

Uplift of Marine Terraces along the San Andreas Fault:
Fort Bragg Region, Northern California

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Abstract

Keywords

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Abstract:

Marine terraces are prominent landforms along the Pacific coast of northern California. These elevated wave cut platforms are the result of sea-level fluctuations superimposed on tectonic uplift. The regional tectonic uplift is a result of the seismically active plate boundary between the North American plate and the Pacific plate known as the San Andreas Fault. The study of these marine terraces helps to resolve rates of tectonic uplift and deformation, as well as provide a better understanding of climatically driven eustatic sea-level history of the Quaternary. This survey of the marine terraces near Fort Bragg contributes to a larger database, aimed at understanding crustal deformation along this major plate-bounding strike-slip fault.

The ~23 kilometer long section of coast around Fort Bragg contains three prominent relatively undeformed terraces with estimated inner edges of ~25 m, ~43 m, and ~59 m. These terraces correspond to the sea-level highstands of ~83 ka, ~108 ka, and ~122 ka respectively, providing a regional average uplift rate of around 0.51 meters per thousand years.

Keywords: Marine terraces, Northern California, Uplifts, San Andreas Fault, Sea-level changes, Quaternary

INTRODUCTION

Background:

Marine terraces along the Pacific Coast have been studied for over a century. The ground-breaking study by Lawson (1893) was the first to analyze the nature and extent of the marine terraces along different portions of the coast. Davis (1932) and Alexander (1953), examining the marine terraces of Santa Monica and Santa Cruz respectively, were two of the first to propose, the now widely accepted model, that the terraces are the result of Quaternary sea-level highstands superimposed on a tectonically uplifting coast. Since these pioneering works, numerous studies have attempted to determine the position, elevation, and consequently the uplift rate of terraces along different sections of the Pacific Coast. Bull and Merritts (1987) claimed that over 40 such studies that had already been done on various points along the coast; countless more have been conducted since 1987 (e.g., Lajoie et al., 1991; Muhs et al., 1990; Orme, 1998; Richardson, 2000; Rockwell et al., 1989; Tellinghuisen, 2000).

There are still, however, large unstudied sections of coastline that need to be examined for a more complete understanding of the nature of crustal deformation along the San Andreas Fault. The Fort Bragg region studied for this paper (Fig. 1) was explored as part of the 2003 California Keck Consortium project, whose goal was to locate, map, and analyze marine terraces along previously unstudied or under documented sections of the northern California coast. This study of the marine terraces of the Fort Bragg region provides a local tectonic uplift rate as well as contributing data useful to the larger issue of crustal deformation along the boundary between the Pacific and North American plates.

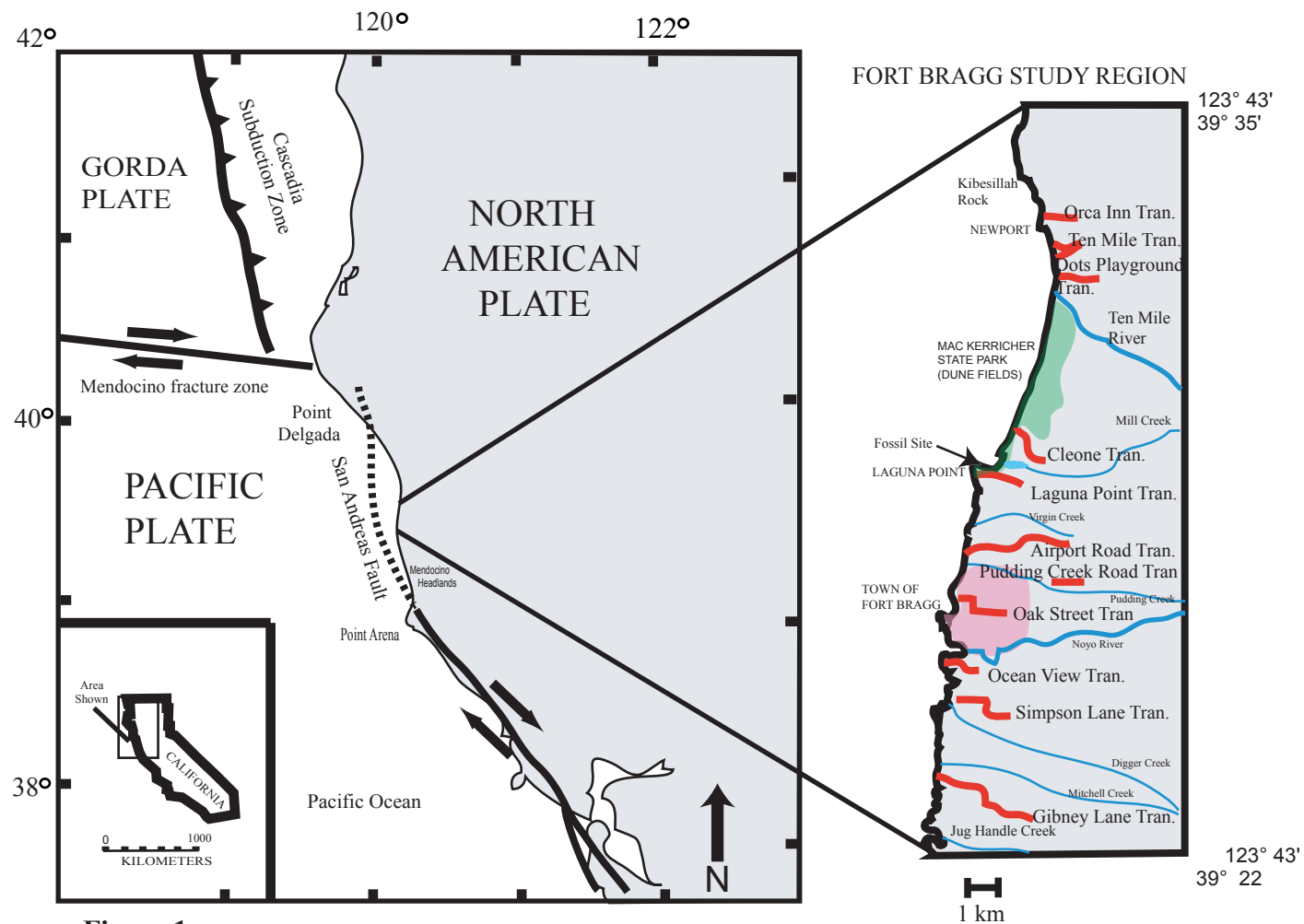


Figure 1.

**Location map with tectonic setting (modified from Muhs et al. 2003).
Transect names are those of nearby roads or other nearby landmarks.**

Terrace Formation:

As stated earlier, marine terraces are the result of sea-level fluctuations superimposed on tectonically uplifting coastal blocks. In order to better understand the formation of marine terraces one must first understand the cause of uplift, the mechanics behind the sea-level fluctuation, and the geomorphic features that marine terraces represent.

Cause of Uplift

The Pacific-North American plate boundary is a dominantly right lateral transform system; however, slight variation in plate motion vectors give rise to a small amount of fault normal compression (Muhs et al., 2003). This component of compression is responsible for the ongoing uplift of the Quaternary marine terraces along much of the California coast (Muhs et al., 2003).

