Locating the active trace of the northernmost San Andreas fault and analyzing the surface uplift and deformation produced by it, Point Delgada, California

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INTRODUCTION

The area near and surrounding Point Delgada was chosen because it is affected by some of the highest rates of crustal deformation, surface uplift, and seismic activity in North America due to its immediate proximity to the northermost San Andreas Fault and the juncture of the North American, Pacific, and Gorda Plates (figure 1). This juncture is known as the Mendocino triple junction.

Point Delgada, CA, is a low, broad, nearly planar, seaward-sloping headland located on the coast 80 km south of Eureka and about 45 km southeast of Cape Mendocino (figure 2). Eroded bedrock at the point forms a surrounding skirt of Pleistocene wave-cut marine platforms that are overlain by Quaternary rounded marine cobbles and fluvial sediments. The platforms are ideal for analyzing surface uplift because their inner-edges form a datum that is horizontal with respect to the earth's geoid at the time of formation. The surrounding rugged coastal terrain is composed of the highly fractured Tertiary rocks of the Franciscan Complex.

This project has two principal objectives. The first is to identify, map, and constrain the location of the active trace of the northernmost San Andreas fault. The second is to define the pattern of surface uplift and deformation along the fault's termination just north and south of Point Delgada.

METHODS

Mapping

Locating and mapping this section of the San Andreas was performed using field reconnaisance combined with analysis of low-altitude, low sun-angle photographs, historical aerial photographs, topographic maps, and most importantly, photographs and maps of the Point Delgada area produced by Francois Matthes, a topographer for the United States Geological Survey (USGS), who visited Point Delgada a few weeks after the historic 1906 San Francisco earthquake. Strike-slip faults, scarps, shutter ridges, and offset stream channels are fault-related features that were identified. Constraining the location of the fault trace was accomplished by detailed trench logging and kinematic bedrock analyses on areas both east and west of the main fault trace.

Surface Uplift Rates and Deformation of Wave-cut platforms

Patterns and rates of surface uplift were determined from detailed total geodetic station surveying of Holocene and Pleistocene marine wave-cut platforms around Point Delgada and about 10 km to its north and south. The goal of a good survey is to obtain a collection of points in one coordinate system that provides an accurate representation of platform area and elevation. Together with an adequate collection of organic material (pholad shells, tree debris) on top of the platforms for radiometric dating, platform elevations and ages are determined. After extensive correction of the survey data, correlation of all points to relative mean sea level, and radiometric dating of the organic material, local uplift rates can be calculated with correlation to global sea level curves. Inner edges of datable terraces on coastlines with constant rates of uplift have been cross-referenced with changes in oxygen isotope ratios in foraminifera from deep-sea sediments to compile a record of sea level fluctuation (sea level curve) of the past 240 ka (Chappell and Shackelton, 1986). For a record of platforms >40 ka in age to exist above the current sea level, it is estimated that uplift rates of at least 0.5 m/ky are needed to outpace simultaneous sea level rise (Ota, 1986), while a record of Holocene platforms (< ~7 ka) requires an even greater uplift rate, estimated to be at least 1.5 m/ky (Merritts, 1996).

To define the nature of past and present platform deformation, bedrock fault orientations and their characteristics were recorded in the three survey areas as well as farther inland, east of the main fault trace. This work also was compared to 3-D boundary element modeling, which allowed comparison of not only uplift rates, but also the general location of the San Andreas by generating deformation patterns based on different fault locations. Using this technique, two models were generated, one using an offshore location of the San Andreas fault and the other using an onshore location similar to the one mapped during this project. The offshore model produced an unfamiliar deformation pattern as well as uplift rates one order of magnitude too small, while the onshore model corresponded closesly with our field observations.

