Determination of Quaternary uplift rates from emergent marine wave-cut platforms around Pt. Delgada, California

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INTRODUCTION

Part of California's "lost coast," Pt. Delgada is located approximately 22 km south of Cape Mendocino, CA, an area renowned for its high seismic activity and mountain building (King Range Mountains 10-15 km north of Pt. Delgada). The high rates of uplift near Cape Mendocino are due to its proximity to the junction of three major plate boundaries: the Cascadia Subduction Zone (CSZ), the Mendocino Fracture Zone (MFZ), and the San Andreas Fault zone (SAF). The exact location of the SAF is uncertain between Pt. Arena and the triple junction. However, a significant, growing body of evidence supports an onshore reappearance of the SAF at Pt. Delgada. Pt. Delgada is surrounded by a flight of warped Pleistocene marine terraces incised in Upper Cretaceous, sedimentary and igneous rocks of the Franciscan complex (Beutner et al., 1980), capped by layers of marine and landslide deposits. Therefore, the SAF may be responsible for the tectonic component of marine terrace formation around Pt. Delgada.

Marine terraces (or platforms) are valuable records of glacio-eustatic sea level fluctuation. Wave processes create as well as destroy terraces, with periods of relatively high sea level (sea level highstands) effacing platforms formed during lower levels. Tectonic processes also influence marine terrace formation and morphology. Indeed without a component of tectonic input marine terrace records are rare, because the current Holocene inter-glacial sea level highstand is higher than most other Holocene and Pleistocene interglacial maximums. Terrace survival, therefore, depends upon uplift rates sufficient to raise the platform above subsequent higher sea levels.

For these reasons, it is widely regarded that terrace formation consists largely of two components: a global change in the volume of water, and local variation in the relative height of the land (Lajoie, 1986). The terrace inner edge, or shoreline angle, approximately represents a high watermark formed at sea level on an erodable surface. The horizontal trace of the inner edge is known as the strandline.

Inner edges of datable terraces on coastlines with constant rates of uplift have been cross-referenced with changes in oxygen isotope ratios in foraminifera from deep-sea sediments to compile a record of sea level fluctuation (sea level curve) of the past 240 ka (Chappell and Shackelton, 1986). For a record of platforms >40 ka in age to exist above current sea level, an uplift rate of at least 0.5 m/ky is needed (Ota, 1986). For a record of Holocene platforms (< ~7 ka old) to be preserved an even greater rate of uplift is required, estimated to be at least 1.5 m/ky (Merritts, 1996). Deformation and emergence of Pleistocene platforms are reflections of long-term crustal deformation, whereas Holocene platforms are records of short-term coastal instability (Lajoie, 1986).

Previous work has been done to correlate platform inner edge altitude and spacing with a global eustatic sea level curve assuming a locally constant rate of uplift (Bull, 1985). Sea level curves from different areas of the world reflect similar variability in sea level altitude at certain ages during the Pleistocene, as well as an almost steady sea level transgression during the Holocene. Abrupt coseismic events may result in platform emergence superimposed on the currently forming platform (coseismic emergence). Because of coseismic emergence, not every platform notch coincides with a sea level highstand. Platforms formed in this way do not correlate directly with a sea level highstand, but are a function of the area's general rate of uplift. Furthermore, a tilt rate may be constructed using the variation in uplift between different localities along a coast. Typically, values for tilt rates are low (~0.01 - 0.001°/ky), and given as the angular change in slope of the strandline per unit time (compiled from Lajoie, 1986).

METHODS

The most direct way of correlating wave-cut platforms to paleo-sea levels is to collect materials from platforms deposited during platform formation, such as pholad shells. In lieu of such material, platform ages and uplift rates must be established through correlation of inner edge altitudes with a global eustatic sea level curve. However, in the sedimentary cover directly above one platform at Pt. Delgada a carbon sample was recovered (age >48,000 B.P.). This date provides a minimum age constraint on the underlying platform.

Nevertheless, without direct sampling from platforms for age correlation, accuracy of inner edge elevations is imperative.

Surveying. The goal in surveying marine terraces is to separate and distinguish terraces through survey of inner edges (strandline). Platform surveys were conducted over several days using a Lietz total geodetic station (angular accuracy 3 arc min at one standard deviation; linear accuracy 5mm +3ppm at one standard deviation) and 377 data points were collected. Because the size and shape of the survey area (Point Delgada) was too large to close each day's survey by re-surveying the original point, a bench mark and several back-sites were shot at the end of each survey day and used to check the following day's setup against the previous day's data. This method of bench marks and back-siting ensured consistency in survey data, as well as providing a physical connection between each day's measurements. Because of tidal variation, measurements of tide level (and time of collection) were made throughout the survey process, and this formed the basis for standardization of elevations to a mean sea level elevation.