Cause of Sea-Level Fluctuation

Quaternary sea-level has fluctuated with the growth and decay of continental glaciers (Gallup et al., 1994). Eustatic sea-level is low during periods of glaciation and high during interglacial periods. The Milankovitch theory maintains that these fluctuations are the result of variations in solar isolation, due to cyclical variations in the eccentricity of Earth's orbit, and the tilt and precession of Earth's axis.

Marine Terraces as Geomorphic Feature

It is the dynamic between this uplift and sea-level fluctuation that creates marine terraces, the depositional and erosional remains of abandoned marine shorelines (Lajoie, 1986). At any given sea-level, shoreline processes carve away at the bedrock creating a sloped platform that terminates in a steep sea cliff shoreward of the platform. When sea-

level rises, most shorelines are eroded, unless the coast is uplifted fast enough to preserve them. However, there is often sufficient time between major sea-level highstands that shorelines which form during these periods are uplifted and preserved.

These processes repeating through time result in the stair-step nature obvious in many areas along the Pacific Coast (Fig. 2). Each horizontal line of the step represents the intertidal and near-shore zone of marine abrasion created during a major sea-level highstand (Bradley and Griggs, 1976). The vertical riser of each step is a relic sea cliff, the height of which is dependent on how fast the land is being uplifted and how much time there has been between highstands (Lajoie, 1986).

Each terrace is analogous to the modern shoreline, with a gentle seaward tilting sloped platform and a cliff face. However, these bedrock features are not as obvious as might be expected because each terrace is covered by a veneer of marine sediment and then is furthered covered with colluvium, terrestrial alluvium, and eolian dune sands as it is uplifted. Within the Fort Bragg study area, the sediment cover can be tens of meters thick. Terrace distinction can be further complicated by landslides, erosion from down-cutting by rivers and streams, and diffusional action by rodents (Anderson et al., 1999).

Uplift Calculation:

In order to calculate the uplift rate of the marine terraces along a section of the coast one must know three crucial elements: the elevations of the terraces above modern day sea-level, the ages of the terraces (which sea-level highstands they correspond to), and the sea-level highstand magnitude (relative to the modern day sea-level).

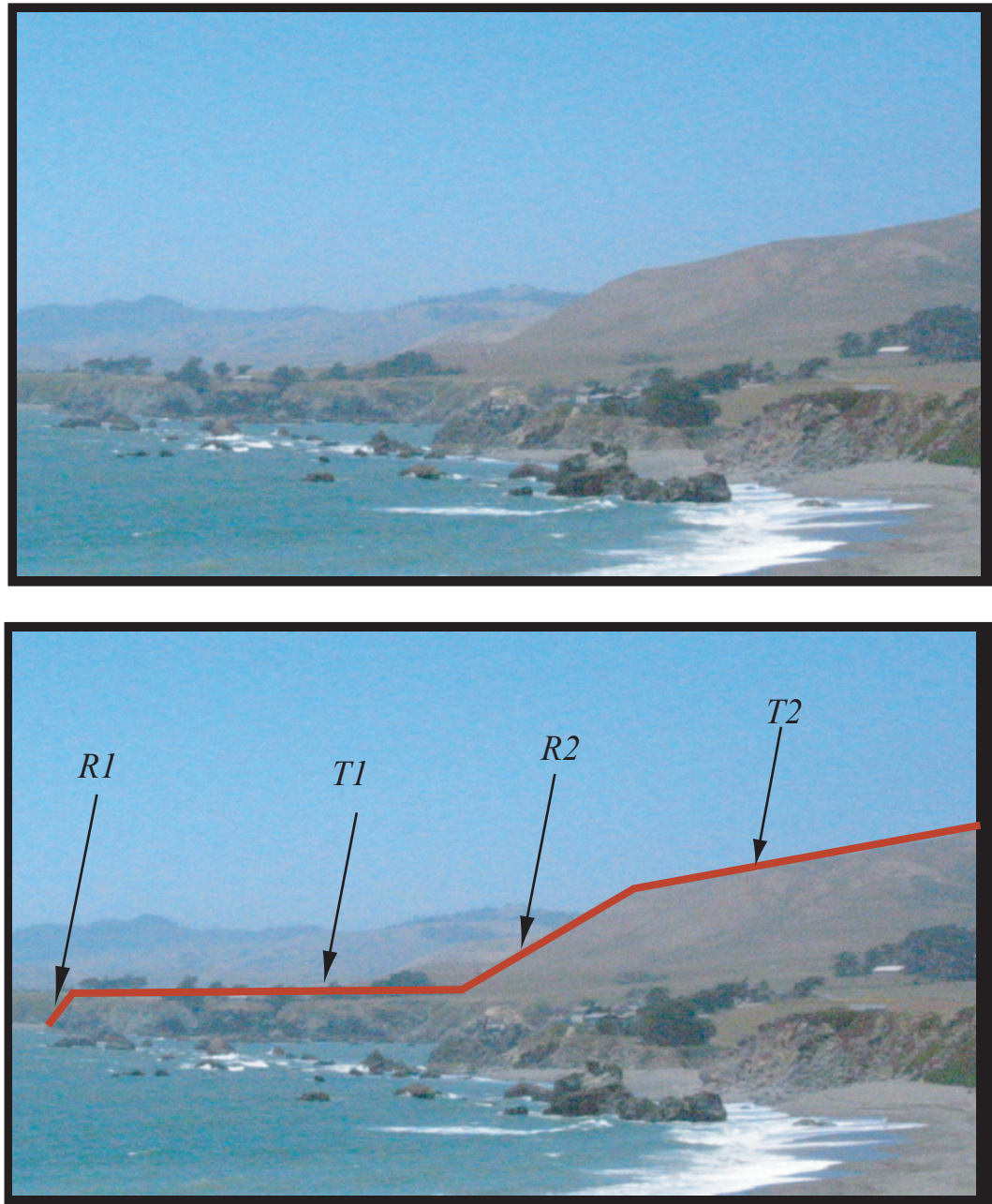


Figure 2.

□ **Photograph of marine terraces near Jenner, California. The stair step nature of terraces is evident along much of the Pacific coast. The low sloping treads of the terraces (T1 and T2) represent relict shore platforms. The vertical or sloping risers of the terraces represent the modern day sea cliff (R1) and a relict sea cliff (R2).**

One can then derive an average rate of uplift by dividing the real amount of uplift by the time elapsed.

For example, if a present day 60 m high terrace was formed during the 122 ka highstand, and this highstand reached 6 m above the modern-day sea-level, then this terrace has a real uplift of 54 meters in the 122,000 years. This would give a rate of 0.44 meters per thousand years. By using the elevations and ages of numerous terraces one can further refine this number. Unfortunately, correctly establishing these three pieces of information can be very difficult.

Complications of Determining Terrace Height

Determining modern day terrace elevation can be complicated by numerous factors. First, the important elevation necessary for the calculations is that of the terrace bedrock (this represents the ancient shoreline). However, bedrock was rarely visible on the terraces around Fort Bragg (as is true in many areas) due to a thick covering of marine sediments, colluvium, terrestrial alluvium, and eolian dune sands. This cover adds an artificial height to the terraces that must be accounted for. The sediment can also obscure entire platforms causing multiple terraces to appear as one (Bradley and Griggs, 1976). Second, in the Fort Bragg region, multiple faults that are part of the same stress system as the San Andreas fault, (Kramer, 1977) warp and deform the terraces making an accurate gauge of uplift difficult (e.g., Muhs et al., 2002; Rockwell et al., 1989). Third, the higher and subsequently older terraces have been subject to increasing erosion which can artificially lower the bedrock elevation. The rivers and streams that are largely

responsible for this erosion also create river terraces that can be confused with marine terraces. Examples of such rivers around Fort Bragg include the Ten Mile and the Noyo.

