CRUSTAL DEFORMATION ALONG THE NORTHERN SAN ANDREAS FAULT, BODEGA BAY TO CAPE VIZCAINO, CALIFORNIA

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INTRODUCTION

Following a successful Keck project in 1999, Merritts and Gardner returned to coastal California with 6 Keck students and one F&M student to do more detailed analyses of 6 study areas along the northern San Andreas fault (SAF). As the fault lies both onshore and offshore at several locations along this 200-km stretch of coastline from Bodega Bay to Cape Vizcaino, students were able to work on both the North American and Pacific plates east and west, respectively, of the San Andreas fault (Figure 1). Slight compression along the San Andreas plate boundary results in long-term uplift that raises wave-cut marine platforms above a fluctuating sea level, producing flights of emergent marine terraces that can be correlated with eustatic global sea level highstands.

For each Keck student, the project goals were to 1) map emergent marine terraces and faults on large-scale air photos and then in the field, 2) survey the terraces and faults with GPS equipment, 3) enter the map data into a GIS compilation that includes all study areas, and 4) use the data to interpret rates and styles of deformation along the length of a major plate boundary. The GIS database was begun during the 1999 Keck project, and was significantly improved since then by the work of Chris Crosby (Whitman College, 2000), one of the 1999 Keck project students. Chris worked as an assistant to Dr. Carol Prentice of the U. S. Geological Survey from 2000-2003, and was able to devote time to the GIS database. Dr. Prentice joined the 2003 Keck crew for part of the field season and collaborated with Merritts and Gardner to help prepare for the summer field season. Andrey Voynov of F&M College accompanied the 2003 Keck students as the GIS specialist, and helped to teach all students how to enter their data into the database and use the GIS software. Just prior to the beginning of the Keck field season, Voynov, Merritts, and Gardner met with Jordan Muller (F&M 1996) at Stanford University to learn how to use Poly 3D, a deformation modeling program, as this would be useful for the Keck projects once students had acquired data on the coast-parallel deformation of marine terraces.

Student Projects

From south to north, the student project areas are as follows, with the name of the student listed next to his or her site:

Study Area	Student	College
Bodega Head	Paul Landis	Trinity U
Sonoma	Breanyn Macinnes	Carleton C
Irish Beach	Annie Covault	Trinity U
Navarro	David Trench	Colorado C
Sarah Liebson	Mendocino	Carleton C
Graham Boardman	Westport	F&M Coll

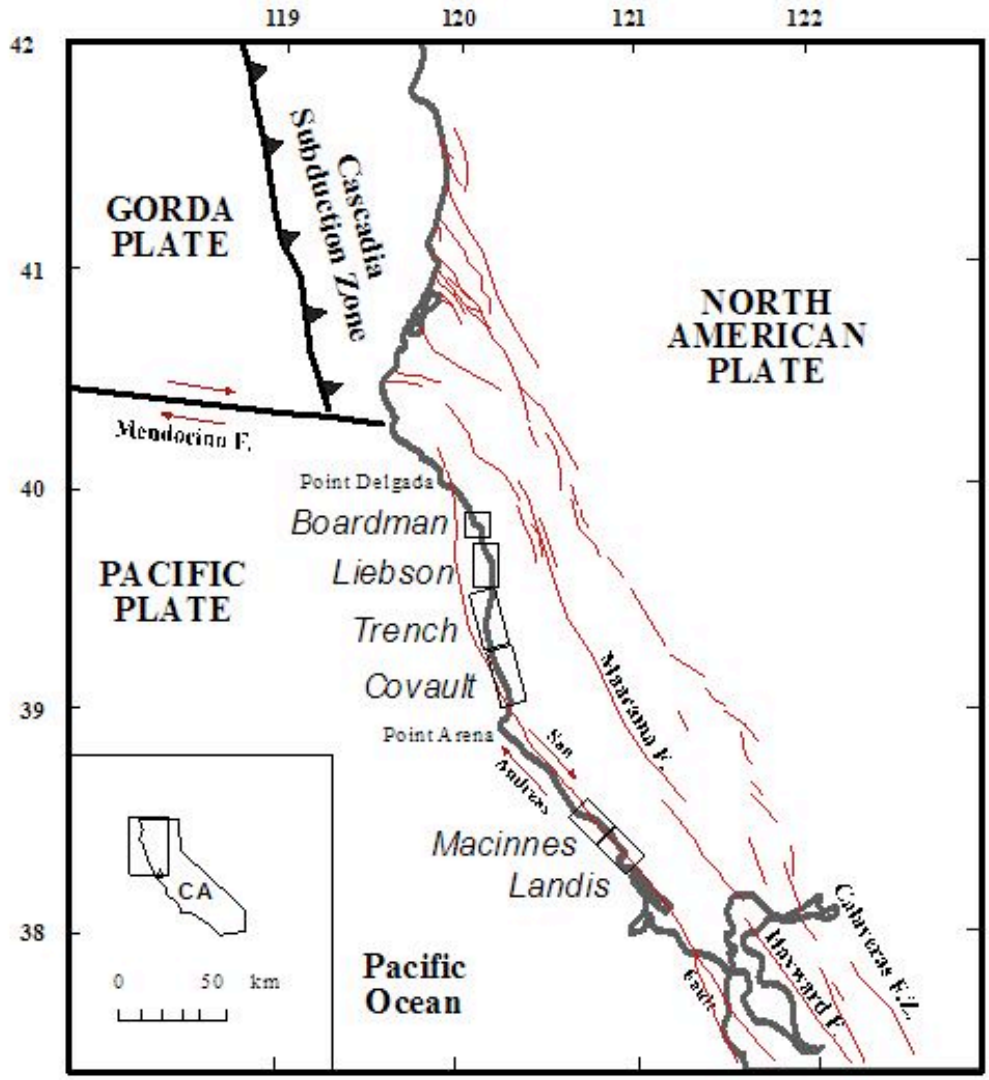

Figure 1. Tectonic setting and location map of 2003 Keck project along the northern San Andreas fault in coastal California. Mapped faults that are part of the San Andreas fault system are shown also; those discovered in this project are not indicated here. Names next to boxes are the last names of students who did their field work in the areas enclosed within the boxes.

