Raised Holocene marine terraces along the northern California coast

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INTRODUCTION

The San Andreas Fault terminates along the northern California coast at the Mendocino Triple Junction. A Keck Geology Consortium project was located southeast of the Mendocino Triple Junction in the Point Delgada area. The purpose of this project was to locate and map deformation caused by the San Andreas Fault in this vicinity. Within this framework, the area northwest of Point Delgada between Gitchell Creek and Miller Flat was studied to determine the number, deformation pattern, and relation to faulting of uplifted Holocene marine terraces.

GEOLOGIC SETTING

Point Delgada and the King Range lie in northern California near the Mendocino Triple Junction (MTJ). At the MTJ, the Gorda Plate, the North American Plate, and the Pacific Plate come together at the intersection of the Cascadia subduction zone, the Mendocino Fracture Zone, and the northern termination of the San Andreas Fault. In this location the San Andreas is allowing the Pacific Plate to move NNW relative to the North American Plate, the Cascadia Subduction Zone is consuming the Gorda Plate, which is moving east, and the Mendocino Fracture Zone is allowing right-lateral movement between the Pacific and Gorda plates. Some of the fastest uplift and deformation rates in North America (Lajoie et al., 1982; Merritts and Bull, 1989) result from these three plate boundaries coming together at the MTJ. South of the MTJ and seaward of the King Range are some of the only Holocene marine terraces exposed in North America. The only other known emergent Holocene marine terraces on the west coast of North America occur in Alaska (Plafker, 1969, cited in Merritts, 1996) and at Ventura, California (Lajoie et al., 1982). The rapid rates of uplift set the stage for mass wasting, which occurs along the coast in the form of numerous slide areas that often cover or destroy the terraces that are the focus of this study.

METHODS

Field. The terraces were surveyed with a Lietz total geodetic station over the course of four days. Over 350 points were surveyed along the coast. Most of these points were on terraces or at the inner edges of terraces. The other survey data points were taken from other places of interest, such as faults, the edge of the ocean (noting the exact time for later tidal corrections), temporary bench marks, and beach inner edges to better define the coastline where the terraces have been wiped out due to slides. The bench marks were put in place and surveyed to minimize error. Because of the linear nature of the platforms, the survey was not closed by resurveying the first station setup point. To fix this problem, three temporary bench marks were established before the total station was moved; these points were then resurveyed to close each survey loop and minimize error.

Pholadid shells collected from boulders that rested on the terraces, and shell fragments in marine sands overlying the terraces were sent for radiocarbon dating. Samples taken from boulders with pholadid borings most closely estimate the true age of the terrace due to the nature of the pholadid; while marine sands can be washed up onto a terrace during a storm, a boulder cannot. After collection and preliminary sorting the radiocarbon samples were sent to Beta Analytic, Inc. for pretreatment and dating.

Lab. The data were first corrected for any errors that occurred in the survey. This was done by looking at the temporary bench mark locations before and after the total station was moved. Any discrepancies were then eliminated. True elevations were established by looking at surveyed sea levels and correlating them with tidal charts. The data points were then converted to absolute elevation above sea level.

Once the data were corrected, it was then plotted on a base map and fitted to the Shelter Cove and Shubrick Peak U.S.G.S. 7.5' quadrangle maps to insure the accuracy of the survey. Platform extent and radiocarbon sample sites were located on the map. The data were then broken up into seven bins, which were correlated to seven stretches of coast that were subdivided based on orientation. All data points in one bin lie roughly on the same plane; the individual bins were projected onto imaginary planes parallel to the coast. Once all the bins were projected, they were reassembled back into one strip (figure 1). By using this method the true slope of the terraces was determined and error induced by changes in the coastline were sharply reduced, allowing tighter control over definition of the terraces. Since almost all of the terraces are no more than 5 meters wide, the data collected at the outer edge was considered to be inner edge, and the corrections of outer edge to inner edge elevation are small enough to be ignored. Terrace heights and slopes were compared with radiocarbon dates so that average uplift and tilt rates could be determined.