It is often very difficult to be certain which terrace corresponds to which highstand. There are currently four commonly used methods to determine the ages of terraces. 1) Faunal analysis of fossils found in terraces can determine if the terrace fauna lived in waters warmer or cooler than that of today, providing a strong clue to its age as a result of the relationship between climate and sea-level magnitude. However, this method often merely serves to narrow down possible terrace ages, or cross check other dating methods (Kennedy et al., 1982; Muhs, 1983). 2) Mollusk fossils in terraces can be subject to amino acid racemization techniques, but the ages derived with this method are often considered tentative (Muhs, 1983). 3) The most widely accepted and accurate method of dating marine terraces is uranium-series analysis of fossil corals (Ku, 1976; Rockwell et al., 1989). Unfortunately fossil corals are extremely rare in the more northerly latitudes of North America, and there is still some level of inaccuracy with this method (Muhs, 1983). 4) In lieu of fossils researchers often are forced to assume the lowest terrace corresponds to a recent highstand and each successively higher terrace represents the next major-highstand that would be preserved assuming a constant uplift rate (e.g., Bradley and Griggs, 1976; Lajoie, 1986)

Quaternary eustatic sea-level curves are used to pinpoint the age and magnitude of each highstand. However, there are multiple variations of Quaternary sea-level curves; this is the result of the using different types of data, collected from different locations, to establish them (e.g., Broecker et al., 1968; Chappell and Shackleton, 1986; Edwards et al., 1987; Gallup et al., 1994; Kukla, 2000; Lambeck and Chappell, 2001; Ludwig et al.,

1996; Muhs and Szabo, 1982). The various types of data used to construct the sea-level history vary in resolution and accuracy, and no one curve is considered overriding. It is also important to note that using one or a combination of these sea-level curves, when assigning ages to terraces of a particular region, can not account for the possibility of local variation in the study area.

METHODS

Determining Location and Elevation of Terraces:

The primary method of locating and estimating the heights of the regional terraces was to determine locations throughout the region using Trimble Pathfinder ProXR Global Positioning Systems (GPS) with real time correction. The GPS recorded horizontal and vertical data with submeter (horizontal) and meter (vertical) accuracy. The locations of the terraces were determined by walking twelve transects roughly perpendicular to the coast along the ~23 kilometer section of coast between Kibesillah Rock and the mouth of Jug Handle Creek (Fig. 1). Transect locations were chosen using aerial photos, topographic maps, and fault maps. Areas not covered by transects include the four kilometer dune field in MacKerricher state Park and terraces around the Noyo and Ten Mile rivers which were significantly eroded and not suitable for data collection.

Multiple GPS positions were recorded at the outer edge, inner edge, tread and riser of each identifiable terrace (Fig. 3). Notes were made about the estimated depth to bedrock at each point. These data were then superimposed on digital orthophoto quadrangles (DOQS) of the region. Additionally, stereoscopes were used to interpret

aerial photos of the region, in an attempt to estimate the location of the inner edge of the terraces, by noting significant changes in elevation. The aerial photography analysis and the GPS data were compared and compiled to determine the exact location of the terrace inner edges.

Once the elevations of the terrace inner edges were determined using the GPS data the bedrock elevations were estimated. Where inner edge bedrock was visible in the field, that elevation was used. Where the depth to the bedrock at an inner edge was not obvious, but an outer edge bedrock depth was available from the same terrace, the inner edge bedrock elevation was estimated using the Bradley and Griggs (1976) regional terrace slope method. The regional terrace slope is calculated by averaging the angle of known bedrock tread slopes measured at three locations in the field area. This regional slope average was then used to estimate the inner edge bedrock point from the height of the outer edge bedrock and the horizontal distance to the inner edge point (Fig. 4).

When no outer edge bedrock was available, a rough estimate of sediment cover was subtracted from the GPS elevation, in order to give a tentative inner edge bedrock elevation. These thickness estimates were a combination of averaged actual sediment deposit thicknesses seen throughout the region, and a best guess field observation. Eventually, all of the inner edge bedrock elevations (both real and estimated) were analyzed, and best fit lines were matched to the points in order to laterally correlate the terraces.

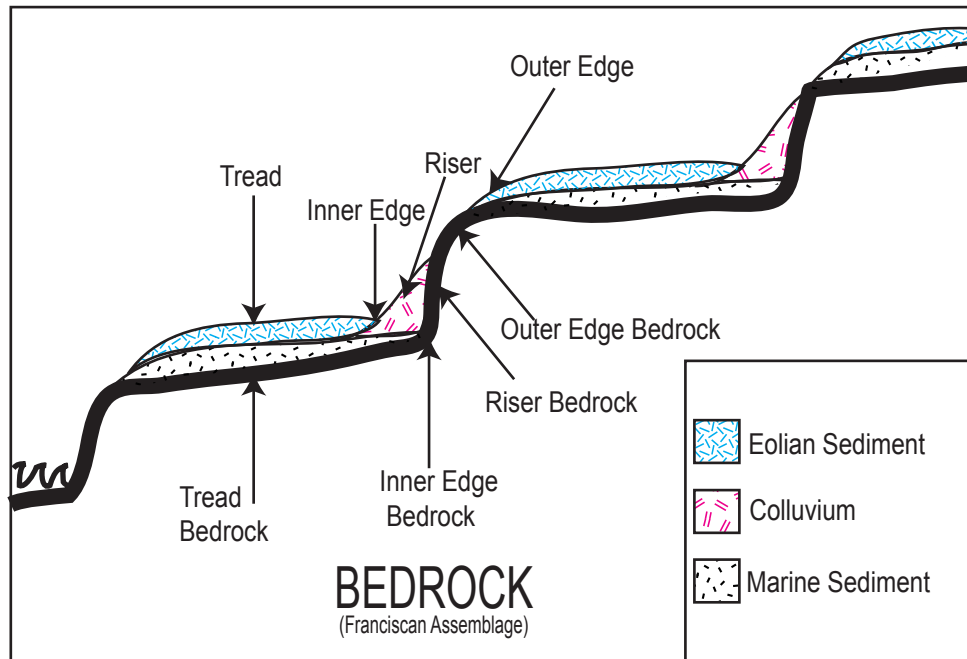


Figure 3.

