Tectonic uplift and deformation near the Mendocino Triple Junction: marine platforms and faulting at Whale Gulch, California

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INTRODUCTION

Whale Gulch is located in the Sinkyone Wilderness Area in northern California, 10 km south of Point Delgada and 90 km southeast of the Mendocino Triple Junction. The San Andreas Fault passes approximately 7 km offshore. Uplift rates in the region range from 0.4 m/ka at Fort Bragg to 4.0 m/ka near the Mendocino Triple Junction (Merritts and Bull, 1989). Two wave-cut marine platforms are preserved in the Whale Gulch area between Jones Beach and Flat Rock; the nearest other platforms are at Point Delgada. The correlation of these platforms with the eustatic sea level curve allows the calculation of an uplift rate which can add another piece to the regional picture of uplift. The area has also undergone significant warping and at least three different periods of faulting.

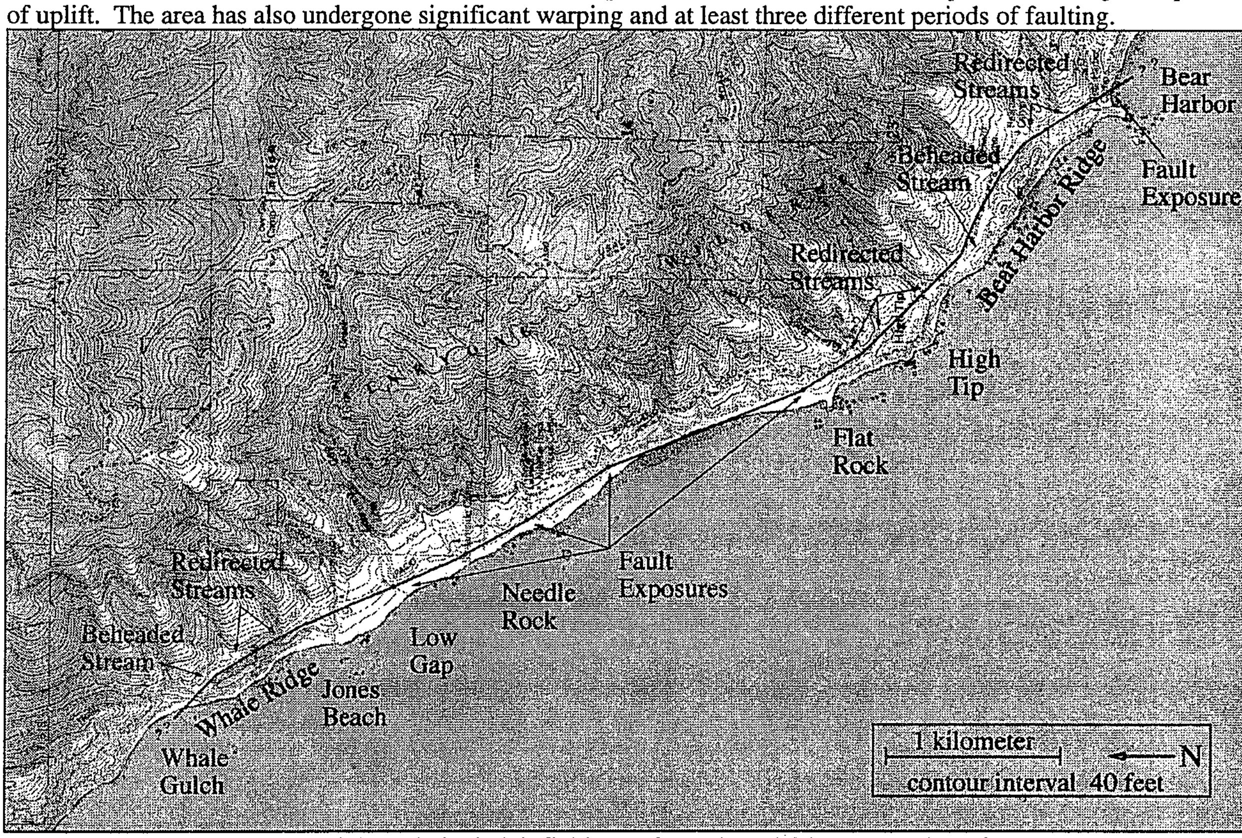

Figure 1. Topographic map of the Whale Gulch field area from the USGS Bear Harbor, CA, 7.5 minute quadrangle. The dark line represents the proposed fault trace discussed below.