Paul Landis' field area began just south of Bodega Head, where the SAF lies close to shore and forms Bodega Bay. His investigation extended as far northward as Shell Beach, spanning ~15 km of the Sonoma County beaches, parks, and local developments. From Bodega Head northward, Landis' field area lies to the east of the San Andreas fault. Landis focused on mapping and correlating ~9 marine terraces that appear to be tilted downward to the south. He explored this possibility with the GPS mapping data, then used Poly 3D to determine what might cause this magnitude and direction of tilt.

Breanyn Macinnes' field area began at the northern end of Landis' and extended northward ~18 km to Fort Ross, just north of where the SAF returns to shore and heads inland east of the Gualala structural block. Marine terraces in this area appear to be deformed not only along the SAF, but also along several previously unmapped faults that might be part of the San Andreas fault system. One of these faults lies along the Russian River, the largest river in the region. Using differences in uplift rates and the locations of possible strands of the SAF system, Macinnes divided her study area into 3 structural blocks.

Annie Covault's field area begins just north of the Gualala block, across the SAF from Point Arena, where the SAF heads offshore and remains offshore until its northern termination at the Mendocino triple junction. Beginning near Irish Beach and working northward ~50 km to the Navarro River, Covault found that several high marine terraces are tilted down to the north substantially, perhaps as a result of a slight compressive bend in the SAF. In contrast to the findings of Landis, Covault concluded that uplift rates diminish with increasing proximity to the SAF.

David Trench's field area begins just south of the Navarro River and extends northward ~50 km to the town of Mendocino, at Mendocino Headlands. Marine terraces along this stretch of coast appear to be untilted, suggesting uniform uplift along the coast. However, he found two different terrace sequences to the north and south of the Navarro River, suggesting a major structural discontinuity along the River (similar to the findings of Macinnes at the Russian River). Trench explored this possibility with the aid of software that enabled him to analyze statistical properties of topography and stream channel networks. Using DEMs and Matlab code written by Dr. Eric Kirby of Penn State, Trench determined miminum, mean, and maximum values of elevation along topographic swaths for the areas to the north and south of the Navarro River. He then used the DEMs and Rivertools (software to analyze stream networks) to determine statistical properties of stream channels and their drainage basins. From this analysis, he concluded that the structural blocks to the north and south of the Navarro River are distinctly different, and that the difference is likely to be due to a change in uplift rates.

Sarah Liebson's study area extends northward from Mendocino to the Ten Mile River, a distance of ~40 km. The area is well-known for its distinctive flight of emergent wave-cut platforms that resemble a staircase; indeed, the coast is referred to as the "Mendocino staircase". Although most of the terraces appear to be uniformly uplifted and of near constant coast-parallel altitude, Liebson found that the outer edge of the lowest terrace is warped down to the west just north of Fort Bragg. A local geologist, David Springer, had discovered a possible strike-slip fault crossing this terrace after a winter of strong El Nino storms in 1998. Springer assisted our crew in finding a shell deposit on this terrace near the fault site (now covered with beach sand), and Liebson, Landis, and Macinnes (with the help of other members of the crew) spent ~5 days looking for solitary coral at this site. At least two solitary coral were discovered, a first for the California coast north of Point Arena. Dr. Dan Muhs of the U. S. Geological Survey is in

the process of completing the U-Th series age estimation of one of these samples.

Graham Boardman's study area was very localized in comparison to that of the other students, as he worked at a site where we had discovered the remnants of two channel mouths, both now offset different amounts from their source area along a newly discovered strike-slip fault. This area is north of Liebson's, just north of the town of Westport. The source of the two sedimentary deposits is thought to be Wages Creek. Both deposits are within the complex of sediments associated with the lowest marine terrace, thought to be ~80 ka based on work to the south in Liebson's area. Boardman used a Total Geodetic Station, in combination with GPS equipment, to do detailed surveying of the uplifted and offset channel and beach deposits exposed in the sea cliff formed along the 80 ka terrace. He collected samples from the major stratigraphic units and, back at F&M, used sieving to analyze grain size and sorting. He also used an SEM and binocular microscope to determine the presence of gypsum in some of the samples, which indicates a brackish water lagoonal environment of deposition. Once he had reconstructed the depositional origin and probable age of each deposit, he estimated a slip rate along the newly mapped coast-parallel strike slip fault.

Conclusions

Together, the 1999 and 2003 California Keck projects have yielded a unique and invaluable database of coast-parallel deformation along nearly the entire length of the northern San Andreas fault, a distance spanning nearly 400 km. Their contributions are significant, as their findings will enable future geologists to examine and model rates and styles of deformation along one of the world's major plate boundaries.