Evidence of Tectonic Uplift along the Oceanic Fault near San Simeon, San Luis Obispo County, California

A Senior Project

presented to

the Faculty of the Earth and Soil Science Department

California Polytechnic State University, San Luis Obispo

In Partial Fulfillment

of the Requirements for the Degree

Earth Science; Bachelor of Science

by

George Gecy

March, 2011

Approval Page

TITLE: Evidence of Tectonic Uplift along the Oceanic Fault in San Simeon

AUTHOR: George Gecy

DATE SUBMITTED: March 2011

Dr. Antonio F. Garcia_____   _____

Senior Project Advisor   Signature

Dr. Lynn E. Moody_____   _____

Department Chair   Signature

Acknowledgements

I would like to thank Dr. Garcia, my friends and my family for all the little help along the way.

Abstract

Post-Seismic satellite imagery after the 2003 earthquake near San Simeon confirmed 10s of millimeters of north-east side uplift along the Oceanic Fault. In order to determine whether or not there has been a history of tectonic uplift northeast of the Oceanic Fault zone, longitudinal profiles of Morro Creek and San Simeon were made using a digital planimeter and 1:24,000 scale maps. Utilizing the stream profiles, convexities could be observed in the streams coinciding where the streams crossed the Oceanic Fault; of the stream profiles, the convexity along San Simeon Creek could be confirmed to be caused by north-east side uplift along the Oceanic Fault.

Table of Contents

Introduction

In 2003 there was an earthquake with a magnitude 6.5 near the town of San Simeon in San Luis Obispo County, California. The topography along the central coast of California is unusual because it is higher in elevation along the coastal ranges than farther inland at the San Andreas Fault zone. This topography formed in response to transpression caused by the oblique plate-motion across the San Andreas Fault (Argus and Gordon, 2001; Spotila et.al. 2007). Through satellite imagery it was determined that 10s of millimeters magnitude uplift occurred in association with the earthquake (McLaren et. al. 2008). This senior project addresses the question of whether there is a history of this uplift in the Santa Lucia Range along the Oceanic Fault Zone. If there has been a history of uplift the stream profiles of streams crossing the Oceanic Fault Zone should show evidence of uplift in the form of a knickpoint or knickzone— convexities in longitudinal profiles of streams. This senior project addresses the problem by generating longitudinal stream profiles of two streams that cross the Oceanic Fault: Morro Creek and San Simeon Creek (Fig. 1). The senior project then determines whether or not there are knickpoints and if they are due to the tectonic uplift in the area or due to some other reason such as along channel rock type change.
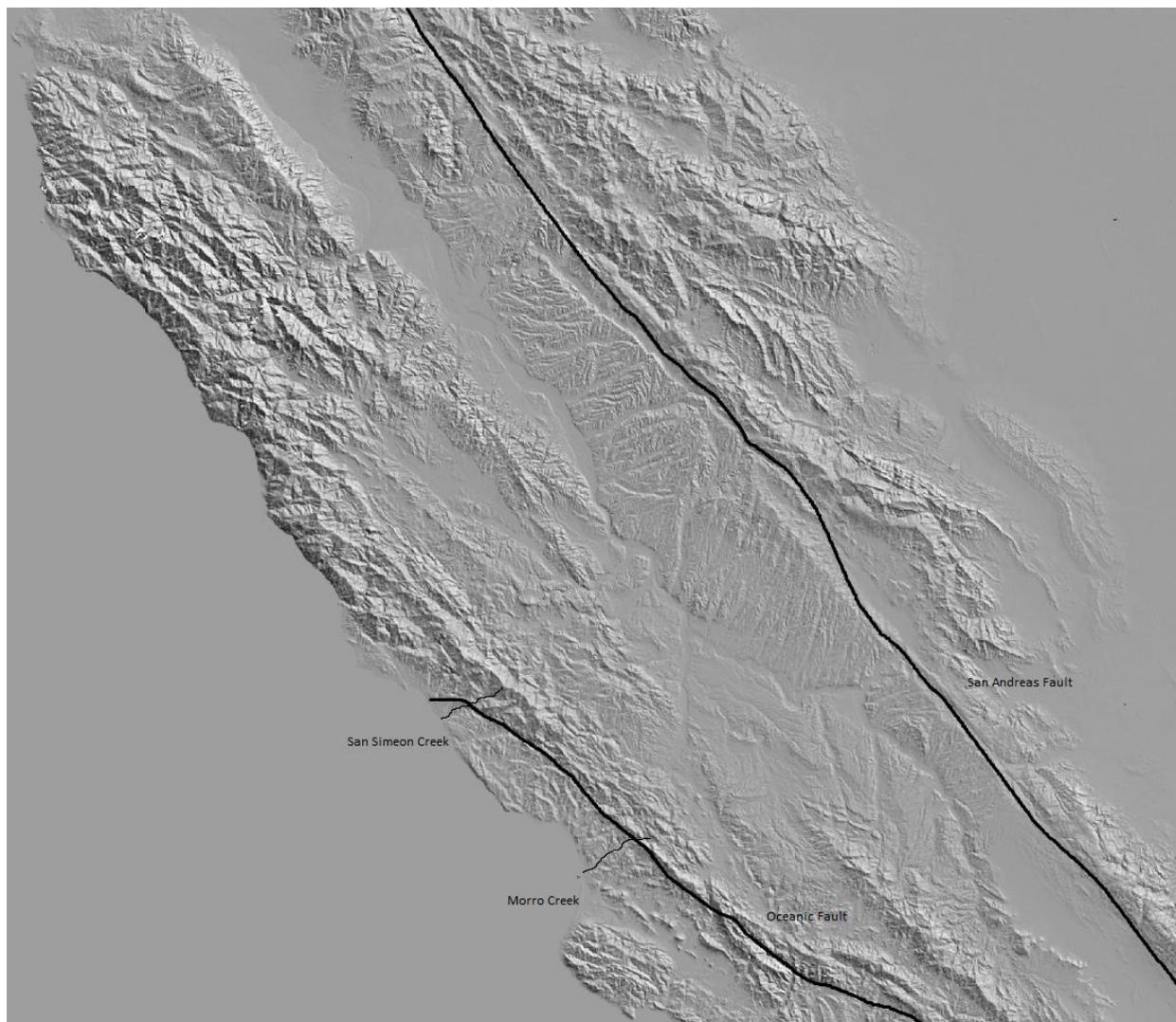
Fig. 1 A Digital Elevation Model of California's Central Coast.