Software. Several graphical and database software packages (including Data Desk, Excel, and Kaleidagraph) were used in the interpretation and analysis of the data. First the data were divided into nine bins or aerially distributed sections . Data Desk supports viewing and manipulating data using field notations in conjunction with myriad statistical analysis techniques. Therefore, for each section, the data were viewed under several different spatial representations: rotational three dimensional plots, projection lines (transects) at several different vantage points (mostly perpendicular to the coastline), histograms, and normal probability plots. These different plots were cross referenced with field notes in Data Desk and a plot of the inner edges made. Where actual inner edges were not surveyed, normal probability plots were used to project minimum elevations for missing inner edges.

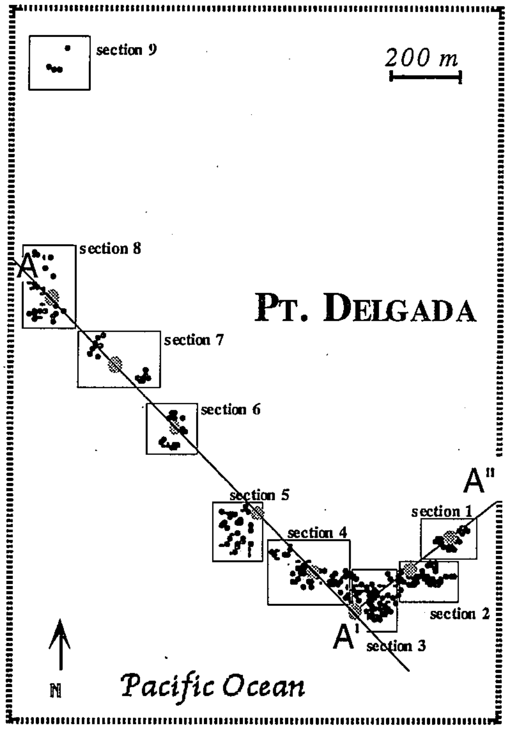

Figure 1: Pt. Delgada survey points, plan view.

Two projection lines (A-A', A'-A") were drawn parallel to the coastline. The northwest-southeast trending line (A-A') also follows the approximate direction of maximum platform tilt (figure 1). Again, using notes and plots from Data Desk, inner edge elevations were summarized for each section and then correlated among sections, and finally projected onto A-A' and A'-A". A sedimentary layer containing the radiometric date constraining underlying platforms to >48,000 B.P. was also plotted onto A'-A". The layer was surveyed and noted during the original total station survey, and it clearly lies directly over a platform for which the inner edge was also noted. Because this platform could be constrained to an age minimum, it was assigned several different possible ages >48,000 B.P. Assigned ages were based on the sea level curve of Chappell and Shackelton, 1986. For each of these ages, the uplift rate is the altitude of the platform at present (at one section) minus the altitude of the highstand at the time of formation, divided by the age of the highstand. Potential uplift rates were used individually to project altitudes of other highstands (predicted platform elevations). These predicted platform elevations were then compared to the altitudes of surveyed platforms to determine a "best correlation."

RESULTS

Assigning an age of 53 ka to the radiometrically constrained platform gave the best correlation, and was used to determine uplift rates at sections 4 and 8. The 53 ka highstand was 30 meters below current sea level. At section 4 (figure 2) the constrained platform is approximately 3.67 meters above sea level, therefore the net uplift of the platform since 53 ka has been 33.67 meters. This yields an uplift rate of 0.63 m/ky. At section 8 (figure 3), the constrained platform is 4.68 meters above sea level, yielding an uplift rate of 0.65 m/ky. Therefore an approximate tilt rate for Pt. Delgada is 0.04 °/ ky.

CONCLUSIONS

If the tilt rate concluded above is constant, a Holocene platform should emerge (uplift rate > 1.5 m/ky) almost 60 km north of Pt. Delgada. However, a Holocene platform has been observed less than 10 km north of Pt. Delgada near Gitchell Creek. Therefore a significant, rapid change in uplift must occur between Pt. Delgada and Gitchell Creek. This uplift is geographically consistent with a significant rise in surface topography, the King Range Mountains, as well as with recent predictions of uplift rates along the northern tip of the SAF (Muller et al., 1995).

