Vertical and lateral displacement of marine terraces near Alder Creek, Mendocino County, California

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INTRODUCTION

The Quaternary marine terraces near Alder Creek in Manchester, CA have been disrupted by the San Andreas Fault (SAF) and displaced both vertically and laterally. Located in Mendocino County in northern California, Manchester is the site of the northernmost trace of the SAF on land before it reemerges for a short distance in Shelter Cove, CA. The four terraces surveyed are located along the last 5km stretch of the SAF, just before it goes offshore at Alder Creek (Refer to Figure 1). The combination of eustatic sea level changes throughout the Quaternary and tectonic uplift created the flight of terraces. Coral found in the lowest terrace, Quaternary marine-terrace 1 (Qmt 1) of Prentice (1989) have yielded Th/U ages of 76+/-4ka (Muhs, *et al.* 1992) and 88+/-2ka (Muhs, *et al.*, 1994) These ages appear to place Qmt 1 in the O^{18} isotope stage 5a sea-level highstand (80-83ka).

Previous work has been done to date the terraces at Manchester, using morphological evidence and terrace elevations (Prentice, 1989). Merritts and Bull (1989) have devised a method of extrapolating coastal uplift rates with sea-level highstands to predict the current altitudes of terraces. By making the assumption of constant uplift rates, the ages of the next three terraces were estimated by Prentice (1989), as follows: Qmt 2 - 103ka (5c), Qmt 3 - 133ka (5e), and Qmt 4 - 214ka (7a) (Prentice, 1989). Recent work has suggested the date for 5e and 7a of 124 ka (Chappell, J. and Shackleton, N.J., 1986) and 195ka, (Martinson, D.G., et. al., 1987) respectively. I used the same assumption that terrace heights were a function of age and paleosea-levels, however, new data attained with GPS surveying and revisions of the global sea-level curve suggest alternate ages for the terraces.

METHODS

In the field, I investigated the territory in three principal phases. The first phase was a reconnaissance, determining if the morphology and the sediments were representative of uplifted wave-cut terraces. Secondly, I mapped the area onto the 7.5' quadrangles and/or aerial photos. Lastly, these areas were then surveyed with GPS equipment. Processing the data involved numerical modeling with the terrace heights and uplift rates. The height of each terrace was measured along the inner edge, the highest extent of wave-cutting during a sea-level highstand. In the area northeast of the SAF (Area 1) as well as the southwest portion (Area 2), the uplift rates were calculated by dividing the total uplift (the height of the terrace minus the paleosea-level) by the accepted age. This uplift rate was then projected through the various highstands throughout the late Pleistocene to determine what terrace elevation would be anticipated. In the case of the 5a highstand, though, there is much disagreement regarding the sea-level elevation. While Gallup, *et al.* (1994) estimated an elevation of -15.5m, there are also estimates as high as 1.5m (Ludwig, *et al.*, 1996). To compensate for this fact, rates were calculated assuming the two different paleosea-levels. In addition, the uplift rate was also calculated using age-estimations for the third terrace.

While the elevations were used to estimate uplift rates and ages, the lateral position of the terraces was used to determine lateral slip rates. The point along a terrace where the inner edge is intersected by the SAF is called the piercing point. The uplift rates were found by simply dividing the distance along the SAF by their proposed ages.