Literature Review

Central Coast Geology

The Central Coast Ranges (Fig. 1) are formed in two terranes, the Salinian terrane and Nacimiento terrane, which are juxtaposed along the tectonically inactive Nacimiento fault (Fig. 2). The basement rocks in the San Simeon region, therefore, vary in lithology from the mélange of the Franciscan Complex of the Nacimiento terrane in the southwest to the Salinian terrane

which consists of Mesozoic Granite intruded into metamorphic rock in the northeast (McLaren

and Savage, 2001) (Fig. 2). Along most of their lengths, Morro Creek and San Simeon creek

flow in the Nacimiento terrane (Fig. 2). The Franciscan Complex mélange is a relatively soft

rock formed in the Cretaceous and Jurassic periods. It is pervasively sheared, made up of an

anastomosing fabric, and is primarily composed of greywacke and sheared greenish black

claystone. Included in the mélange are exotic cm^3 to km^3 blocks of blueschist, conglomerate,

greenstone, red or white chert, greywacke, shale, and serpentinite. (Hall, 1976). Additionally, the

Nacimiento terrane includes portions of the Coast Range Ophiolite, which consists of ultramafic

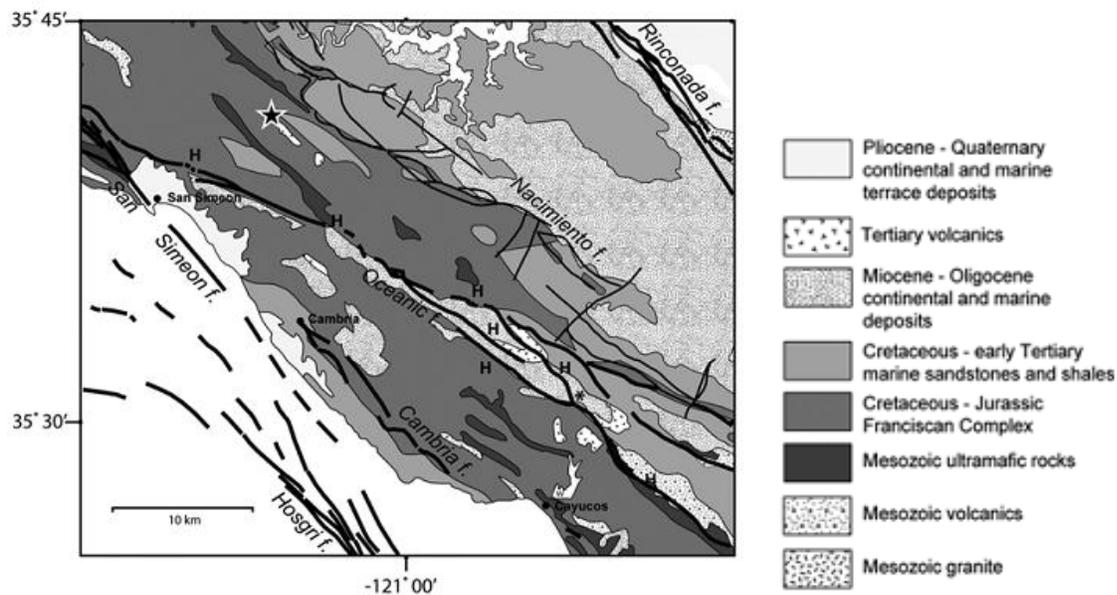rocks, gray to black fractured and weathered basalt, and other metavolcanic rocks (Hall, 1974).

Fig. 2 Basement rock map west of the San Andreas Fault (McLaren et. al. 2008) the star is the San Simeon earthquake epicenter.

Tectonics

The tectonics of California's central coast is characterized by northwest-trending dextral

shear between the Pacific Plate and Sierra Nevada-Central Valley microplate along with a

component of oblique convergence and crustal shortening along the plate boundary at the San Andreas fault zone (Argus and Gordon, 2001). Faults in the area include north-northwest striking, right-lateral strike-slip Hosgri-San Simeon fault system to the southwest, and a the Oceanic Fault, a reverse fault that strikes west-northwest, and locally strikes northeast (Hardebeck, 2010) (Fig. 2). In the San Simeon Area the transpressional plate boundary motion is accommodated by northwest striking dextral faults that are subparellel to the San Andreas Fault such as the Rinconada Fault and by more westerly striking reverse faults such as the Oceanic Fault (McLaren et. al., 2008).