□ **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 highstand.**

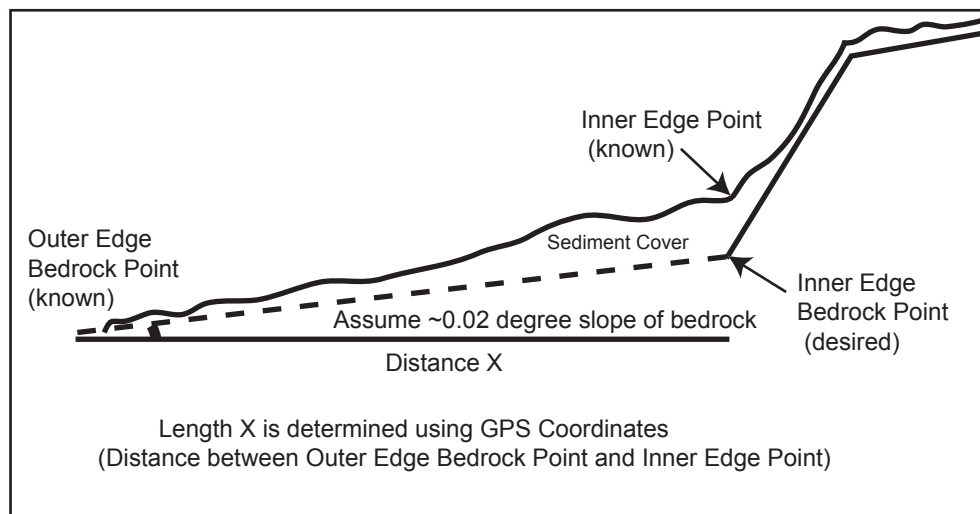


Figure 4.

□ **Diagram illustrating the slope method of estimating the elevation of an inner edge bedrock point. By knowing the outer edge bedrock elevation, distance X, and an average slope of the bedrock in the region, one can use trigonometry to estimate the inner edge bedrock point. Refer to Bradley and Griggs (1976) for how to determine an average bedrock slope.**

Determining Age of Terraces:

Once the number, location, and elevation of the terraces had been determined, it was essential to assign an age to each terrace. In order to find corals suitable for uranium-series dating, marine sediment from various locations throughout the field area was sieved. This proved unsuccessful at all sites except for a relict cove in the lowest terrace on the southern tip of MacKerricher State Park (Fig. 5). At this location two small fossil corals believed to be *Balanophyllia elegans* (Merritts, pers. comm.) were uncovered. These two corals are scheduled to be dated in March, 2004. An accurate date from these corals would be extremely valuable because it would be only the second uranium-series date in the 1,207 kilometers between Cayucos, California and Bandon, Oregon (Muhs et al., 1994). This fossil cove at MacKerricher State Park was also studied by Kennedy et al. (1982), and although he did not identify any coral species, he did conduct amino acid racemization on various mollusk species found in the cove, as well as a faunal analysis of the forty species he documented (Kennedy, 1981).

The tentative date for this lower terrace, proposed by Kennedy et al., was used in order to begin assigning terraces to highstands, prior to acquiring a coral date. 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 highstand ages and magnitudes (Fig. 6). This sea-level curve was chosen because it combines data from multiple well accepted studies conducted around the world.



Figure 5.

□ Sieving for coral at Laguna Point on the southern tip of MacKerricher State Park. This site contains an intertidal shoreline fossil assemblage that has now been uplifted. This fossil site is likely part of the ~25 m terrace. Person sieving is fellow Keck student Bre MacInnes who is 1.6 meters tall.

□

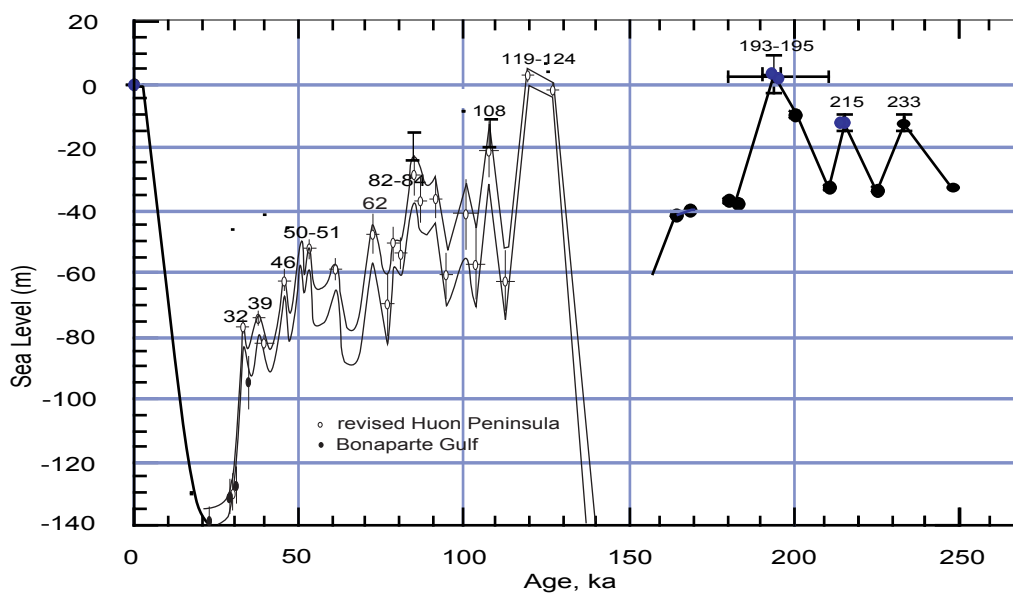


Figure 6.

A revision of the Darter (2000) eustatic sea-level curve. This curve synthesizes data from numerous studies. Original source of the sea-level curve for 124 ka to present is from Lambeck and Chappell (2001); the two lines illustrate the upper and lower limits of their estimates.

RESULTS AND DISCUSSION

Number, location, and elevation of terraces:

Analysis of the GPS data and aerial photo mapping shows that the area contains three relatively continuous broad terraces (Fig. 7). The elevation of the bedrock inner edge of an individual terrace varies up to nine meters at different points along the coast. However, the terrace elevations experience no general trend of increasing or decreasing uplift rate in either particular direction parallel to the coast (Fig. 8). The slight rise in elevation of the second terrace to the north is likely due to local faulting in the area of the Orca Inn, Ten Mile, and Dots Playground transect (Fig. 8).

The lowest terrace has an average elevation of 25 m, and a range of inner edge elevations from 22 m on the Cleone transect to 28 m on the Oak Street transect. The second highest terrace inner edge has an average elevation of 43 m, and a range from 40 m on the Gibney Road transect to 49 m on the Dots Playground transect. The third terrace has an average elevation of 59 m. The inner edge elevations of this terrace range from 57 m on the Airport Road transect to 62 m on the Ten Mile transect.

There are several factors that could account for the range in inner edge bedrock elevations of the same terrace. First, multiple small faults visibly warped and deformed the terraces north of MacKerricher State Park. However, the inner edges of the terraces were relatively unwarped. These faults, and others not visible from the field, could account for some of the terrace elevation fluctuations. Second, general variation in topography of the original bedrock surface can also account for the range of inner edge