STRATIGRAPHY

The bedrock marine terraces and the overlying sediments are exposed along the beach in the 3.3 km between Jones Beach and Flat Rock. The stratigraphic sequence developed in response to sea level regression and coastal uplift. A wave-cut platform comprised of argillite and graywacke is overlain by 1-6 m of marine gravel and sand (beach deposits), which in turn is locally overlain by thin lagoonal clay deposits containing abundant charcoal, which in turn is overlain by up to 60 m of alluvial gravels that are generally coarse grained and poorly sorted debris flow deposits. The alluvial unit forms a broad constructional alluvial fan surface which is thickest midway between Needle Rock and Flat Rock. This stratigraphic sequence is typical of that associated with a regressing sea level and abandonment of a platform cut during a time of relatively high sea level (Merritts, pers. comm., 1995). The stratigraphic sequence appears to be continuous: there are no unconformities or buried paleosols, and the mixing of layers (particularly in the transition from marine sands to alluvial gravels) at the boundaries suggests a smooth transition between sedimentary styles.

PLATFORM SURVEY

We performed a detailed survey of the platforms between Needle Rock and Flat Rock in order to accurately determine their elevations and spacings. We used a Lietz total geodetic station, which has horizontal and vertical errors of less that ±3 and ±6 cm, respectively, at each set up. The data points were statistically corrected for cumulative error based on measured error in resurveying temporary benchmarks. In the field, we categorized survey points into three platform designations: D, E, and F. Subsequent data analysis and geologic reasoning suggests that platforms D and E were likely cut during the same high stand.

Platform F (subsequently referred to as the "major platform") is the most laterally extensive platform, extending from Jones Beach all the way to Flat Rock. Hageman (1984) assigned it an age of 45 ka, and other workers have considered it to be contemporaneous with the platform at Point Delgada, which is also commonly correlated with the 45 ka sea level high stand (Merritts and Bull, 1989; McLaughlin et. al, 1983). The platform is warped considerably, and ranges in elevation from 3 to 13 m. The inner edge elevation at Flat Rock is approximately 10 m, and that value is used in the analysis in order to make comparisons with the lower platforms at Flat Rock.

Platform E has not been previously described, but its inner edge is clearly exposed at Flat Rock and was surveyed at 6 m above sea level. Platform D is separated from platform E by a 2 m wide linear gully, forming the seaward block of Flat Rock. Platform E dips slightly to the north, while platform D dips slightly to the south. Their difference in orientation suggests that the separation has occurred since the platforms were cut, possibly due to faulting or rotational slumping. Therefore, I propose that platforms D and E were cut during the same sea level high stand. These two surfaces will subsequently be referred to as the "lower platform", and the elevation used in the analysis will be the preserved inner edge elevation of 6 m.

A third terrace was reported by Hageman (1984) to exist approximately 50 m above sea level. This terrace is buried below a layer of soil, and I did not find it in the field. Thus, it is used with some reservation in the platform age correlation discussion below.

RADIOCARBON DATING

In order to constrain the timing of terrace formation and subsequent sedimentation in the Whale Gulch area, I collected a total of sixteen samples of organic material from six sample sites in the stratigraphic units above the major platform. Three of these samples were radiocarbon dated by Beta Analytic, Inc. in Miami, Florida. All three samples, WG1C, WG4, and WG2D, reported ages beyond the limits of dating technology.

WG1C was the sample most likely to constrain the age of platform. It was collected from a stick trapped under a meter-wide pholad-bored boulder directly on the marine platform. Due to its small sample size, WG1C was dated using extended counting. The age was reported as >47,030 years BP. WG4 was collected from charcoal floating on top of one of the units of lagoonal clay near the bottom of the alluvial unit. It was dated using AMS analysis; the age was reported as >48,800 years BP. WG2D was the stratigraphically highest sample collected. It was collected from a channel cut-and-fill several meters above the base of the alluvial unit. It was dating using AMS analysis, but still produced an infinite age of >45,600 years BP.

It was tempting to try to make age comparisons between these samples based on the three infinite values that were reported, particularly since I am trying to correlate the stratigraphy with an event that may have occurred at about 47 ka. However, the differences in reported values reflect differences in the instrumentation and measurement of the samples, not in the samples themselves. The three values should be considered equivalent, and may be taken to mean that the samples are all older than 45,000 years, the approximate limit of radiocarbon dating technology.

PLATFORM AGE CORRELATION

Because the reported radiocarbon dates were all beyond the limit of the dating technology, there is no absolute control on the timing of the sea level high stands which cut the platforms at Whale Gulch. Therefore, we must rely on the spacing of the platforms in order to estimate the ages of their formation. The fluctuating sea level will produce a unique spacing of marine terraces for each coastal uplift rate. Through correlation of the marine terraces with the eustatic sea level curve, we may be able to constrain the timing of formation and thus the uplift rate. The spacing of the major and lower terraces surveyed suggests three possible age hypotheses (see figure 2).