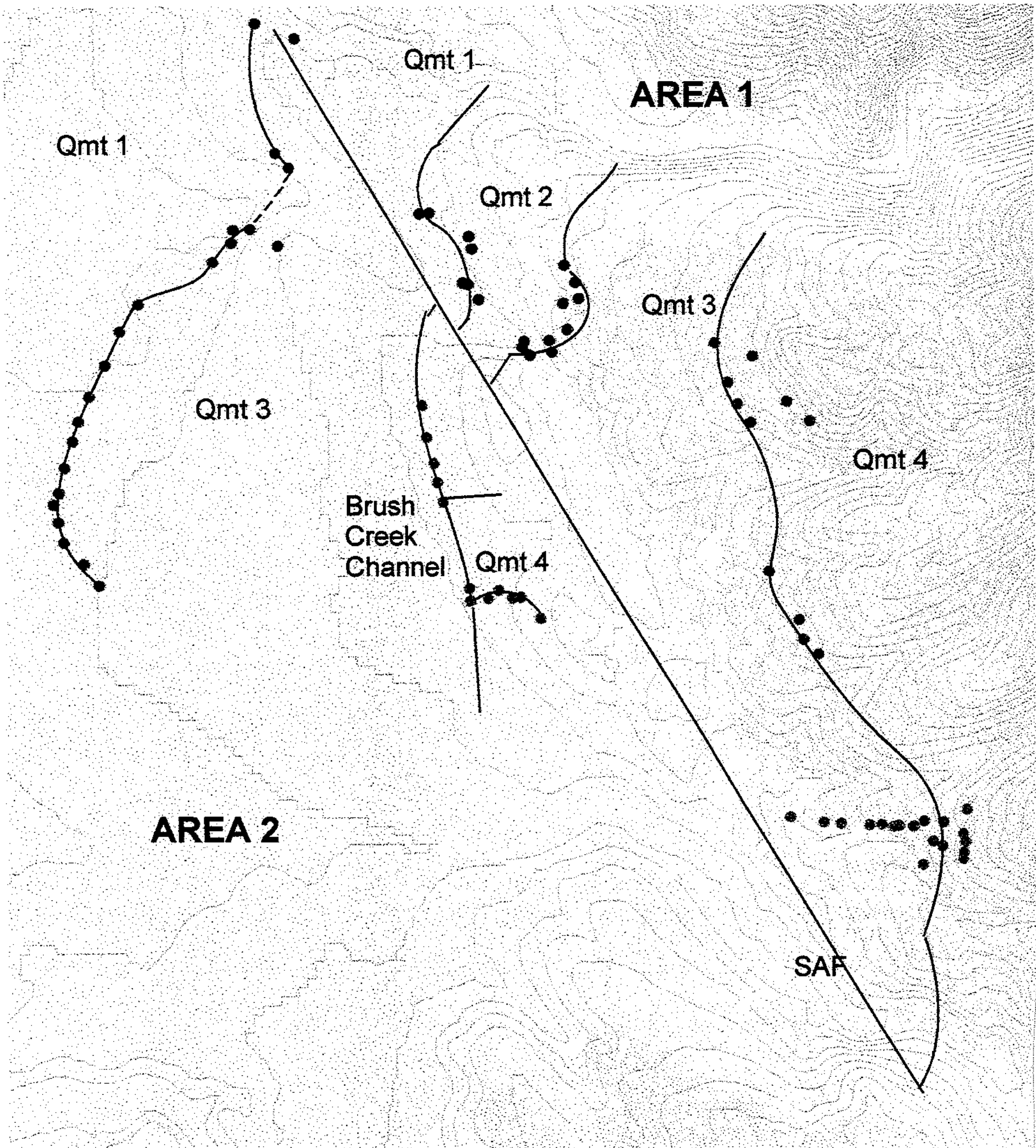

Figure 1: Map of Manchester with the terraces and piercing points. The Brush Creek channel piercing point is also identified in Area 2, although ithe modern day creek is located to the southeast.

RESULTS

Area 1: In the field, the average inner edge elevations of the marine terraces were found to be 42m, 71m and 115m for Qmt 1, 2 and 3, respectively. Insufficient data was available for Qmt 4. Anticipated terrace elevations were calculated for Area 1 with five models. First, it was assumed that the age of Qmt 1 is 83 ka. The two paleosea-levels, -15.5m (PSL1) (Gallup, *et al.*, 1994) and 1.5m (PSL2) were factored in, predicting the following heights:

O^{18} isotope stage	Age	Uplift rate (PSL1)	Height	Uplift rate (PSL2)	Height
5a (Qmt 1)	83ka	.68mm/yr.	42m	.47mm/yr.	42m
5c (Qmt 2)	103ka	.68mm/yr.	60m	.47mm/yr.	39m
5e (Qmt 3)	124ka	.68mm/yr.	90m	.47mm/yr.	65m

PSL1 does not predict elevations that are very reasonable compared to the field evidence. The Qmt 2 estimate is too low by 11m, and the Qmt 3 estimate by 25m. PSL2 predicts even lower heights, yielding an elevation that is 50m off. Also, if Qmt 2's elevation (39m) was lower than Qmt 1's (42m), it would have been destroyed by Qmt 1's formation. These results, along with the inconsistencies in the 5a elevation, prompted me to try an older age for Qmt 3 - 195ka, the date of the 7a highstand. The elevations it predicts are listed below:

O^{18} isotope age	Age	Uplift rate	Height
5a (Qmt 1)	83ka	.58mm/yr.	33m
5e (Qmt 2)	124ka	.58mm/yr.	78m
7a (Qmt 3)	195ka	.58mm/yr.	115m

In this model, the predictions are within 9m for both Qmt 1and 2.