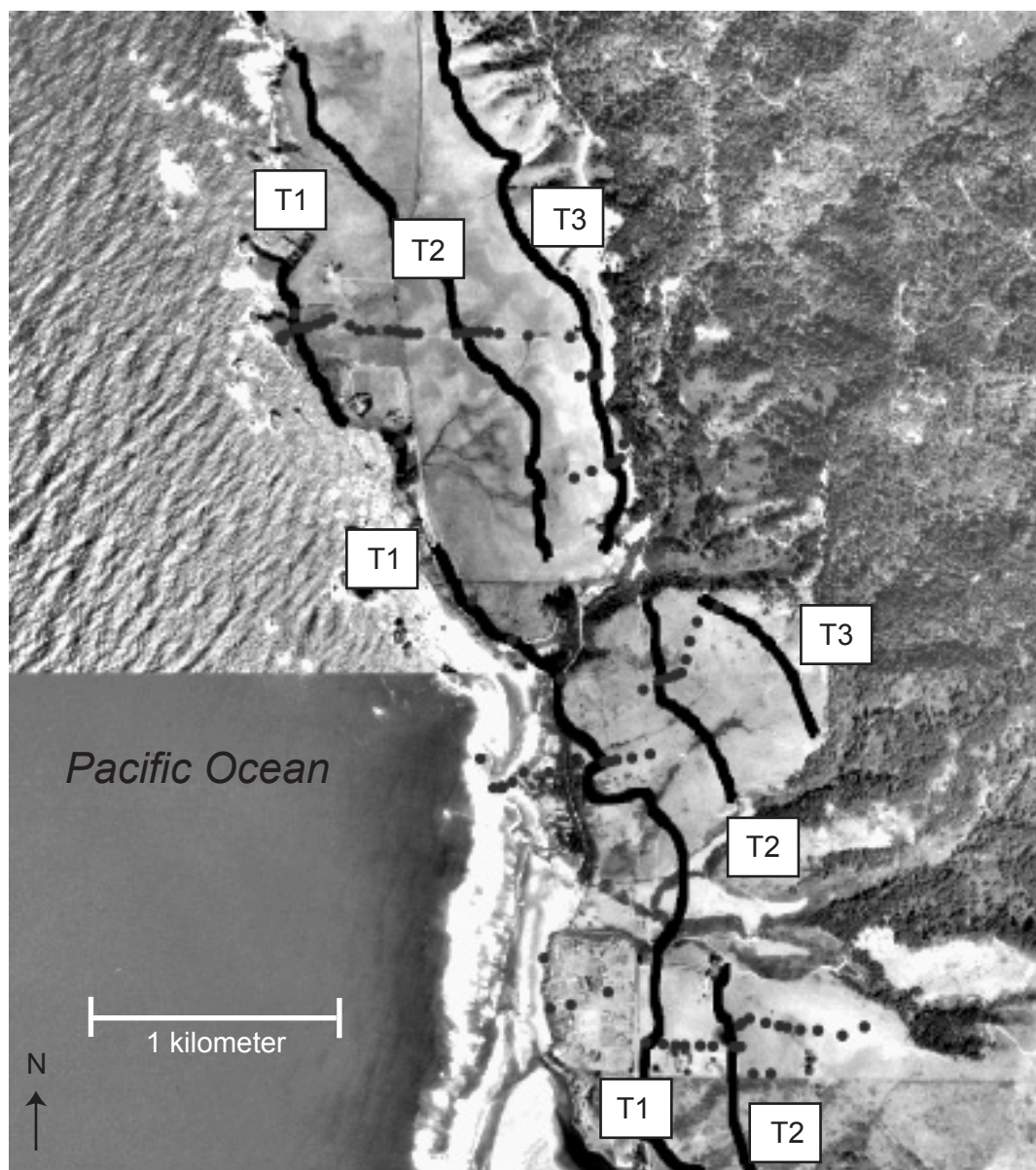


Figure 7.

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.

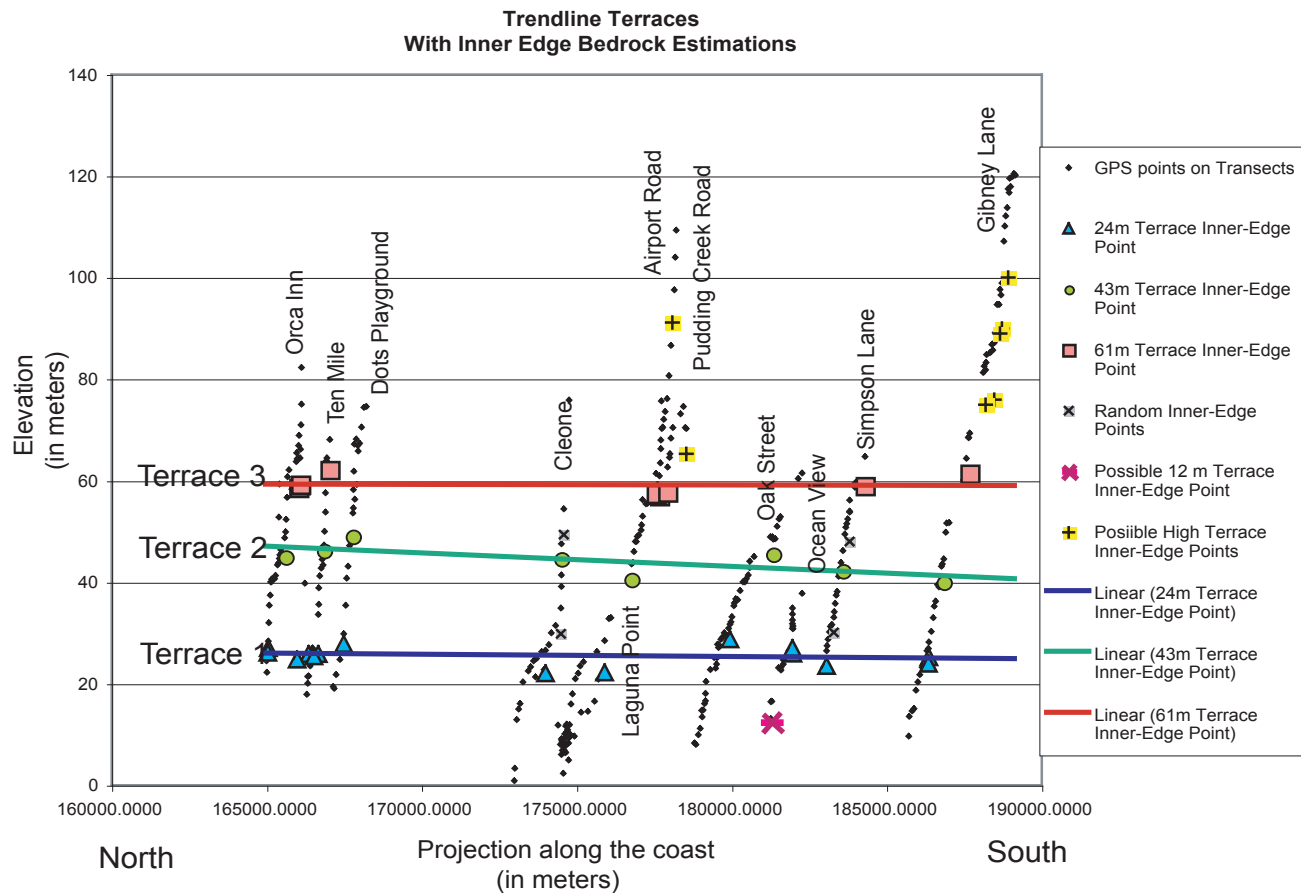


Figure 8.

□ Plot of transects 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 the Orca Inn, Ten Mile, and Dots Playground transects.

bedrock elevations. This topographic variation on the original shoreline can be up to three meters (Bradley and Griggs, 1976). Third, the methods used to estimate depth to bedrock (when bedrock inner edge points were not visible) have considerable uncertainty; this is likely the largest factor in the variation of inner edge elevations. Only the ~24 m terrace (the lowest one) had actual bedrock exposures; the other elevations were calculated using the slope method or by subtracting an estimated sediment depth from an inner edge point. Elevations estimated with these two methods can be inaccurate by up to ten meters (Merritts, pers. comm.).