LOCATION

Trending back onshore just north of Deadmans Gulch, the active trace of the San Andreas continues northward into the King Range mountains for at least 13 km along a N 1-37° trend (figure 3). This project was responsible for mapping the fault north of Telegraph Creek, which is about 2 km north of its intercept with the coastline. Using the Matthes maps for identifying areas to concentrate investigation, an approximate 8 m right-lateral offset of Telegraph Creek and its steep banks along a ~N 15° W trend was disovered. Rising from the creek, an obvious scarp climbs the southern face of Telegraph Hill trending ~N 13° W. On top of Telegraph Hill, a 2-10 m-wide depression trending ~N 3° W is aligned with a line of springs crossing Kaluna Canyon to the north, which in turn, connects to a slightly larger N-S depression crossing the Kaluna Ranch. About 4 km north of Telegraph Hill, there is a disturbed E-W trending ridgeline that is followed by N-S trending scarp with a 0.5-1.5 m vertical headwall. Continuing to the north towards Saddle Mountain, there is a lineation of distrupted E-W ridgelines that appears as a shutter ridge in low-altitude, low-sun angle black-and-white photography. This lineation terminates at a distictive notch, common in strike-slip fault topography, in which there is a small fault oriented N 31° W, 86° NE with slickenlines trending S 34° E, 25° and N 34° W, 14°. Approximately 2 km north of the notch, there is a small strike-slip fault oriented N 9° W, 74° SW with one set of lineations measuring S 57° E, 7° extending the entire 10 m height of a Kings Range Rd. roadcut. Connecting these structural and geomorphic features on a topographic map gives a trace trending ~N 13° W, approximately 13 km length.

HISTORY OF FAULTING

The history of faulting in the Point Delgada area can be categorized into three separate episodes based on fault characteristics and orientation. The oldest episode is recorded by reverse faults with mineralized gouge zones formed during deformation associated with the Cascadia subduction zone more than 1-2 m.y. ago. The next episode of faulting, less than 1-2 m.y. ago, produced reverse faults with moist gouge zones and no mineralization that represent deformation that occurred at the leading edge of the San Andreas fault propogating ~5 cm/yr (Castillo and Ellsworth, 1993). Young, high-angle right-lateral and reverse-oblique faults representing deformation caused by the active trace of the San Andreas fault represent the most recent episode of faulting.

SURFACE UPLIFT AND DEFORMATION

Uplift in the Whale Gulch area is defined by one or two raised wave-cut platforms >47 ka and <83 ka in age (figure 1). Their deformation appears as one broad, low-amplitude syncline approximately 2 km in length with very few platform inner-edges exposed in the mountain front. If the age constraints are correct, the maximum uplift rates are 0.6-0.7 m/ky.

An assigned age of 53 ka for one platform at Point Delgada radiometrically constrained to be >47 ka gave the best sea level/platform elevation correlation for that area (figures 4 & 5). The 53 ka highstand was 30 meters below current sea level, and the constrained platform is 3.67 meters above sea level at its southern end, therefore the net uplift of the platform since 53 ka has been 33.67 meters. This yields an uplift rate of 0.63 m/ky. At the northern end, the constrained platform is 4.68 meters above sea level, yielding an uplift rate of 0.65 m/ky. Uplift rate differentials provide an approximate tilt rate for Pt. Delgada of 0.04 °/ ky.

If the tilt rate estimated above is constant, one would predict Holocene emergence (uplift rate > 1.5 m/ky) to occur almost 60 km north of Pt. Delgada. However, a Holocene platform has been observed less than 10 km north of Pt. Delgada near Gitchell Creek. Therefore a significant, rapid change in uplift must occur between Pt. Delgada and Gitchell Creek. This necessary rise in uplift is geographically consistent with a significant rise in surface topography, the King Range Mountains.

Holocene platforms are first seen less than 10 km north of Point Delgada and continue until the south side of Big Flat (figure 1). Art Bloom has shown that Holocene platforms require uplift rates >1.5 m/ky; therefore this is the minimum uplift rate for the two prominent 3090-3240 B.P. to 340-500 B.P. Big Flat area platforms, with a maximum near 4.0 m/ky.