The San Simeon Area is in the northern part of the Los Osos Domain which is bound on the north and east by the Oceanic Fault and the Santa Lucia Range, on the west by the Hosgri-San Simeon Fault zone and on the south by the Santa Ynez River Fault and the Western Transverse Ranges (Lettis et. al., 2004). Farther east of the Santa Lucia Range are the Southern Coast Ranges which extends to the San Andreas Fault (Fig. 3). It is within the Los Osos Domain, specifically near the Oceanic Fault, where the 2003 San Simeon earthquake nucleated (Fig. 2; Hardebeck et. al., 2004). Morro Creek and San Simeon Creek flow from the Southern Coast Ranges Domain, into the Los Osos Domain and across the Oceanic fault (Fig. 1; Lettis, et. al. 2004).
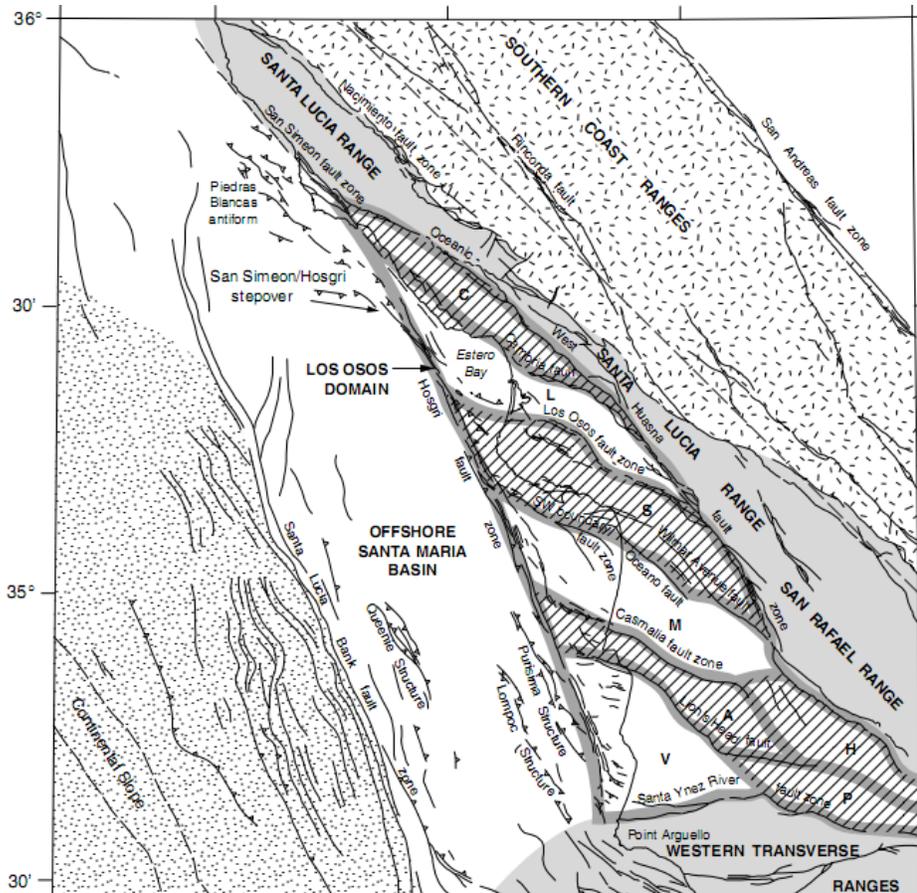
Fig. 3 A map of the Los Osos Domain (McLaren and Savage, 2001).

San Simeon Earthquake

On the 22 of December 2003, there was an earthquake with a moment magnitude of 6.5, nucleated beneath the Santa Lucia Range between the Oceanic Fault and Nacimiento Fault ~10 km east-northeast of San Simeon, California (Hardebeck, 2004) (Fig. 4).
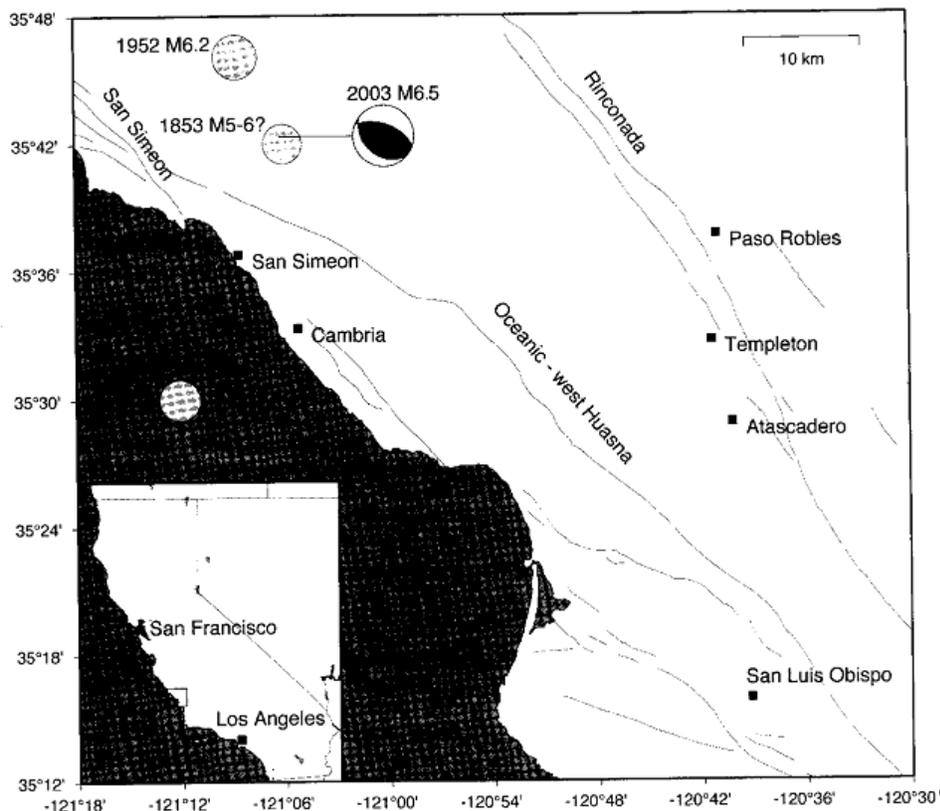
Fig. 4 A map of the hypocenter of the 2003 M 6.5 San Simeon earthquake with moment-tensor solution (Hardebeck, 2004).