DISCUSSION OF DATA

In the middle of the stretch of exposed Holocene platforms between Gitchell Creek and Miller Flat are the greatest rates of uplift, up to 4.4 m/kyr. Uplift rates are less at the ends of the exposed terraces. The uplift rate at Miller Flat is 2.0 m/kyr, and just northwest of Gitchell Creek, the uplift rate is 2.7 m/kyr (table 1). The only real exception to this trend is just north of Gitchell Creek on the active platform where a radiocarbon date was correlated from an older survey (Merritts, 1996), and was probably mislocated as it yielded an extremely high apparent uplift rate of 9.2 m/kyr. The dates were obtained from pholadid shells, which lived when the terrace was still submerged, and from shell fragments in marine sand that overlies the terraces and could be younger than the terraces.

Rates of rotation varied between terraces and between locations on an individual terrace. Average rotation rates were calculated for three well-exposed terraces (#1, 3, and 5) (figure 1). The rates for the two southward-sloping terraces are 3.1 and 3.7 rad/kyr. The northward-sloping terrace at Miller Flat has had an average rotation rate of 6.3 rad/kyr.

Two young faults were mapped with the survey points (figure 1); they seem to correspond to separate jumps in platform height and/or platform slope. Since the bedrock was not closely examined during the survey process, many faults observed in the field were not included in the survey data, so it is unclear if there are faults associated with most of the major changes in platform attitude.

The actual number of terraces present is open to some interpretation. There are at least three young terraces present: one is at Miller Flat, one is terrace 2-3-4, and there is the active platform that stretches almost the entire length of the study. The age of the southernmost terrace (#5) is approximately 3175 years B.P. This terrace is just north of Gitchell Creek; it is significantly older than that of any of the other terraces. Furthermore, the date was on shell fragments in marine sands that were more than one meter above the terrace and separated from it by a terrestrial debris flow; therefore, the shell fragments are probably substantially younger than the actual terrace. Terrace 5 could be the same as terrace 2-3-4 to the north of it, but it is most likely a separate terrace (figure 1). Different ages on the same terrace could also be the result of uneven uplift. Merritts (1996) showed that cosesmic uplift of marine terraces can be uneven, which can result in the same platform being uplifted beyond tidal range at different times, which would effectively result in different ages calculated for the same terraces.

CONCLUSIONS

There are two possible explanations for the deformation history of the terraces. Either they all have been rotated around some focal point to the south, or they have been deformed in a synform-antiform fashion. The best exposed and most continuous sections of terraces all slope to the south; the exception is the terrace at Miller Flat. The lack of northward sloping terraces may be due to destruction of these terraces by mass wasting, which is quite frequent in the area. An alternate explanation is that what has been interpreted as three or four terraces may be a series five or six terraces that have all been rotated around a focal point somewhere to the south.

Terrace 1 at Miller Flat is somewhat of an enigma; it is the only well-exposed platform that slopes to the north. The Miller Flat terrace also has another terrace (#2-3-4) of similar age that terminates into the eroded seaward side of it. The terrace at Miller Flat could be the result of a unique period of rotation, with it being the only terrace left showing the different period of rotation, or more likely, since the terrace would rotate back to horizontal as the other terraces rotated, the terrace at Miller Flat could be on the north side of an antiform. The antiform could have formed in a two-part process with the Miller Flat terrace being formed first, and part of the terrace (#2-3-4) that terminates into it second.

Initial results have shown that the uplift of Holocene wave-cut terraces north of Point Delgada has occurred at rates of up to 3.49 m/kyr. Deformation of the same terraces has occurred with a maximum mean rate of 6.33 radians/kyr. Along the stretch of coast between Gitchell Creek and Miller Flat there are at least three exposed Holocene platforms with ages ranging from 3175 to 450 years B.P. Deformation of the terraces most likely takes the form of faulted synforms and antiforms but could be the result of tilting about a fulcrum. At this point, it is impossible to say whether the faulting is a cause or a result of the deformation.