Despite the range in inner edge bedrock elevations, it is important to note that there is no overlap of the elevations between the terraces. The terraces are spaced far enough apart to be easily distinguished as three separate terraces.

Two transects (Cleone and Simpson Lane) included miscellaneous inner edge points around 30 m and 48 m respectively; however, the classification of these points as inner edge points was tentative because they did not mark as sharp a break in slope as most inner edge points. A few inner edge points were also identified above 70 m, but a lack of exposed bedrock, due to the large amount of colluvium, and the high level of erosion from stream cutting, make it extremely difficult to determine an accurate elevation for these potential higher terraces.

The Ocean View transect contained a possible inner edge around 12 m (Fig. 8). An inner edge at this elevation was not visible anywhere else in the field area and was consequently disregarded as representing a major terrace. However, if this inner edge point actually represents a terrace that is elsewhere eroded or covered, it would have

significant implications for the correlation of the terraces to sea-level highstands and would greatly affect the calculated regional uplift rate.

Age of Terraces and Uplift Rate:

Analysis suggests that the ~25 m terrace represents the ~83 ka highstand, the ~43 m terrace formed during the ~108 ka highstand, and the ~59 m terrace corresponds to the ~122 ka highstand. These age assignments are based on the following lines of reasoning: Kennedy et al. (1982) conducted amino acid racemization and faunal analysis on fossils from the fossil site on the southern point of MacKerricher State Park. He concluded that the fossils were deposited during either the ~83 ka or ~108 ka highstand due in large part to the cool water aspect of the fauna (Kennedy et al., 1982). This fossil site is most likely part of the terrace with the inner edge elevation of ~25 m. However, it is also possible that the fossil site is part of a ~12 m terrace whose inner edge is covered by sediment (Fig 9A,B).

The ~83 ka date for the terrace containing the fossils is favored over the ~108 ka date for multiple reasons. First, this is the lowest visible terrace and it most likely represents the more recent of the major highstands (Merritts, pers. comm.). Second, along the Californian coast the ~108 ka highstand is rarely preserved or only partially preserved (Muhs et al., 1994; Orme, 1998), further increasing the likelihood that the

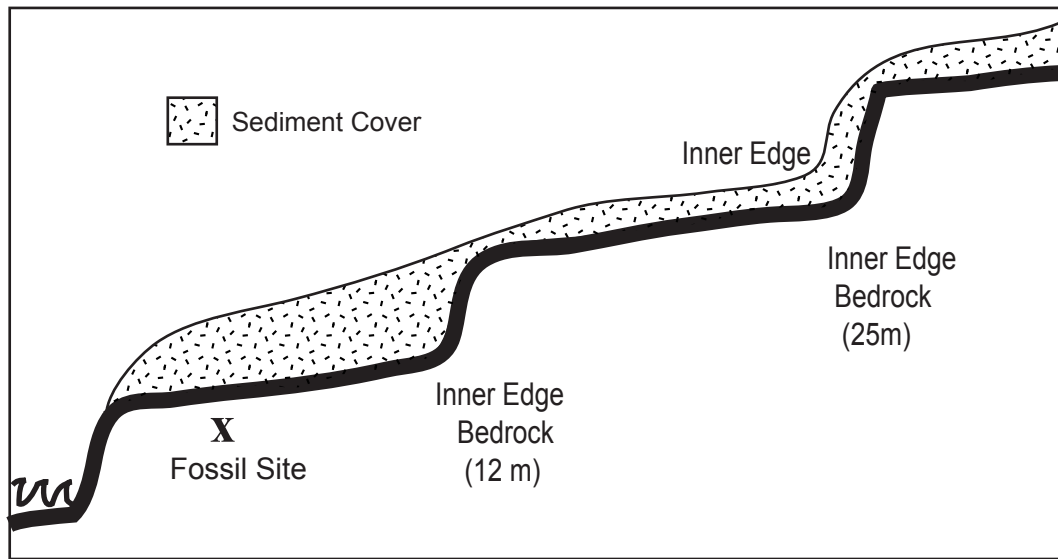


Figure 9A.

□ Schematic cross section of a flight of marine terraces. Thick sediment deposits can obscure inner edge points; as a result, transects can fail to identify a terrace. It is possible, but unlikely, that the MacKerricher fossil site is part of a ~12 m terrace that was not identified except on one of the transects.

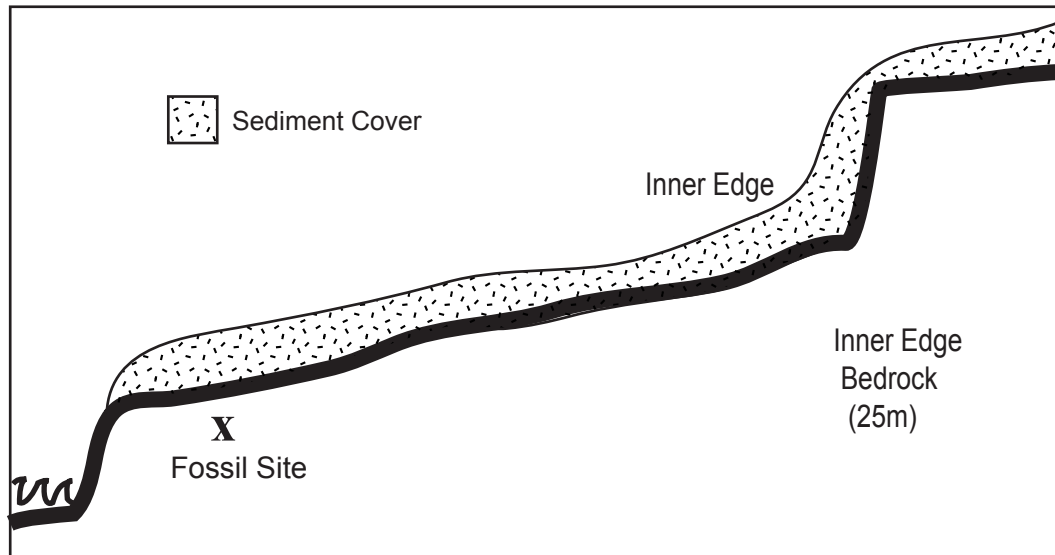


Figure 9B.

□ The more probable scenario in which the MacKerricher fossil site is part of the ~25 m terrace.

~25 m terrace (the broadest and most continuous in the Fort Bragg region) corresponds to the ~83 ka date. Third, a ~23 m terrace, 61 km south of Fort Bragg at Point Arena, contained two *Balanophyllia* corals that produced uranium-series ages of $76,000 \pm 4000$ yr and $88,000 \pm 2000$ yr (Muhs et al., 1994). This same ~23 m terrace at Point Arena also correlated to the ~83 ka highstand on the basis of faunal and amino acid data (Kennedy et al., 1982). The area around Point Arena contains terraces of relative spacing (Muhs et al., 2003) similar to the Fort Bragg region.

