Deformation of the western edge of the North American plate in proximity to the San Andreas fault in north-central California as recorded in late Quaternary marine terraces

Charles Hampton
Department of Geoscience, Trinity University, 715 Stadium Dr. San Antonio, Tx 78212
Faculty Advisor: Thomas W. Gardner, Trinity University

INTRODUCTION

A transform boundary exists along the coast of California between the North American and Pacific plates. Much of the plate movement along the boundary is accommodated along the San Andreas fault, the most extensive of several fault systems along the transform boundary. The San Andreas traverses the length of southern and central California, and terminates at the Mendocino triple junction where the Pacific plate abuts the Gorda plate as it subducts under North America (See fig 1, Merritts, this volume). Along its southern length the San Andreas sits to the east of the continent's edge, but just to the south of San Francisco the fault turns off shore. For the next ~400 km to the north the fault's path alternates between onshore and offshore terrain. At a point ~150 km north of San Francisco, CA, the San Andreas fault path returns to land where it remains for ~40 km before heading offshore again. The area to the west of this boundary, known as the Gualala block, is an emergent section of the pacific plate. At the northern terminus of the Gualala block, the San Andreas bends from a northwest trending, linear path, toward a slightly more northerly trend as it heads out to sea. Localized uplift has been observed on the edge of the North American plate just to the north of the plate boundary represented by Alder Creek (fig. 1).

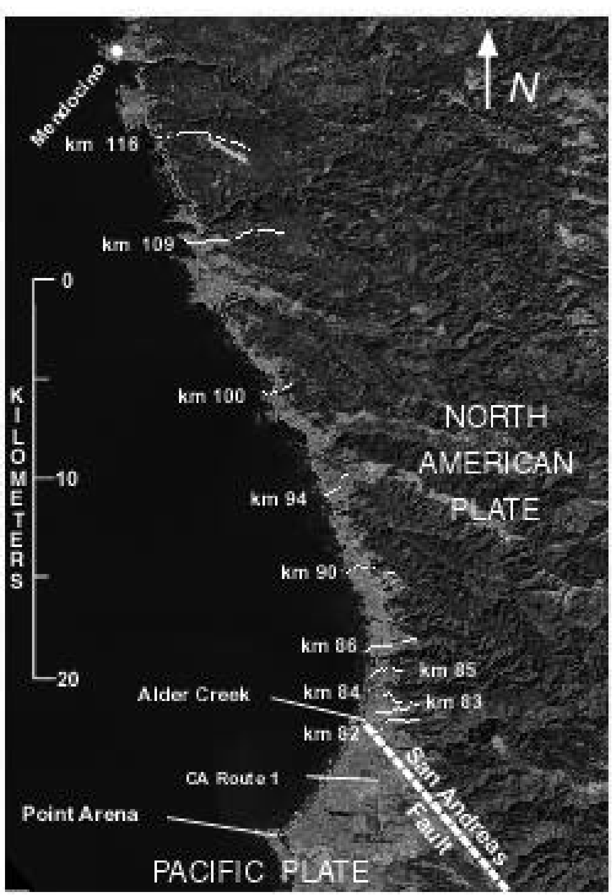

Figure 1. Study area showing positions of transects (km marks and solid lines) and the San Andreas fault. The transform boundary is located as it leaves shore by the mouth of Alder Creek.

Coastal uplift is a useful indicator of Quaternary (past 2 million years) crustal deformation on both local and regional scales (Hanson et al, 1994). Uplift is preserved in paleowave-cut platforms known as marine terraces, which extend laterally along a coastline. Marine terraces not only record vertical tectonic movements but also Quaternary changes in eustatic (global) sea level. Terraces observed today on the California coast preserve highstands from periods of minimum glaciation throughout the late Quaternary, as well as those fluctuations since the most recent glacial advancement (Lajoie, 1986; Hanson et al., 1994). Detailed mapping of marine terraces between the town of Mendocino and the boundary between the North American and Pacific plates represented by the mouth of Alder Creek (fig. 1) helps constrain the spatial variation in Quaternary uplift rates in the study area. It is hypothesized that a slight restraining bend along the San Andreas fault causes localized uplift just to the north of the transform boundary.

CORRELATION OF TERRACES AND SEA LEVEL HIGHSTANDS

Ten transects covering ~35 km of coast (fig.2) provide elevations of relict wave-cut platforms formed by sea level highstands during the Quaternary. Data were collected using a Pro XRS Global Positioning System (GPS) receiver made by Trimble. The instrument received a real time correction signal (broadcast by the US coast guard) that increased its vertical precision to ± 1m and its horizontal precision to a sub-meter level Platform inner edge elevations were correlated to sea level highstands plotted on the eustatic sea level curve compiled for this project (Darter, this volume). Terrace correlation assumes a constant rate of uplift at any given transect. Terraces were correlated to the 80, 125, 195, 290, 330, and 410 ka sea level highstands (fig.2) based on an assumption of a uniform uplift rate, and guided by correlations done to the north of the study area by Merritts and Bull (1989). Once terraces had a date assigned to them they were correlated between adjacent transects along the coast, and uplift rates at each transect were calculated. To determine an uplift rate, elevations of high stands were subtracted from the elevation of the terrace inner edge and the difference in elevation was plotted against the age assigned to the terrace. This is represented by the equation:

$$U = \frac{y_1 - y_2}{t} \qquad (1)$$

Where U is uplift rate, y_1 is present terrace elevation (m), y_2 is total uplift terrace uplift since formation (m) and t is the age of the terrace (ka).