In the first study of this earthquake, it was concluded that it was a typical thrust earthquake for the central coast region with a moment tensor depth of 8 km and estimated ~30-km-long rupture plane, but no visible rupture on the surface (Hardebeck, 2004). This locates the earthquake in the Santa Lucia range within Franciscan Complex rocks (McLaren et. al., 2008). In a later study by McLaren et. al. (2008), the mainshock was found to slip on a northwest-striking fault surface that dips 58° toward the northeast, and concluded that the fault surface was probably part of the Oceanic Fault system. Using satellite interferometric synthetic aperture radar (InSAR) imagery the area is shown to have been uplifted ~72mm along the rupture surface in the

central part of the rupture surface, ~48mm at the northwest end of the aftershock zone and

~45mm at the southeast end of the aftershock zone (McLaren et. al., 2008).

Stream Incision and Knickpoints

Fluvial incision in bedrock rivers can reveal the presence of features such as active faults

through changes in the channel where direct structural or mapped data may be unavailable or

unobtainable (Whittaker et. al., 2007). Streams that flow through tectonically active areas show

concave up longitudinal profiles because of relatively high stream power caused by persistent

base-level fall (Pazzaglia et. al., 1998). The existence of differences from the ideal concave up

gradually sloping stream forms, such as knickpoints, can imply and predict geological processes

in an area (Kirby and Whipple, 2001).

Knickpoints are steep reaches that form in response to changes in base-level fall or where

incision encounters a relatively resistant substrate (Gardner, 1983). The scale and difference in

rates of incision causing knickpoints depends on various factors including rock uplift,

competence of the underlying rock type, and channel bed erosion processes (Whipple, 2001).

Generally there are three scenarios for knickpoint behavior in homogenous substrate of variable

resistances: inclination which occurs by rotation about the knickpoint face or midpoint; parallel

retreat, where the knickpoint face moves upstream; and replacement, where the knickpoint is

eroded in place down to base level (Gardner, 1983) (Fig. 5). One significant implication of the

results of Gardner (1983) is that unless sustained by differences in rock type or faulting,

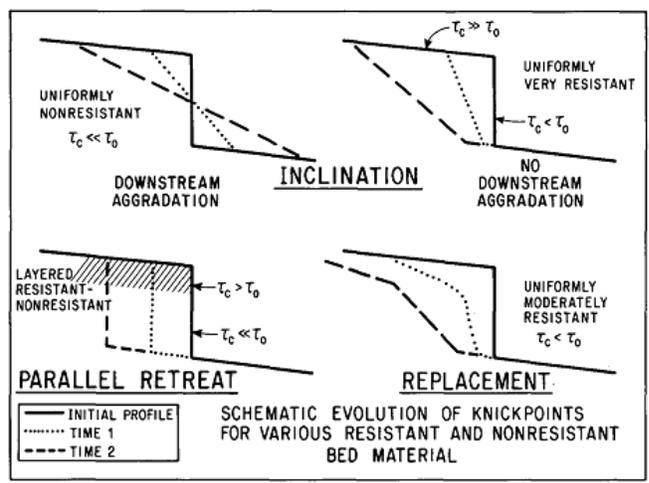knickpoints and other channel convexities do not persist over graded time.