The ages of the two higher terraces were determined using the assumption of a constant uplift rate (Lajoie, 1986; cf. Orme, 1998; cf. Rockwell et al., 1989). By assigning the ~25 m terrace to the ~83 ka highstand, and assuming that sea-level at this point in time was around -20 meters below modern sea-level, this yields an uplift rate of 0.54 meters per thousand years. If this uplift rate was applied to the next two major highstands of ~108 ka and ~122 ka one would expect to see terraces with elevations of 40 m and 64 m respectively (Fig.10). Thus, the predicted terrace elevations vary from the actual average terrace elevations of 43 m and 59 m by three to four meters; however, it is important to remember the range in elevations of these terraces are 40 - 49 m, and 57 - 62 m. There are three possible explanations for this inconsistency between the estimated terrace elevation and the actual averaged terrace elevation. First, the sea-level curve is inexact in either age or magnitude. This is possible due to the variability and uncertainty associated with Quaternary sea-level curves. It is also possible the generalized sea-level curve doesn't adequately represent local variations. Second, inaccuracy associated with the field elevation estimates could partially be responsible for

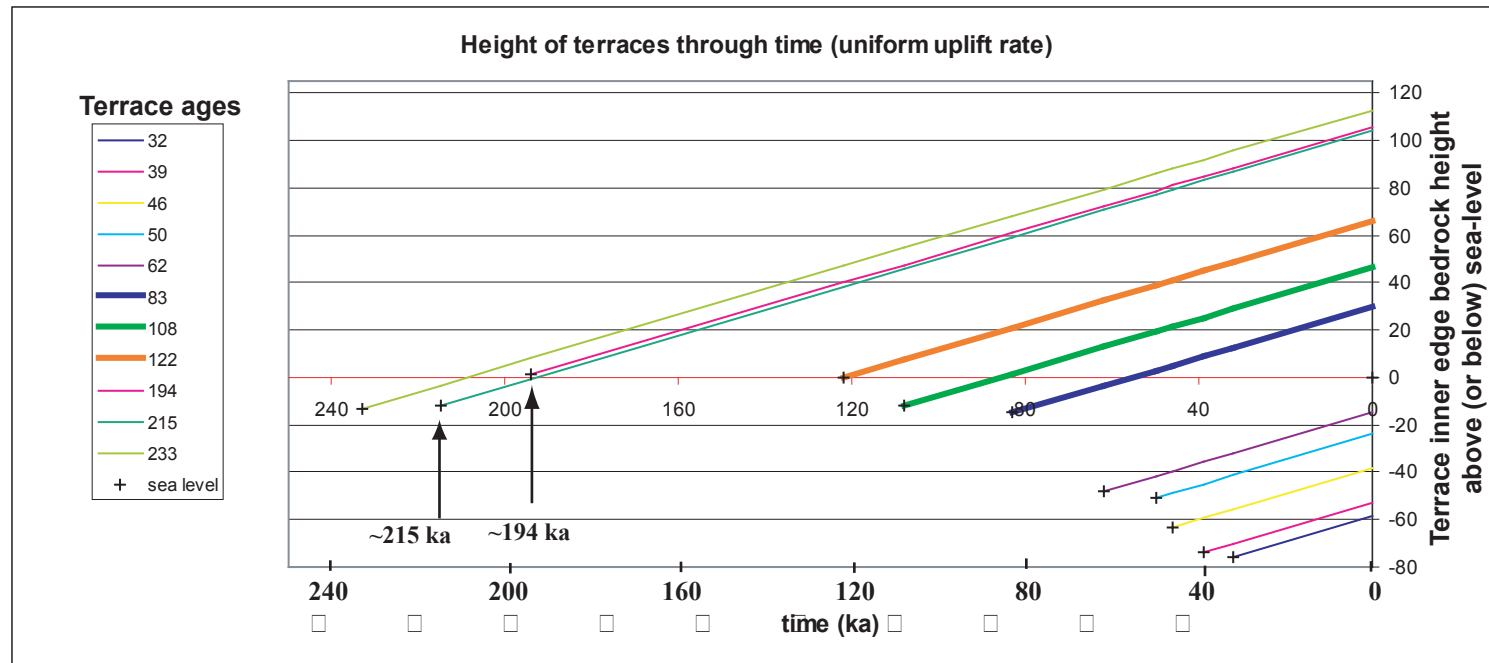


Figure 10.

□ If one assumes a uniform uplift rate of 0.54 and uses the Darter (2000) sea-level curve to pinpoint highstand ages and magnitudes, one can predict the current elevations of terraces formed during the highstands. The thick lines represent the three terraces in the Fort Bragg field area. The predicted elevations of the ~108 ka and ~122 ka terraces vary from the actual elevation by ~4 m. One can also predict which terraces will have been eroded by subsequent highstands. For example, a terrace which formed during the ~215 ka highstand would most likely not be seen in the field today, because the ~194 ka highstand would have eroded it.

the discrepancy. Third, it is possible that uplift is not constant. While it seems likely that the tectonic setting has remained relatively unchanged for ~125,000 years, local variation in fault geometry could affect the uplift rate enough at different points in time to make the assumption of constant uplift invalid.

Assuming that the sea-level curve is correct, and using the three prominent terrace elevations of ~25 m, ~43 m, and ~59 m, the average uplift rate of the marine terraces of the region is ~0.51 m/ka (Fig 11A). This is the most likely scenario; however, if the 12 m terrace (seen only in the Ocean View transect) represents a highstand, this will affect the age assignments and consequently the uplift rate. If a ~12 m terrace corresponds to the ~83 ka highstand, then the ~25 m highstand would most likely correlate to the ~108 ka highstand, and the ~43 m and ~59 m terraces would have been formed during the ~122 ka and ~194 ka highstands respectively (Fig. 11B). The average uplift for the region would then be ~0.33 m/ka. However, this scenario is considered unlikely for two reasons. First, the area around Point Arena contains three terraces of roughly the same spacing (~23 m, ~42 m, and ~64m) with a uranium-series date from the lowest terrace (~23 m) of ~83 ka. Second, the broadness and continuity of the ~25 m terrace around Fort Bragg make it unlikely that it was formed during the ~108 ka highstand which according to Muhs et al., (1994) and Orme (1998), is rarely preserved or only partially preserved.

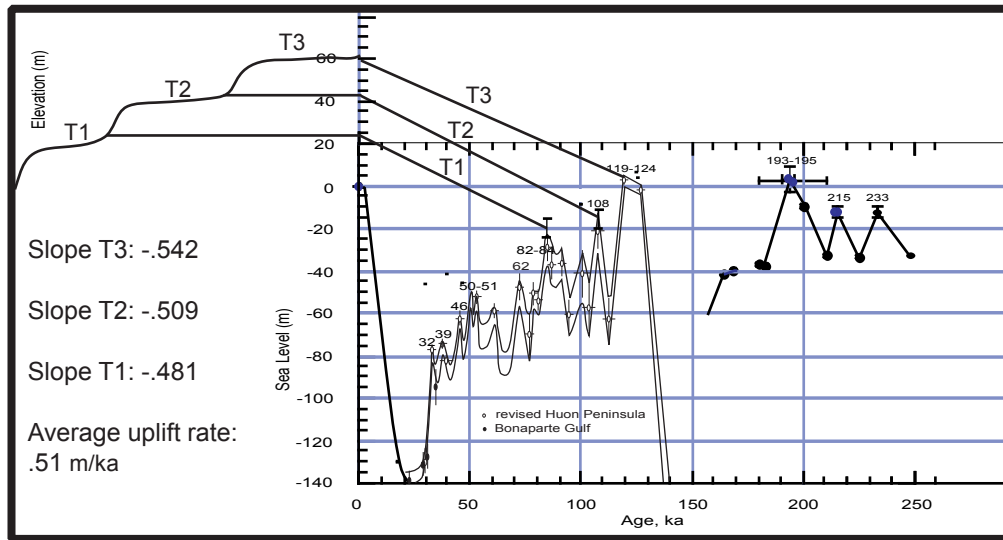


Figure 11a.