Uplift rates at most transects are consistent with uplift rates calculated by Kennedy et al., (1982) on terraces along the coast of California, Oregon, and Washington. The exception was the uplift rate at transect km 82 and 83 (fig. 3), which was 1.0 m/ka (on the order of three times the rate of 0.3 m/ka that was determined for the other transects). Increased uplift is very localized, extending only 1-3 km from the boundary. The uplift rate at transect km 82 and 83 confirmed the study's hypothesis that greater than normal uplift was occurring in relation to the restraining bend on the transform boundary.

CONCLUSIONS

Uplift accompanies right lateral movement in localized areas along the transform boundary between the North American and Pacific plates. Ten kilometers north of the town of Point Arena, California, a localized zone of uplift sits adjacent to the San Andreas fault. Tectonic activity may be causing the extraordinary uplift at the North American plate boundary at Alder Creek. A localized kinematic (pure motion) analysis of the San Andreas fault implies a restraining bend in the Point Arena area. Ellsworth (1991) explains that transform boundaries accommodate lateral translation between two rigid plates. Plate convergence and divergence will not occur as long as the transform boundary does not deviate from a small circle azimuth of the pole describing relative plate motion. When deviation from the small circle path does occur, such as by a bend in the transform boundary, plate convergence or divergence occurs. On a right lateral fault such as the San Andreas, counter-clockwise bends cause convergence and thus compression – clockwise bends, such as the one at Alder Creek, cause divergence and thus extension.