Area 2: Southwest of the fault, the terraces that I mapped had lower elevations than their counterparts in Area 1. The inner edge elevations of Qmt 1 and Qmt 3 are 20m and 48m, respectively. Qmt 2 was either absent or undetectable in the field. The predicted elevations are listed below.

O^{18} isotope stage	Age	Uplift rate	Height w/alt.correction
5a (Qmt 1)	83ka	.23mm/yr.	20m
5e (Qmt 3?)	124ka	.23mm/yr.	35m
7a (Qmt 3?)	195ka	.23mm/yr.	47m

As in Area 1, the age of 195ka predicts a more uniform uplift rate, and hence, a more reasonable age estimate.

Lateral Displacement: Two terrace piercing points were identified in the study area - the piercing points between Qmt 1 and Qmt 3. In addition, the remnants of an old river channel were located at the inner edge of Qmt 3. This 300m-wide channel was correlated with the modern day Brush Creek, which has been diverted by movement along the fault (Refer to Figure 1). Using both terrace age models, I used the displacement of the piercing points to calculate the following SAF slip rates:

Piercing point	Distance	Age #1	Slip rate	Age #2	Slip rate
Qmt 1	1300m	83ka	16mm/yr.	83ka	16mm/yr.
Qmt 3	2750m	124ka	24mm/yr.	195ka	15mm/yr.
Brush Creek	3000m	124ka	23mm/yr.	195ka	14mm/yr.

When using model 1, the slip rates for Qmt 3 and Brush Creek are inconsistent with that found for Qmt 1. If the slip rate since 83ka is 16mm/yr, then the slip rates prior to 83ka were drastically different in this model. In the period from 124ka to 83ka, the slip rate would have to have been 35-41mm/yr. for Qmt3 and Brush Creek to be in their present position. In model 2, however, the rate from 83ka to 195ka would have been 13-15mm/yr. The magnitude of such a decrease in slip rate in model 1 also suggests that the age of Qmt 3 is 195ka.

CONCLUSIONS

The numerous models detailed above do not mesh to form one incontrovertible model of coastal uplift. Neither model 1 nor model 2 can satisfy the elevations that are found in the field. In model 1, however, it is quite clear from the low Qmt 3 elevations that an age older than 124ka is required for Qmt 3 - an age of 195ka is more likely. In model 2 where this age is assumed, there are still inconsistencies present. In the case of the Qmt 1 height, however, the elevation was calculated using the lowest 5a paleo-elevation (-15.5m) (Gallup, *et al.*, 1994). Research in Florida and Bermuda has yielded a paleosea-level of -8m (Ludwig, *et al.*, 1996) - such an estimate would make the anticipated terrace elevation match the actual elevation.

In regards to the uplift rates calculated in Area 2, the data would seem to suggest that an earlier age for Qmt 3 is more appropriate. It is important to note, however, that the area in which the Qmt 1 terrace elevation was recorded in an area of considerable drainage. Nearby outcrops along the shore displayed several meters of alluvium/ colluvium on top of bedrock. Had it been possible to calculate the depth of bedrock in the field, the elevation surely would have been lower and have produced a lower uplift rate. The inaccuracies due to the overlying sediments make it difficult to make conclusions about this perplexing area. Nonetheless, the model that seems to satisfy the field evidence the most indicates the following ages: Qmt 1 - 83ka, Qmt 2 - 124ka, Qmt 3 - 195ka. The SAF slip rates are in accordance with the age designations as well, if we assume a constant slip rate model (model 2). The change in slip rate with model 1 between 124ka and the present is substantial, but not impossible. The estimation of 23-24mm/yr. is in relative accordance with Prentice's (1989) estimation of 16-22mm/yr. since 124ka..

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