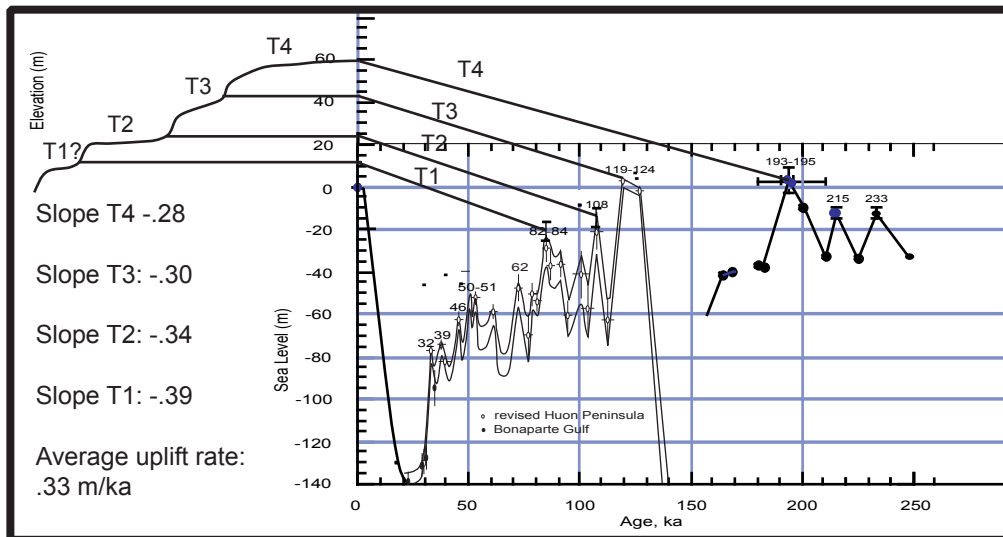


Figure 11b.

Sea-level curve modified from Darter (2000) indicates general highstand ages and magnitudes to correlate with terrace elevations, in order to determine an average uplift rate. The slope of the diagonal line connecting the highstand to the terrace inner edge elevation is the average uplift rate for that terrace. Refer to Lajoie (1986) for step-by-step method of constructing and interpreting these diagrams. Figure 11A shows the uplift rates assuming the three terraces of elevations ~25 m, ~43 m, and ~59 m represent the ~83 ka, 108 ka, and 122 ka highstands respectively. Figure 11B shows the less likely scenario in which there is a fourth ~12 m terrace which represents the ~83 ka highstand and the successive three terraces represent the ~108 ka, ~122 ka and 194 ka highstands.

Previous studies in adjacent areas:

Surveys of marine terraces approximately 10 kilometers south of the Fort Bragg region near the Mendocino Headlands have located four inner edge terrace heights at 20-24 m, 38-42 m, 58-63 m, and 83-89 m (Muhs et al., 2003). The first three inner edge heights correspond well to those in the Fort Bragg study area; however, some of the ages assigned to these terraces differ. Muhs et al. agree that the ~22 m terrace represents the ~83 ka highstand and base their correlation on the uranium-series coral dated on the ~23 m high terrace at Point Arena (51 kilometers south of their study area) (Fig. 1). Muhs et al (2003) propose that the ~42 m high terrace represents the ~122 ka sea-level highstand based on the previous studies they conducted in areas along the coast where the ~108 ka highstand was not preserved. Muhs et al, (2003) also proposes that the ~60 m terrace correlates with the highstand around ~200 ka. They loosely used the Shackleton and Opdyke (1976) sea-level curve to calculate a regional uplift rate around 0.3 m/ka. Using the Darter (2000) sea-level curve, their assignments would give uplift rates ranging from 0.29 m/ka to 0.54 m/ka, implying an extremely non-uniform uplift rate through time.

Additionally, Muhs et al. (2003) refute a study by Merritts and Bull (1989) of the same Mendocino area terraces in which the ~22 m terrace was assigned to the ~108 ka highstand, the ~42 m terrace to the ~122 ka sea-level high, and the ~60 m terrace to the ~210 ka highstand. Additionally, Merritts and Bull (1989) claim to have seen a ~10 m high terrace, which they correlate to the ~83 ka highstand. Muhs et al. (2003) take special note of this assertion to show that what was previously interpreted as the 10 m terrace is most likely just an outer edge erosional feature of the ~22m terrace. The

uncertainty in the Mendocino area has prompted the current study underway by David Trench, a member of the 2004 Keck Geology Consortium program from Colorado College.

Merritts and Bull (1989) also studied the region 15-70 km north of Fort Bragg where terrace elevations and uplift rates seem to increase with proximity to the Mendocino Triple Junction; there are however no absolute dates for terraces in this area. Using predominantly the Chappell and Shackelton (1986) sea-level curve they calculated an approximate uplift rate of 0.4 m/ka for an area just 3 km north of the Fort Bragg study area with terraces of ~10 m, ~25 m, ~45 m, and ~65 m. They also calculated an uplift rate of 1.2 m/ka for an area 50 km north of the fort Bragg study area. They associate this drastic increase in uplift rates to the north is with the migration of the Mendocino Triple Junction. As the triple junction has migrated northward it appears to have caused increased uplift rates near its local (Merritts and Bull, 1989). However, the amount of time since the triple junction passed the Fort Bragg region is more than enough to have resulted in the complete degradation of associated terraces (Merritts, pers. comm.).

While the uplift rate calculated in for the Fort Bragg study area of 0.51 m/ka is higher than those calculated for the immediate surrounding areas (0.3 m/ka to the south and 0.4 m/ka to the north) it is important to remember that these calculations involved correlations based on slightly different sea-level curves, and that the general terrace elevations of the surrounding regions are quite similar the those seen in Fort Bragg.

CONCLUSION

The region around Fort Bragg contains a valuable record of Quaternary tectonics, sea-level changes, and geomorphic processes. The ~23 km section of coast from Kibesillah Rock to the mouth of Jug Handle Creek, contains three relatively prominent and undeformed marine terraces of elevations ~25 m, ~43 m, and ~59 m. While the age assignments of these terraces remain somewhat tentative awaiting the completion of uranium-series dating of coral from the lowest terrace, there is strong evidence to suggest the three terraces represent the ~83 ka, ~108 ka, and ~122 ka highstands. These correlations provide an average uplift rate of 0.51 m/ka. Future research in the area should focus on the possible presence of a ~12 m terrace which would have a considerable effect on the age correlations and subsequently the uplift rate.

Synthesis of previously published studies, with the results of the 2004 Keck project, will hopefully help elucidate the mechanisms controlling uplift rate and aid in a better understanding of the nature of crustal deformation along the San Andreas Fault.

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