Fig. 5 Models of knickpoint evolution. τ_C is critical bottom shear stress needed to initiate erosion. τ_O actual bottom shear stress. (Gardner, 1987).

Methods and Materials

Longitudinal or "long" profiles of Morro and San Simeon Creeks (Figs. 6 and 7) were generated using a digital planimeter to make measurements on 1:24,000 scale topographic maps. The maps used are the Pebblestone Shut-in, Cambria, Atascadero, and Morro Bay North U.S. Geological Survey 7.5 minute quadrangles. The long profiles were compared to 1:24,000 scale geologic maps in order to evaluate the relationship between knickpoints, rock types and faults.

Results

The Morro Creek long profile (Fig. 6) is convex where the channel crosses the Oceanic fault starting around 122 m/400 ft in elevation. Continuing back upstream approximately 2500m along the channel the knickpoint flattens out at approximately 259 m/850 ft in elevation. The stream flows across the ultramafic rocks of the Coast Range Ophiolite upstream of the fault into Franciscan Complex mélange (KJfme) farther downstream.

The San Simeon Creek long profile (Fig. 7) is convex where the channel crosses the Oceanic Fault, also at approximately 122 m/400 ft in elevation. The convexity continues back approximately 2000m along the channel until approximately 244 m/800 ft in elevation where the profile flattens out. Upstream the profile is gently concave for approximately 500 meters where at approximately 274 m/900 ft it returns to its previous convex state. The convexity between 122 m/400 ft and 244 m/800 ft is formed entirely within the relatively weak, sheared mudstone and sandstone of the Franciscan Complex mélange (KJfm).
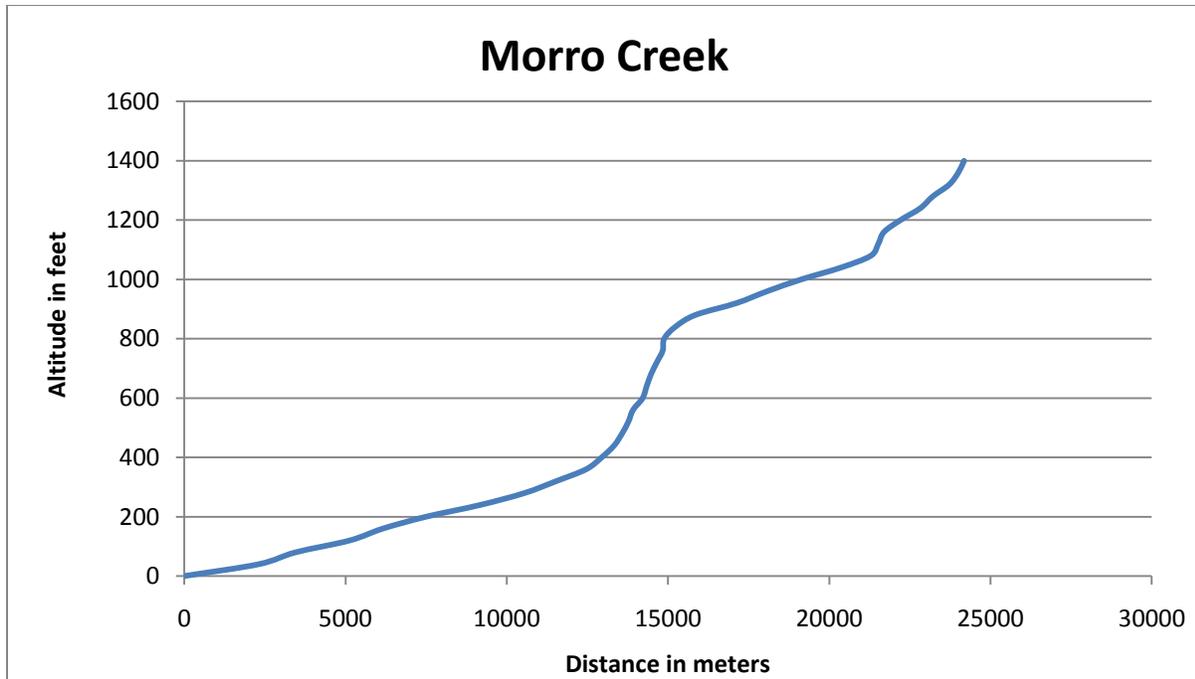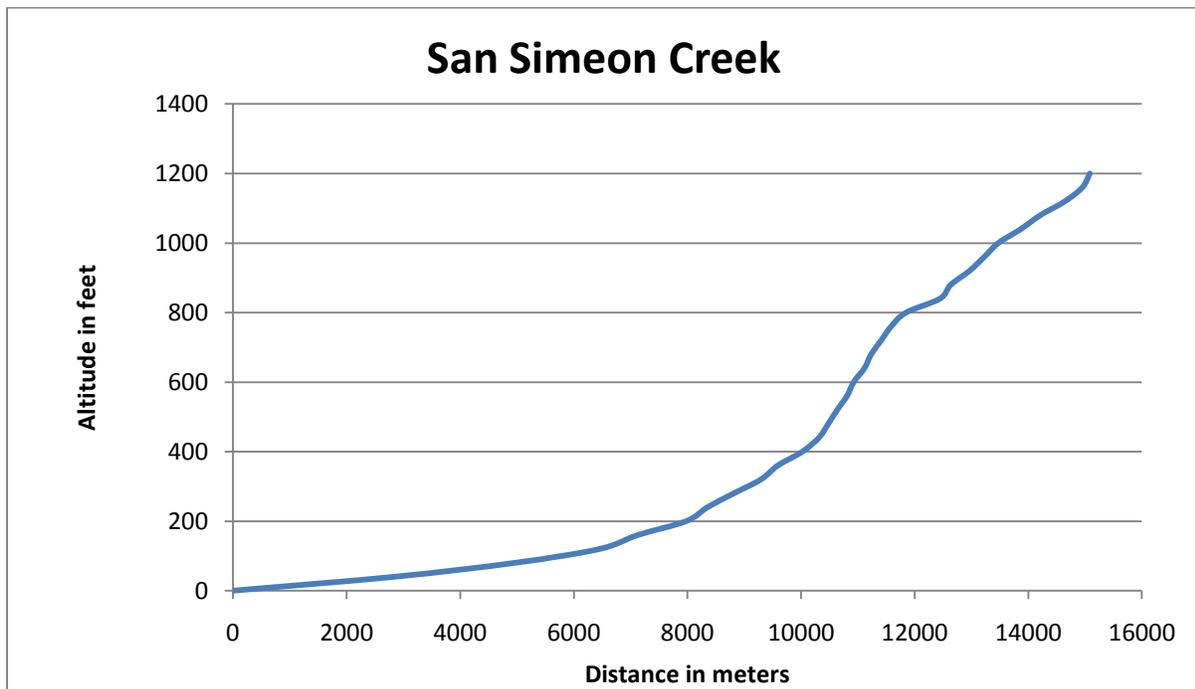
Fig. 6 Stream Profile of Morro Creek.