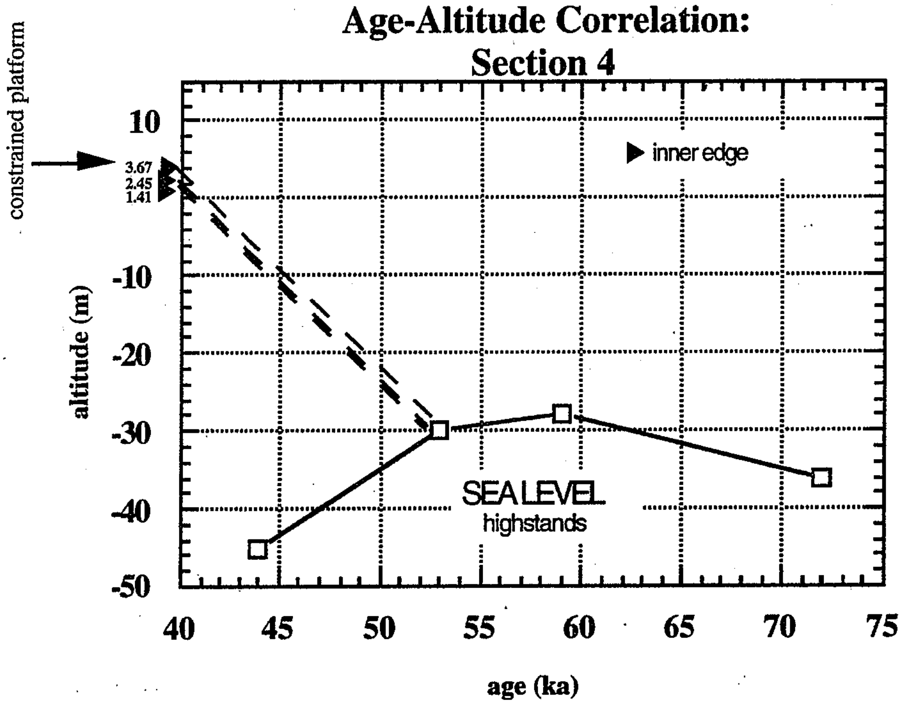

Figure 2: Projection of observed platform inner edge elevations onto a graph of sea level high stands for section 4. Note slope of the line is equal to local uplift rate.

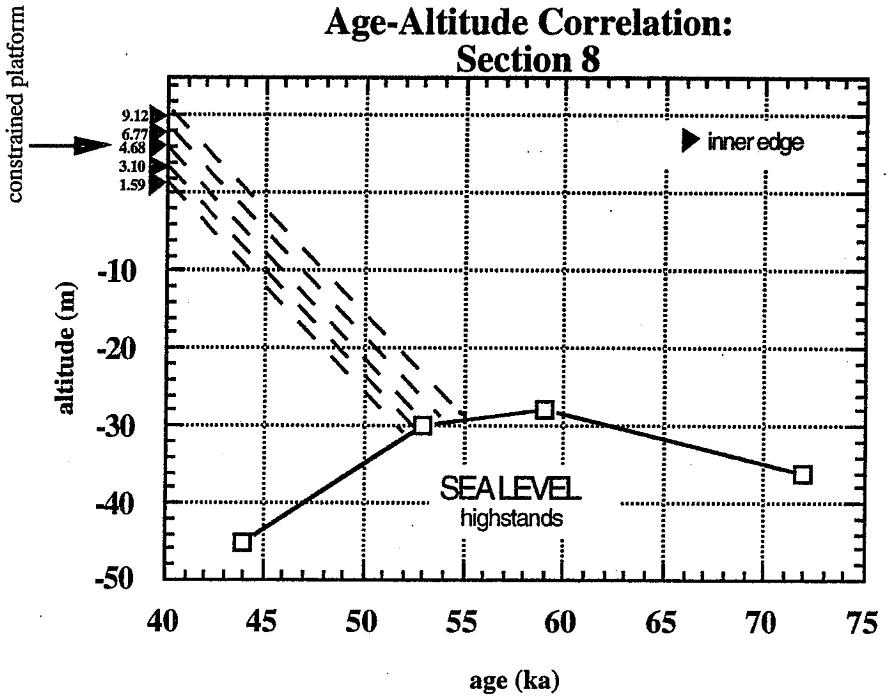

Figure 3: Projection of observed platforms onto graph of sea level highstands for Section 8 Note that there appears to be two platforms, the 53 ka and 59 ka. There are no noted inner edges for the 59 ka platform, only notches on the tread.

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