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FINAL REPORT- NAGW-3691
Application of High Resolution Topography and Remote Sensing: Imagery to the Kinematics of Fold-and-Thrust Belts

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Summary

This report summarizes one year of funding for NASA contract NAGW-3691, Application of High Resolution Topography and Remote Sensing: Imagery to the Kinematics of Fold-and-Thrust Belts. I never received year three from NASA. The funds were to support on going tectonic and topographic studies along the front of the central Transverse Ranges and expand the topographic studies to the north. Below are results from the first two years of actual funds that I received from NASA (see attached Federal Cash Transaction Reports).

The main focus of this contract was to define and understand the major tectonic processes affecting the formation and evolution of the topography in convergent tectonic settings. The results will be used to test ongoing space-based geodetic measurements and will be compared with present-day seismicity in the central Transverse Ranges and adjacent basins. Two major factors that controls topography in active regions are (1) tectonic uplift due to fault-normal compression and (2) subsequent erosion. The central Transverse and Temblor Ranges are excellent regions for these focused topographic studies. The tectonic processes leading to the mountain building are relatively straightforward and thus are easy to model. Available evidence suggests that the topography in this region is relatively young, ~ 3.5 Ma or less. In addition, , erosional processes may be relatively easier to model compared to larger and more ancient mountain belts. For example, in larger mountain belts, topographic relief may cause significant orographic effects and high elevation may result in part of the topography located above snowline. Both factors complicate interpretation of erosional processes that may be controlled by elevation. Mountain ranges that are significantly older may have experienced a much wider variety of erosional or climatic conditions over their lifetime. While erosion rates have certainly not been consistent in the Transverse or Temblor ranges over its 3.5 Ma lifetime, we are sure that the region was spared the Pleistocene glaciation that affected parts of the Sierra Nevada Range.

Abundant geologic and seismic evidence suggests that oblique plate motion in the region is effectively partitioned into strike slip and compressional regimes (Mount and Suppe, 1987, Zoback et al., 1987). In the Temblor Range, the San Andreas fault accommodates most of the strike slip component, while compressional structures in the range accommodates an unknown fraction of the compressional component. In contrast, to the south in the central Transverse Ranges, the San Andreas and San Jacinto faults accommodate strike slip components, while compressional-related buried structures in the Los Angeles, San Gabriel and San Fernando basins and folding and faulting in the San Gabriel mountains accommodate much of the compressional component. Because of this partitioning, we are considering only the compressional component of plate motion as the tectonic "driver" for topography. This component has resulted in thrust faulting and folding and consequent crustal shortening and thickening. Isostasy that requires that crustal thickening leads to elevated topography. Since the Pacific-North American plate motion vector changed by about 10° from a more westerly orientation between about 3.4 and 3.9 Ma (Harbet and Cox, 1989), it is likely that most of the topographic relief in the Temblor Range dates from this period. A simple model of crustal shortening that assumes 50% of the estimated amount of fault normal compression is accommodated in this region can create the entire relief of the Temblor Range in about 3 million years even allowing for several km of erosion.

In year 1 of funding, I have studied available literature, seismic data, and geodetic data in an attempt to constrain the tectonic boundary conditions for topographic growth of the Temblor and central Transverse Ranges. A key finding is as much as 1-3 mm/yr of this shortening is currently accommodated across the Temblor Range., given that the total shortening rate across central California is about 47 ±2 mm/yr.

(1) <u>Geomorphic and Topographic Studies - Temblor Range, central California</u>

Objectives. The major objectives were to determine the long-term slip rates, recurrence intervals, and structural styles in the Temblor Range, central California, and to provide a kinematic model for the present-day convergence between the Peninsular and Transverse Ranges, southwest of the San Andreas Fault. We have used topographic data coupled with topical field studies to address the neotectonic and kinematic development of active fold-and-thrust belts.

Results. The initial geometry and preliminary rates of deformation in a region just northeast of the San Andreas fault have been determined by combining topographic studies with geomorphic analysis, over a 1500 km^2 portion of the Temblor Range.

Topography and geomorphology studies reveal (1) a province of small folds, parallel to the San Andreas fault and (2) a region of alluvial deposition, northeast of the Temblor Range. Geomorphic features, such as numerous wind gaps at the crest of the Temblor Range, trellis-like drainage patterns and captured drainage's on the west-side of the range, and large land-slide scarps at the base of the eastern and western flanks of the range, and large-scale drainage patterns perpendicular to fold axes indicate active uplift. In addition, the presence of grabens and depressions at the range crest imply that the crest of the range is an active anticline. Based on preliminary balanced cross-sections, using topographic slope of the range and assuming a dip on the basal decollement, a minimum shortening rate of 1.3 -1.5 mm/yr for the southwest portion of the range is indicated. In the San Joaquin Valley, topographic features agree with Quaternary structure contour maps. Geomorphic trends are consistent with geological and geophysical data, suggesting that s_1 is oriented normal to the San Andreas fault, and much of the slip deficiency normal to the San Andreas fault is partitioned with the fold- and thrust-belt of the Temblor Range.