CONCLUSIONS

With the transfer of northerly San Andreas shear motion onto the westerly Medocino fracture zone only 25 km to the north, the area north of Point Delgada and south of Punta Gorda could be better defined as a process zone translating shear motion, than by one or two major strike-slip faults found in older sections of the San Andreas. The main active fault trace is now mapped onshore from discovery of the following features: 8 m of right lateral offset of Telegraph Creek stream channel, a prominent line of springs at the head of Kaluna canyon, an east-facing scarp and shutter ridge north of Horse Mountain, and two exposures of a youthful vertical fault with horizontal slip indicators crossing prominent saddles and notches on the eastern flank of the King Range.

Surface uplift and deformation can be summarized by an increase of uplift rates more than one order of magnitude over 15 km north from Whale Gulch to Big Flat. This increase in surface uplift rates is evidenced by

Pleistocene platforms south from Point Delgada, and emergant Holocene just north of Point Delgada to Big Flat with rates as high as 4 m/ka.

Faulting in the Point Delgada area can be sumarized by three episodes: 1) reverse faults associated with the Cascadia subduction zone formed more than 1-2 m.y. ago, 2) reverse faults representing the deformation that occurred at the leading edge of the San Andreas fault propogating ~5 cm/yr formed less than 1-2 m.y. ago, and 3) young, high-angle right-lateral and reverse-oblique faults representing deformation caused by the active trace of the San Andreas fault formed most recently.

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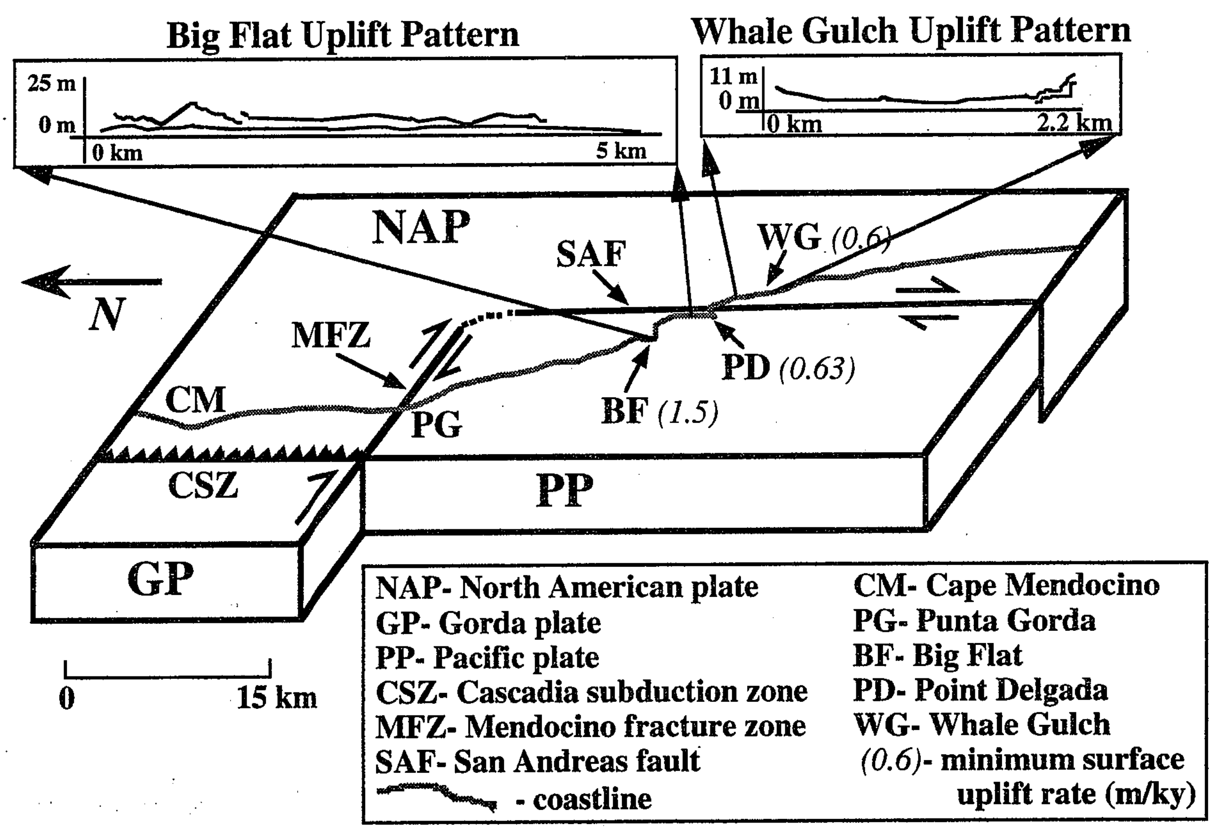
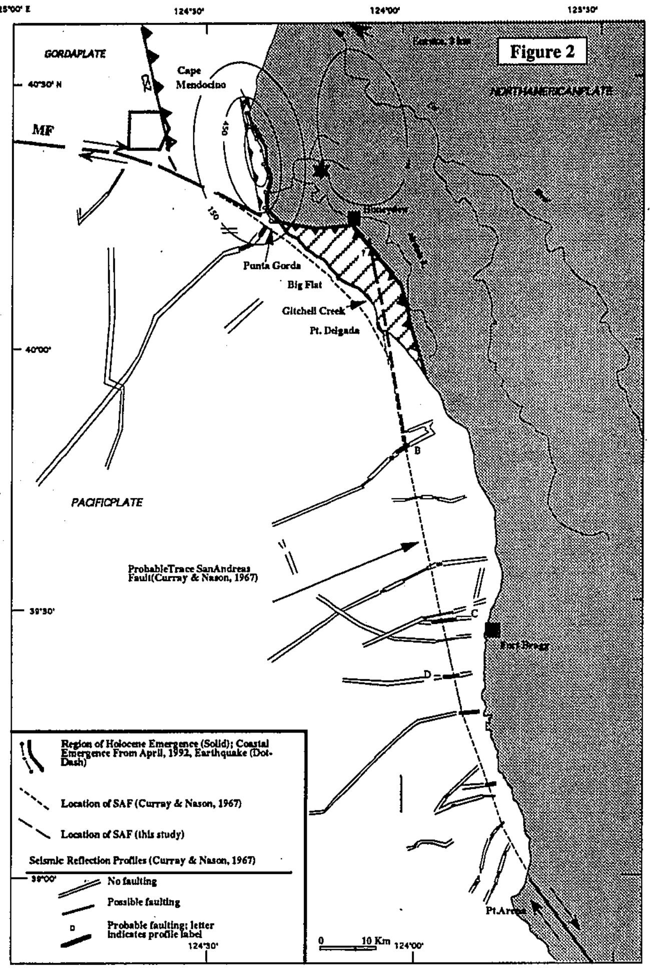