Fig. 7 Stream profile of San Simeon Creek.

Discussion

It is unknown whether the origin of the knickpoint observed along the profile of Morro Creek is due to tectonic uplift or due to a lithological control because Morro Creek flows from ultramafic igneous and hydrothermal metamorphic rocks downstream into weak rocks of the Franciscan Complex mélange. Therefore, the convexity may be due to a rock type contrast along the channel. That is not to say that active faulting via north-east side up slip along the Oceanic Fault is not a factor, but that results of this study are inconclusive because a strong lithological control cannot be ruled out.

Normally in tectonically active areas, bedrock stream profiles are concave up because of relatively high stream power caused by persistent base-level fall and the orographic effect of repetitively high topography (Pazzaglia et. al. 1998). In San Simeon Creek the profile instead shows a convexity. Gardner (1983) points out that unless sustains by special rock type relationships, or active faulting, knickpoints over time degrade and are smoothed out. However, the knickzone observed on San Simeon Creek is not associated with a special rock type relationship, and in fact no rock type change occurs across the entirety of the convexity. It has been shown that active faulting can cause convexities in the longitudinal profiles of streams (Kirby and Whipple, 2001). Therefore the convexity of San Simeon Creek is consistent with north-east side up slip and associated uplift along the Oceanic Fault zone.

