UPLIFTED, QUATERNARY, MARINE TERRACES ALONG THE MARGIN OF THE NORTH AMERICAN PLATE: NORTH CENTRAL CALIFORNIA BETWEEN ALDER CREEK AND MENDOCINO

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INTRODUCTION

Deformation of marine terraces along the coast of Northern California is the result of dextral slip along the San Andreas Fault (SAF) which forms the Pacific-North American plate boundary (Merritts, Fig. 1, this volume). The plate boundary is characterized by numerous emergent, Pleistocene, marine terraces that extend for hundreds of meters above sea level (Fig. 1. a). These relict shorelines record both fluctuating Quaternary sea-level highstands and tectonic uplift. Their rates of uplift can be determined by correlation of inner edge elevations (which approximate mean sea level at the time of formation) to paleo sea-level highstands (Lajoie, 1986; Merritts & Bull, 1989). If the elevation and age of these sea-level highstands are known, then uplift rate can be calculated for each marine terrace. The primary methods that have been used to determine these sea-level highstands are benthic foraminifera oxygen isotope analysis ($^{18}O/^{16}O$), radiocarbon dating (^{14}C), and uranium-thorium series ($^{230}Th/^{234}U$) dating of marine reef terraces (Mesolella et al., 1969; Muhs, 2002; Veeh & Chappell, 1970). Worldwide data of Quaternary eustatic sea levels (Darter, 2000; Hampton, 2000; Lambeck and Chappell, 2001) have been combined to form a paleo sea-level curve for this research.

This study investigates a flight of 4 marine terraces from Alder Creek, where the SAF goes offshore about 210 km north of San Francisco, to Mendocino, a distance of ~50 km (Merritts, Fig. 1, this volume). Terrace inner edges were correlated to sea-level highstands, and used to calculate uplift rates.

Methods

The lateral and vertical extent of the lowest four marine terraces between Point Arena and Mendocino were measured using a real-time, differentially correcting, GPS Trimble GeoXT receiver, which uses the FAA WAAS (Wide Area Augmentation System) satellite for real-time correction. Elevation and UTM coordinates were collected along 24 transects that run relatively perpendicular to and along the coast. GPS data, field mapping, and aerial photo analysis were confined to the four lowest and laterally most continuous terraces. The inner edge elevations for these terraces range from 23 m to 178 m above mean sea level (amsl). These data are compiled in an extensive GIS database that includes georeferenced digital orthophoto quadrangles, field descriptions, internal links to Excel spreadsheets and graphs, air photo-mapped inner edge lines, fault traces, and digital field photographs.

Inner edge elevations are correlated to Quaternary sea level highstands using the method developed by Lajoie (1986) and Merritts and Bull (1989). Here, I assume a simple deformation model of constant uplift rate at a location. Terraces are correlated to eustatic highstands at oxygen isotope stages (OIS) 5e (~121 ka), OIS 7 (~194 ka), OIS 9 (~330 ka), and OIS 11 (~410 ka) (Figs. 1b, 1c, 1d). Uplift rates are calculated as the slope of

Insert fig 1 here…..

the line connecting the modern terrace inner edge elevation to the paleo sea-level highstand. The modern elevation of a marine terrace inner edge represents both real and apparent changes in sea-level (Lajoie 1986). A change in real sea level refers to the absolute vertical fluctuation of the ocean surface. A change in apparent sea level is not a change in real sea level; the perceived change is a consequence of the land moving vertically up or down (Lajoie 1986). Taking these factors into account, I use the following equation to determine the rate of uplift for any marine terrace inner edge:

$$U = \frac{y_1 - y_2}{t} \qquad \text{(Eq. 1)}$$

where U is the rate of uplift in meters per thousand years (m/ka), y_1 is the present measured elevation of the inner edge (m), y_2 is the elevation of the sea-level highstand (m) during which the terrace formed, and t is terrace age in thousands of years (ka).

Equation 1 was used to determine uplift rates for three transects along the coast. These transects were selected because they contained the largest number of bedrock inner edges. Calculated uplift rates for the three transects with the best preserved terrace flights increase southward from 0.2 m/ka near Mendocino to 0.4 m/ka near Alder Creek (Figs. 1a, 1b, 1c).

An along-the-coast correlation of inner edges (Fig. 2) indicates that the terraces decrease in elevation northward from Alder Creek, resulting in a down-to-the north tilt of the terraces, but become nearly horizontal near Mendocino. The distance between the SAF and the coastal terraces increases from 0 km at Alder Creek where the SAF goes offshore to ~10 km at Mendocino. The highest uplift rate of 0.4 m/ka was determined for the terraces closest to the SAF at Alder Creek.

DISCUSSION

The uplift rates calculated from this study are different from those found by Hampton (2000) during a similar Keck project. The 0.4 m/ka uplift rate determined by this study versus the 0.9 m/ka uplift rate found by Hampton (2000) for the terraces just north of the SAF suggests that uplift near the SAF may not be occurring at the rate suggested by Hampton. The reason for this difference in uplift rates is that Hampton correlated two inner edge points from the OIS 5e terrace (in the Transect 3 area) to two separate highstands. This error resulted in a higher uplift rate.

The rather uniform increase in uplift rate with proximity to the SAF implies a simple tectonic explanation. The SAF is a transform fault, but it is not oriented in a perfectly straight line. It is hypothesized that the slight bend towards the northeast as it goes offshore at Alder Creek plays a role in the increased uplift rate seen in the terraces closest to the fault. Prentice et al. (1991) observed several features that indicate compression along the SAF near Point Arena which may be causing the higher uplift rate: a Quaternary thrust fault resulting in Miocene bedrock overlying Pleistocene marine terrace sediment; the sole of a thrust fault existing in the Miocene bedrock; and faulted sediments within the marine terraces.

CONCLUSIONS

Data in the form of elevation points and terrace correlations has been gathered for the marine terraces between Alder Creek and Mendocino. The large number of data points on and along terraces helps to constrain their elevation and deformation. Correlations of terrace inner edges to eustatic sea-level highstands assume a constant rate of uplift at a given location over the past ~410 ka. Ages of terrace formation are ~121 ka, ~194 ka, ~330 ka, and ~410 ka. Revised uplift rates, ranging from 0.2 m/ka (~50 km north of the SAF at Alder Creek) to 0.4 m/ka (<1km north of SAF at Alder Creek), call into question the degree of tectonic influence that the fault has on its surrounding topography proposed by Hampton (2000).

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Insert Figure 2 here……

Figure 2. Inner edge correlation along the coast from Mendocino to Alder Creek. A point's symbol corresponds to the terrace on which it is located. "IE" stands for a non-bedrock inner edge measurement; "IEb" refers to a bedrock inner edge measurement. Smaller, nearly continuous dots are elevation points taken along Highway 1. Heavier lines are inferred inner edge correlations. The inner edge points enclosed in the transect delineations are correlated to sea-level highstands (Fig. 1).