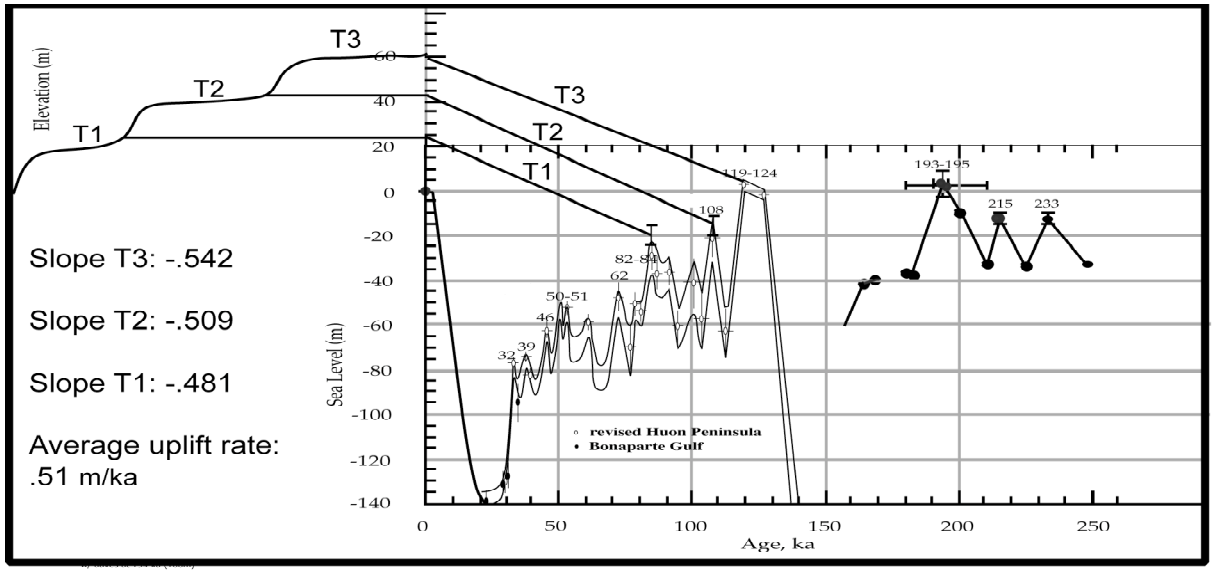

Figure 4. Sea-level curve modified from Darter (2000) indicates general high-stand ages and magnitudes to correlate with terrace elevations, in order to determine an average uplift rate. The slope of the diagonal line connecting the high stand to the terrace inner edge elevation is the average uplift rate for that terrace.