REFERENCES CITED

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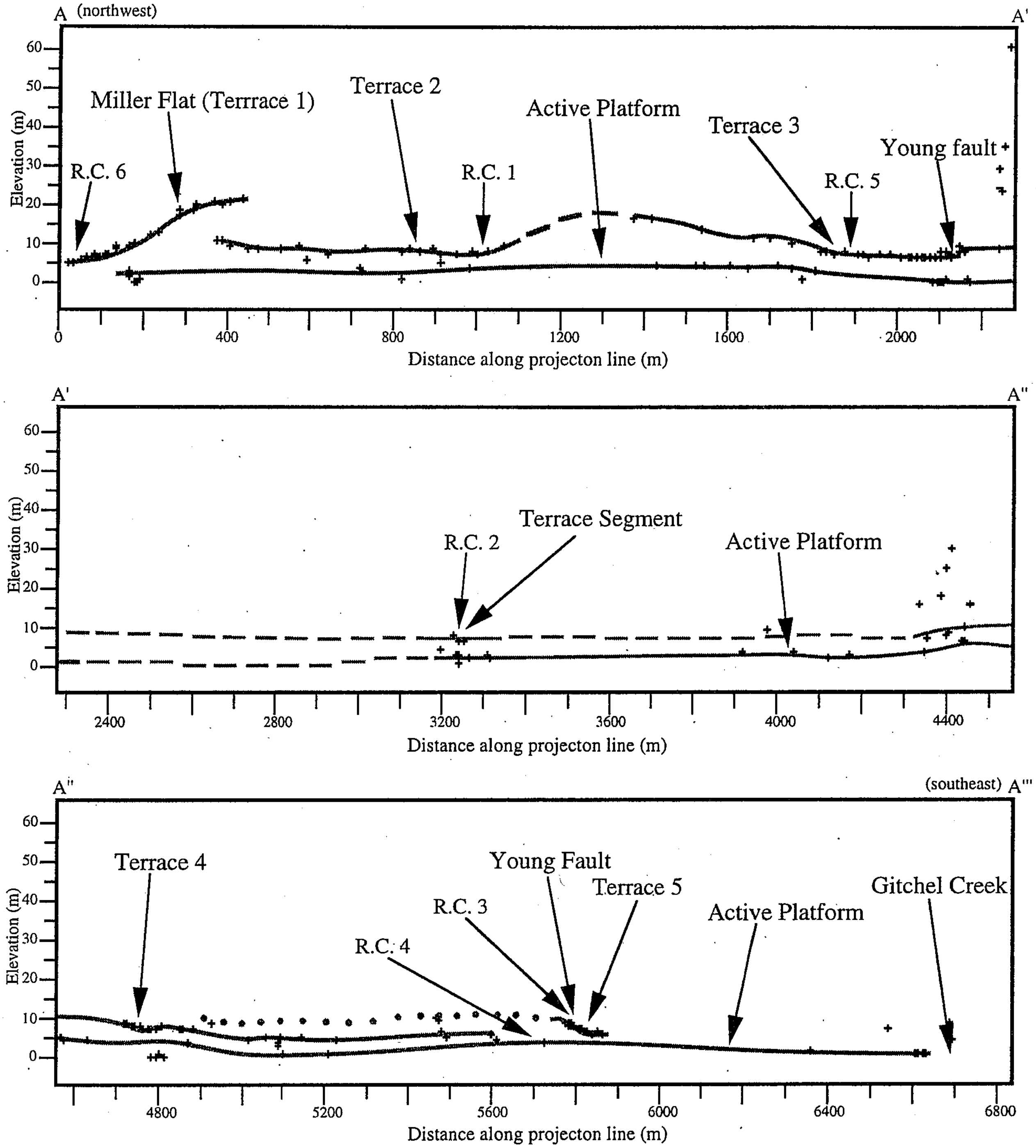

Figure 1. Survey data projected to a plane approximately parallel to the coastline running from northwest at A to southeast at A'''. Data points are expressed as small black crosses, solid lines show definite terraces, dashed lines show probable correlation between terraces, and dotted lines show possible correlation between terraces. Radiocarbon sample sites (R.C.) are shown as well as surveyed faults.

Table 1. Radiocarbon dates and uplift rates

Radiocarbon site number	Description and location	Elevation (m)	Radiocarbon intercept age (years B.P.)	Mean uplift rate (m/kyr)
1	Pholadid shell recovered from boulder resting on terrace 2	8.32	2380	3.49
2	Shell fragments from marine sands 20-30 cm above terrace segment	6.97	1580	4.41
3	Shell fragments from marine sands about 1.3 meters above terrace 5	8.59	3175	2.70
4*	Pholadid shells in bedrock borings in active platform just north of Gitchel Creek	4.14	450	9.20
5*	Broken fragments of gastropod and clam shells from beach gravels above terrace 3	7.04	2140	3.29
6*	Pholadid shells in bedrock borings in terrace 1 (Miller Flat)	5.52	2700	2.04

*NOTE: #4-#6 were taken from Merritts, 1996, and may not yield true uplift rates due to poor corelation between the different surveys. The elevations of #4-#6 are aproximate numbers.