The first possible correlation matches the major terrace with the 103 ka high stand. The lower terrace would then correlate with the 83 ka high stand. At an uplift rate of 0.2 m/ka, these terraces would correspond with the modern elevations of 10 m and 6 m respectively. However, this hypothesis seems unlikely for two reasons. First, an uplift rate of 0.2 m/ka would be anomolously low, given other research which assigns an uplift rate of 0.4 m/ka at Fort Bragg (to the south) and 1.0 m/ka at Point Delgada. Secondly, this uplift rate would not provide any any sea level high stand which would explain Hageman's (1984) 50 m terrace. This hypothesis is rejected as unlikely.

The second pair of sea level high stands that might have produced the paired Whale Gulch terraces occurred at 64 ka and 57 ka. An uplift rate of 0.6 m/ka in this scenario would produce paired terraces at 10 m and 6 m. Hageman (1984) advanced an age of 62 ka for the major platform as one of his hypotheses and correlated his 50 m platform with the 103 ka high stand. However, he rejected this hypothesis because of the absence at Whale Gulch of the 83 ka terrace that one would expect to see preserved at 37 m with an uplift rate of 0.6 m/ka.

The final hypothesis matches the modern terraces with the 46 ka and 40 ka sea level high stands, predicting an uplift rate of 1.2 m/ka. This age assignment would be most consistent with regional uplift estimates by other researchers (McLaughlin et. al, 1983; Hageman, 1984; Merritts and Bull, 1989). In this hypothesis, Hageman's (1984) 50 m terrace correlates almost perfectly with the 64 ka high stand. There is no visible record of the 57 ka high stand which should be preserved at 40 m, though this terrace could be buried under the sedimentary pile. Older terraces which would have been cut by the 83 ka and 103 ka high stands could have been eroded away or buried by alluvial debris flow material from the mountain front.

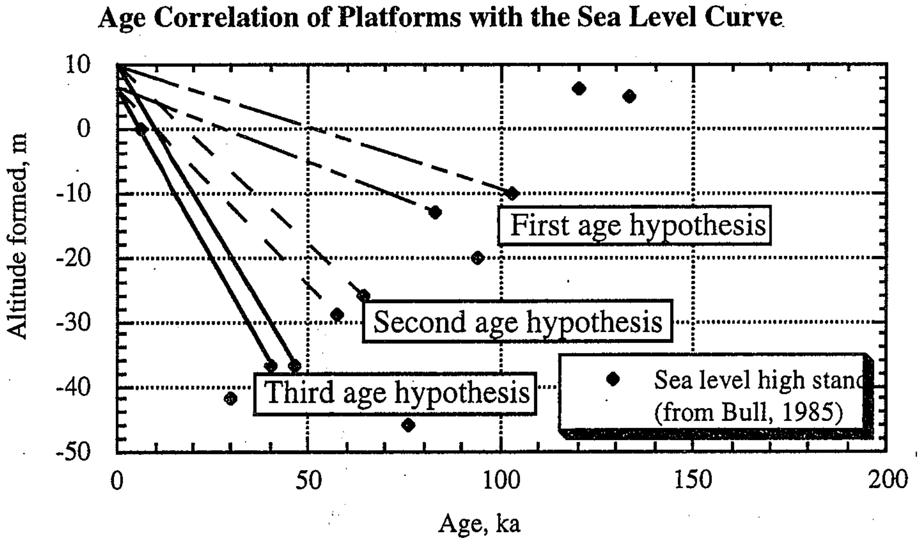

Figure 2. Spacings between remnant marine terraces can be correlated with high stands on the eustatic sea level curve. The first hypothesis matches the 10 m terrace with the 103 ka high stand and the 6 m terrace with the 83 ka high stand. The second hypothesis matches the two terraces with the 64 ka and 57 ka high stands, respectively. The third hypothesis matches the terraces with the 46 ka and 40 ka high stands. The slope of the lines in each hypothesis represents the uplift rate.

The infinite radiocarbon dates throw some doubt into the third age hypothesis. If the major terrace was cut at 46 ka, the sedimentary deposits overlying it must all be younger. Though we have very little idea of sedimentation rates in this region, one might expect the accumulation of 2 to 3 meters of marine sands and several meters of alluvial gravels to take as much as a few thousand years. If this were the case, then we would expect to get finite dates (less than 45 ka, which is the approximate limit of radiocarbon dating) higher up in the stratigraphic section. This did not occur; the stratigraphically highest radiocarbon sample was reported as >45600.