Conclusion

Studies of the 2003 San Simeon Earthquake revealed that uplift occurred along the Oceanic Fault during and within a year of that one event (McLaren et. al., 2008). Observations of stream longitudinal profiles that cross the fault reveal knickzones near the fault that could be due to late Quaternary-time uplift. Evidence for the contribution of tectonic uplift to knickpoint development along Morro Creek remains ambiguous due to a strong rock type control. The knickzone in San Simeon Creek however, substantiates the late-Quaternary time north-east side uplift along the Oceanic Fault.

References

Argus, D.F and R.G. Gordon. 2001. Present tectonic motion across the Coast Ranges and San Andreas fault system in Central California. Geological Society of America Bulletin 113:1580-1592.

Gardner, T.W. 1983. Experimental study of knickpoint and longitudinal profile evolution in cohesive, homogeneous material. Geological Society of America Bulletin 94:664-672.

Hall, C.A. and S.W. Prior. 1975. Geologic map of the Cayucos-San Luis Obispo region, San Luis Obispo County, California. United States Geological Survey, miscellaneous field studies Map MF-686, scale 1:24,000.

Hall, C.A., 1974. Geologic Map of the Cambria region, San Luis Obispo County, California. United States Geological Survey, miscellaneous field studies Map MF-599, scale 1:24,000.

Hall, C.A., 1976. Geologic Map of the San Simeon-Piedras Blanca region, San Luis Obispo County, California. United States Geological Survey, miscellaneous field studies Map MF-784, scales 1:24,000.

Hardebeck, J.L, J. Boatwright, D. Douglas, R. Goel, V. Grazier, K. Hudnut, et. al. 2004. Preliminary report on the 22 December 2003, M 6.5 San Simeon, California earthquake. Seismological Research Letters 75:155-172.

Hardebeck, J.L. 2010. Seismotectonics and fault structure of the California central coast. Bulletin of the Seismological Society of America 100:1031-1050.

Kirby, E and K. Whipple. 2001. Quantifying differential rock-uplift rates via stream profile analysis. Geological Society of America 29:415-418.

Lettis, W.R., K.L. Hanson, J.R. Unruh, M.K. McLaren, and W.U. Savage. 2004. Quaternary tectonic setting of south-central coastal California. In: Keller, M.A. (Ed.), Evolution of sedimentary basins/offshore oil and gas investigations—Santa Maria Province, U.S. Geological Survey Bulletin 1995-AA, p, 1-21.

McLaren, M.K and W.U. Savage. 2001. Seismicity of south-central coastal California; October 1987 through January 1997. Bulletin of the Seismological Society of America 91:1629-1658.

McLaren, M.K., J.L. Hardebeck, N. van der Elst, J.R. Unruh, G.W. Bawden, and J.L. Blair. 2008. Complex faulting associated with the 22 December 2003 M-w 6.5 San Simeon, California, earthquake, aftershocks, and postseismic surface deformation. (in English) Bulletin of the Seismological Society of America 98:1659-1680.d

Pazzaglia, F. J., Gardner, T. W., Merritts, D. J., 1998. Bedrock fluvial incision and longitudinal profile development over geologic time scales determined by fluvial terraces. In: Tinkler, K. J.,

Wohl, E. E. (Eds.), Rivers over Rock: Fluvial Processes in Bedrock Channels. American Geophysical Union, Washington D. C., pp. 207-235.

Spotila, J.A., N. Niemi, R. Brady, M. House, J. Buscher, and M. Oskin. 2007. Long-term continental deformation associated with transpressive plate motion: The San Andreas fault. Geological Society of America 35:967-970.

Whipple, K.X. 2001. Fluvial landscape response time; how plausible is steady-state denudation? American Journal of Science 301:313-325.

Whittaker, A.C, P.A. Cowie, M. Attal, G.E. Tucker, G.P. Roberts. 2007. Bedrock channel adjustment to tectonic forcing; implications for predicting river incision rates. Geology [Boulder] 35:103-106.