(2) Frontal Fault System - central Transverse Ranges

Objectives. The major objectives of this research was to determine the long-term slip rates, recurrence intervals, and structural styles on the Sierra Madre segment of the frontal fault system, central Transverse Ranges, and to provide a kinematic model for the present-day convergence between the Peninsular and Transverse Ranges, southwest of the San Andreas Fault. Conventional wisdom holds that the Sierra Madre segment of the frontal fault system has a significantly lower slip rate than other segments of the frontal fault system, the Cucamonga fault to the east and the San Fernando fault to the west. Yet some of the high peaks of the San Gabriel Mountains are located along the presumably inactive Sierra Madre segment. Why did the eastern continuation of the frontal fault system (e.g., Sierra Madre fault) "choose" not to fail during the 1971 San Fernando earthquake? Had failure on the Sierra Madre segment, say a thousand years ago, relieved accumulated strain? Was the magnitude 6.6 San Fernando or 6.7 Northridge earthquake characteristic for the frontal fault system, or might we expect larger, magnitude 7.5 or even 8.0 earthquakes? Although the potential magnitude of an expected earthquake along the fault system has been traditionally calculated using rupture patterns based on presumed segmentation of the fault, a comparison with large historically active reverse faults suggests the possibility of simultaneous ruptures of several segments [see attached, Rubin, 1997].

In light of the 1994 M = 6.7 Northridge earthquake, the potential for large, or even great earthquakes along the southern flank of the central Transverse Ranges is a topic of great interest and debate. This earthquake have sparked fundamental questions regarding the potential size of an earthquake in the Los Angeles region. The fold-and-thrust belt of the central Transverse Ranges provide an ideal settings for the application of high accuracy and resolution topographic data and high resolution imagery for neotectonic studies. Over the past year my efforts were divided into integrated tectonics and topographic studies on the frontal fault system along the southern flank of the San Gabriel Mountains and (2) topographic and tectonics studies across the central Transverse Ranges, just south of the San Andreas fault. To establish active faulting in regions of crystalline rocks, such as in the San Gabriel Mountains has proved to be quite difficult [Crook et al., 1987]. In addition, the geomorphic characteristics of large thrust faults are complex; surface ruptures have different trends, displacements have diverse directions, minor faults cross-cut zones of rupture. Thus reverse faults do not display a simple clean-cut surface trace, instead reveal a complex pattern of surface faulting, commonly across a wide zone. Large-scale topographic studies, combined with detailed topical topographic and geomorphic studies (triangular faceted faces, tilted stream terraces, river drainage patterns, etc.) were used to study active tectonics. Topographic studies (using USGS DEM and SPOT) across the southern flank of the San Gabriel Mountains reveal systematic topographic steps that indicate thrust faulting in the crystalline rocks, north of the mountain front, may be younger than previously thought. Pronounced elevated topography along the San Andreas fault, near Wrightwood, may be the result of interaction between the northern projection of the Sierra Madre or related faults and the San Andreas fault at depth. Initial synoptic topographic studies along the central Transverse Ranges and adjacent smaller mountains (e.g., San Rafael Hills and Verdugo Mountains) indicate that the topography profiles are asymmetric, with steep southern flanks. Topographic steps are common and appear to coincide with changes of stream drainage directions. The topographic steps do not correlate with bedrock lithology and are tectonically controlled.

Results. The regional kinematic framework between the San Fernando and Sierra Madre segments of the frontal fault system of the central Transverse Ranges has been discussed in detail by Crook et al. [1987]. These workers and many others [Elhig, 1975; Weldon and Humphreys, 1986] have concluded that seismic activity and associated seismic hazards east of the 1971 San Fernando surface rupture are low. Crook et al. [1987] were unable to positively identify either fault scarps or displaced alluvium in units younger than late Pleistocene.

My work suggests that many of the faults within the Sierra Madre segment have been active during late Quaternary time and pose a significant seismic hazard to the metropolitan region. Geomorphic studies have revealed a very different pattern of surface deformation and faulting along the Sierra Madre segment. Much of what was considered an inactive fault segment may be quite active and may represent a significant seismic hazard in the San Gabriel and Los Angeles basins [Rubin and Sieh, 1993a and b, see attached Rubin, 1993b]. Critical points of our preliminary studies are:

(1) Between Claremont and Tujunga, many alluvial fans are highly deformed.

(2) Both modern stream channels (e.g. Arroyo Seco) and active fan surfaces show multiple topographic steps that indicate recent deformation.

(3) Relatively fresh fault scarps in Duarte, Upland, and La Verne have been identified, all of which are potential excavation sites for paleoseismic studies. Permission has been obtained for excavation on one of the more promising sites.

(4) Based on topographic profiles and geomorphic studies, thrust faulting in the crystalline rocks north of the San Gabriel mountain front may be younger than previously thought.

References

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Central Washington University Revised Budget for Year Two and Three*
NASA Proposal on High Resolution Topography Data

Dr. Charles M. Rubin, Department of Geology

	1995
CMR Salary	36,000
Benefits @ 28% of salary:	10,080
Travel (trips to JPL and AGU meetings): (1 AGU meeting) (1 JPL trip and San Gabriel field work)	2,000
Procurement, Materials and Supplies:	
Disk storage and memory:	5,000
TM and SPOT imagery, DEM:	8,000
Other: (clerical, telephone, xerox, postage)	500
Computer Maintenance:	500
Publication Costs:	1,500
Overhead: @ 59% of salary	21,240
Total:	83,320

* Rubin never received funding for year three