However, the infinite dates do not necessarily discount the 3rd age hypothesis. The radiocarbon samples could be just at the edge of the dating technology. In an uplifting region, sedimentation rates could be somewhat higher than expected. Furthermore, marine platforms are cut at the point when sea level is stable relative to the shore; in other words, the terrace is cut when the rate of sea level change matches the uplift rate. Therefore, the terrace should have been cut somewhat before the 46 ka reported date of the high stand, possibly as long ago as 48 ka (Merritts, pers. comm., 1995). The combination of these factors suggests that we cannot rule out the 46 ka age hypothesis.

The evidence to distinguish between the second and third hypotheses is not strong. However, the third hypothesis seems more likely, based on the spacing of the terraces and the similarity to other uplift estimates. The infinite radiocarbon ages cast doubt on this hypothesis, but do not rule it out. For want of better estimates of sedimentation rates and better dating, I tentatively choose this hypothesis as the correct one and estimate an uplift rate of 1.2 m/ka at Whale Gulch.

FAULTING AND DEFORMATION

Given the proximity of both the San Andreas Fault and the Mendocino Triple Junction, it is not surprising to find a fairly complicated history of uplift and deformation preserved in the rocks of the Whale Gulch area. In addition to the active uplift that has been occurring in the region for at least 300,000 years (Merritts and Bull, 1989), the area has been extensively faulted during several periods of deformation.

Old Faults. A complex set of brittle faults is inherited from deformation of the accretionary wedge in the Cascadia Subduction Zone. These faults are generally <1 cm wide, and many of the surfaces have calcite slickenlines in several orientations, suggesting a complex deformational history. Faulting occurred after the rocks were deposited in the mid-Miocene, and could have occurred as recently as the Pliocene (Beutner, pers. comm., 1995).

Shear Zones. A set of large near-vertical shear zones is found throughout the field area, but is most concentrated near Bear Harbor and north of Whale Gulch. These zones range in width from 50 cm to 15 m, and tend to be filled with rock that has been heavily sheared or brecciated. This material is often shiny black on a fresh surface and is easily broken in the hand. These zones strike northwest and dip steeply to the northeast or very steeply to the southwest. They were formed before the marine platforms, since they rise all the way to the top of the bedrock but do not offset the platform surface. Fault gouge can be found in some of the shear zones, suggesting that they may have been reactivated by the most recent generation of faulting.

Young Faults. The most prevalent set of faults in the Whale Gulch area is a family of young thrust faults. They range in width from less than a centimeter to as much as 40 cm wide, and are distinguished by the presence of fresh clay gouge and breccia in the fault zone. The gouge is often soft and wet as a result of water moving along the fault planes. Although there is some local variability, faults measured as far north as Big Flat by Ed Beutner and Greg Schorr (during the Keck Project) fall into the same family of young thrusts and have very similar orientations, consistently striking to the northwest and dipping to the northeast. The only exceptions are the young shears at Shelter Cove that appear to be directly related to the San Andreas Fault.

In places where these faults can be seen at the contact between bedrock and the cover sediments, they generally do not offset the platform or disturb the sediments. However, two faults near Flat Rock offset the platform by as much as 40 cm, suggesting that the faults must have been active during or slightly after the formation the terraces. There appears to have been little motion along these faults since sedimentation began.

Warping. When originally formed, marine platforms are flat surfaces, inclined 1-3° toward the ocean like the modern platform. This is no longer true: near Needle Rock and Flat Rock, the major platform is as high as 13 m, whereas between them it drops to less than 4 m. The contact between the marine and alluvial units is similarly warped, suggesting that much or all of the warping has occurred since the platform was cut. Because the survey data run in a line along the beach, it would be unreasonable to try to calculate a fold axis.

LINEAR VALLEYS

Two shore-parallel linear ridges (figure 1), one to the north of Jones Beach and one to the south of Flat Rock, stand out as anomalous in the Whale Gulch area. Streams turn at right angles to flow behind them until coastal retreat allows them to flow back out to the sea, leaving beheaded streams behind each ridge. They are the only shore-parallel ridges in the region, except the escarpment formed by Woods Gulch/Humboldt Creek along the San Andreas Fault on Point Delgada. Several researchers in the past have mapped faults along these valleys. Beutner et. al. (1980) mapped a fault behind both ridges based on geomorphic expression, and Hageman (1984) mapped a fault behind Bear Harbor Ridge based on fault offsets in the stratigraphy.

Based on an examination of the near-vertical shear zones and the striking geomorphology, I tentatively map a strike-slip fault behind these two valleys as shown in figure 1. Several of the shear zones line up with the valleys, including exposures at Bear Harbor, Flat Rock, Needle Rock, and Low Gap. There is questionable evidence for the fault at the mouth of Whale Gulch. The fault could represent an old arm of the San Andreas system, but must have been inactive since before the terraces were cut, because neither the platform surface or the overlying sediments are disturbed by the fault.

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