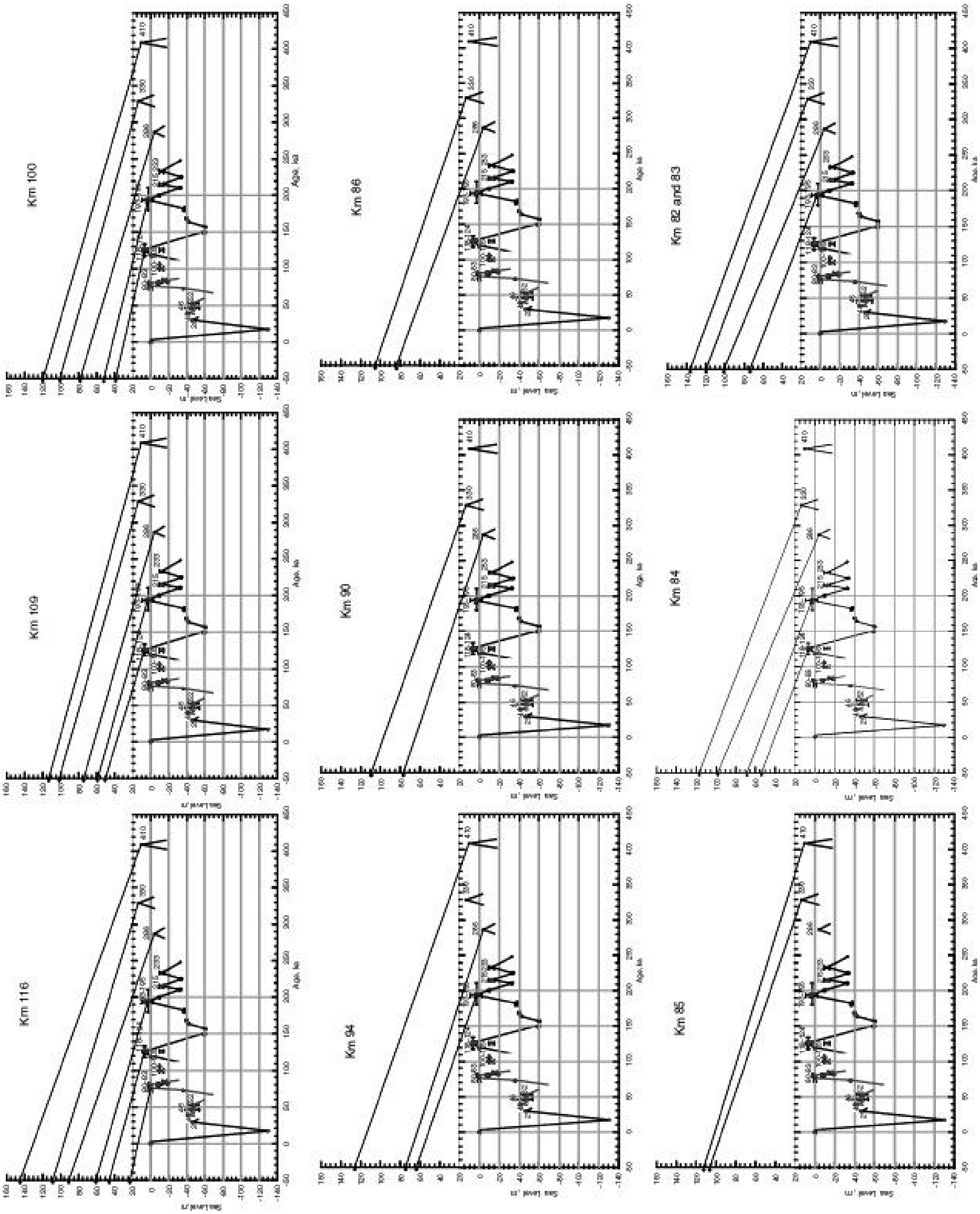

Figure 2. Correlation of terrace inner edge elevations to eustatic sea level curve for all transects. Sea level highstands 0 - 233 compiled by Darter (this volume). Highstands 286, 330, and 410 estimated from oxygen isotope ratio curve (Pirazzoli et al., 1991). Tie lines connect inner edge elevations for each transect to its proposed elevation and age of formation. Correlation assumes a constant uplift rate.

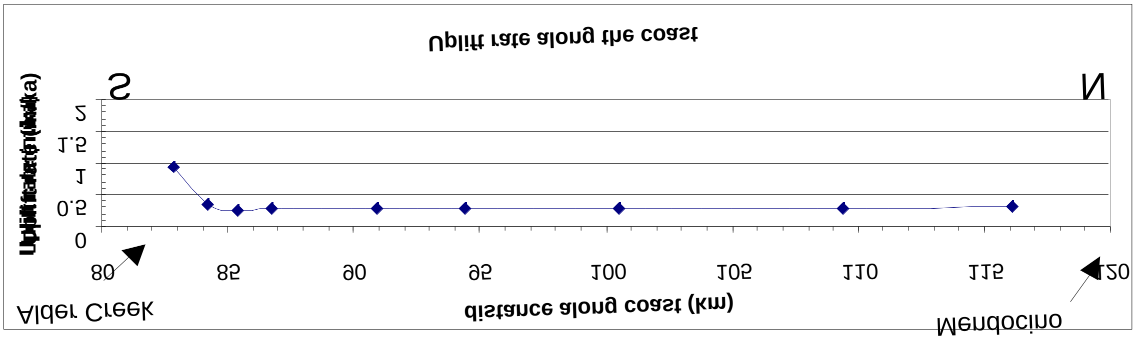

Figure 3. Plot showing uplift rate at each transect in the study area.

Bilham and King (1989) developed several models to better understand strain caused by transform boundaries. One model, which shows extension and compression associated with a clockwise restraining bend, offers an explanation of the increased uplift just to the north of the transform boundary at Alder Creek. The lowlands to the south of Alder Creek may be an extensional basin. The rapid topographic change observed when crossing the plate boundary at Alder Creek may be the transition from areas of extension to areas of compression. The most intense compression in the model seems to fit over the extraordinary uplift determined in the study. Without a detailed structural analysis of the area the model should not be taken for anything more than a hypothesis.

This study focused on the analysis of marine terraces and therefore was restricted to within ~ 2 km of the coast. Within that constraint, higher than normal uplift extended only one to three kilometers. To better understand the extent and cause of deformation associated with the transform boundary it will be necessary to extend the analysis inland and further south along the fault.

REFERENCES CITED

Bilham, R. and King, G., 1989, The morphology of strike-slip faults: Examples from the San Andreas fault, California: Journal of Geophysical Research, vol. 94, no. B8, p. 10,204-10,216.

Darter, J., Eustatic sea level curve compilation: This volume.

Ellsworth, W., 1991, Putting the pieces together: Nature, vol. 349, p 371-372.

Hanson, K., Wesling, J., Lettis, W., Kelson, K., and Mezger, L., 1994, Correlation, ages, and uplift rates of Quaternary marine terraces: South central coastal California, *in* Alterman I., McMullen, R., Cluff, L., Slemmons, D., eds., Seismotectonics of the Central California Coast Ranges: Boulder, Colorado, Geological Society of America Special Paper 292, p. 45-71.

Kennedy, G., Lajoie, K., and Wehmiller, J., 1982, Aminostratigraphy and faunal correlations of late Quaternary marine terraces, Pacific coast, USA: Nature, vol. 299, p. 545-547.

Lajoie, K., 1986, Coastal tectonics, *in* Wallace, R., ed., Active tectonics: National Academy Press, Studies in Geophysics Series, Geophysics Research Forum, p. 95-124.

Merritts, D. and Bull, W., 1989, Interpreting Quaternary uplift rates at the Mendocino triple junction, northern California, from uplifted marine terraces: Geology, vol. 17, p. 1020-1024.

Merritts, D., This volume.

Pirazzoli, P., Radtke, U., Hantoro, S., Jouannic, C., Hoang, C., Causse, C., Borel, and Best, M., 1991, Quaternary raised coral-reef terraces on Sumba Island, Indonesia: Science, vol. 252, p. 1834–1836.