Figure 1. Tectonic plate configuration of the Mendocino triple junction, including the "Lost Coast" of the northern California coastline. Surface uplift rates are included and are increasing to the north as you near the triple junction. Notice the different rates and patterns of uplift on different sides of the San Andreas. The 1906 event resulted in uplift on the land west of the fault north of Point Delgada, which would correspond to greater uplift near Big Flat.

Figure 2. Map showing Gorda, Pacific, and N. American plate configuration and the trace of the San Andreas north of Point Arena. Offshore fault location was determined using seismic reflection profiles (Curray and Nason, 1967). Areas of coastal emergence are also shown in relation to recent earthquake epicenters.



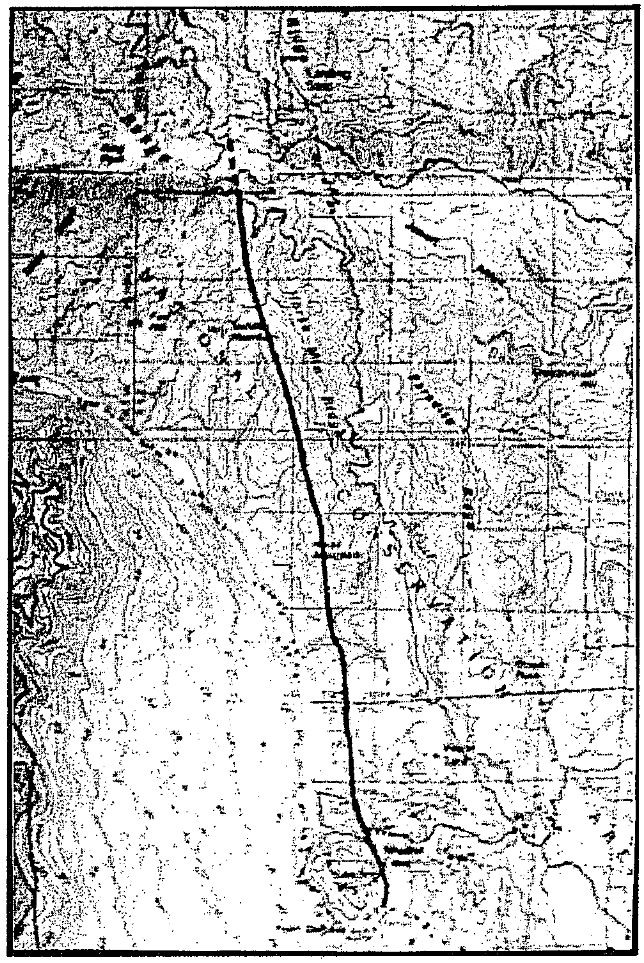


Figure 3. Topographic map showing the interception of the active trace of the San Andreas with the coastline at Point Delgada, just north of Deadmans Gulch. The trace trends ~N 13° W as it slices through the King Range. The map was created by linking structural and geomorphic features discovered during field reconnaisance aided by low-altitude, low sun-angle photographs, historical aerial photographs, and field maps produced by Francois Matthes only only weeks after the 1906 San Francisco earthquake.

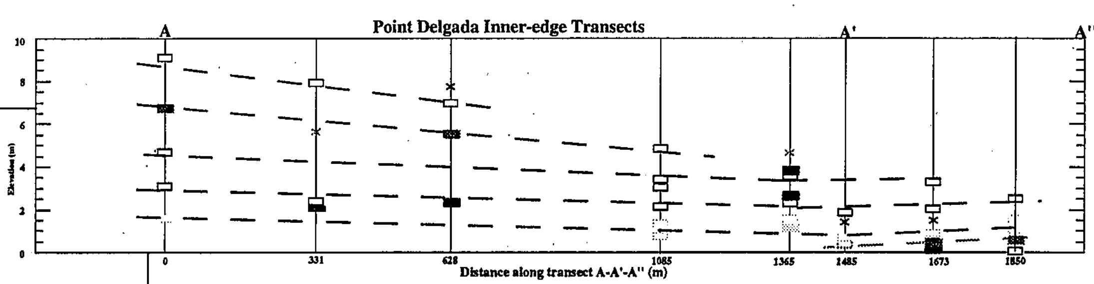


Figure 4. Point Delgada inner-edge elevations at section transects. Third-highest platform was age constrained to >47 ka and was assigned to the 53 ka sea level highstand because of a best-fit platform elevation correlation. This yields uplift rates of 0.63 m/ky and 0.65 m/ky at the southern and northern sections, respectively. Calculated as the difference in uplift rate per unit distance, the tilt rate is approximately 0.04°/ky to the north. The appearance of emergant Holocene platforms begins less than 2 km to the north.

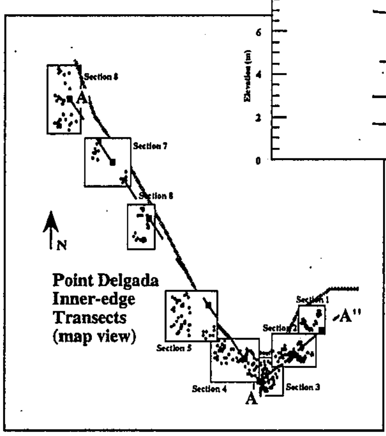


Figure 5. Point Delgada survey points and transects (map view).