3-D Mapping of Active Faults in Southern California: Eastern Ventura Basin and San Gorgonio Pass—San Bernardino Regions.

Award # 02HQGR0033

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Program Elements I & II
Key Words: Neotectonics, Tectonic Structures, Seismotectonics, Regional Seismic Hazards

Investigations

In both the eastern Ventura basin and San Gorgonio Pass- San Bernardino regions we used the catalog of relocated 1975-1998 earthquakes of Richards-Dinger and Shearer (2000). A clustering algorithm was applied to the relocated earthquakes in order to obtain tighter earthquake clouds and thus better-defined fault surfaces. In the Ventura basin, we also added the California Tri-Net earthquake catalog for the period 1999-2002 (fig.1). We then imported the earthquakes into Gocad, a 3D modeling software that allowed us to separate earthquakes into coplanar clusters associated with different faults and fault strands and to fit optimized surfaces to them. We also imported into Gocad the focal mechanisms catalog of Hauksson (2000) to identify and map faults which do not have well-defined earthquake clusters associated with them, and to determine the slip direction on most faults.

Results

1) Ventura basin. We have mapped 25 faults and fault segments (fig. 2) with varying degree of confidence (fig. 3) to depths of 25 km. In particular, we identified a reverse fault (FV1, fig. 2, 4) just W of the Northridge thrust that is part of the Oak Ridge trend. Further to the W, there are very few events, and none of the available focal mechanisms shows an orientation compatible with the Oak Ridge fault, which cannot therefore be imaged from earthquake data.
There is no well-defined earthquake cluster that can be associated with the S. Cayetano thrust either, just scattered seismicity. However, there are 8 events (the largest of M=4.1) which show reverse mechanisms with one nodal plane dipping to the N by 40°-60°. Their location is compatible with the possible location of this fault at depth (figs. 2, 3).
The following table shows the nature of some of the mapped faults (figs. 2, 3) as determined from analysis of focal mechanisms (color indicates fault quality index, see fig. 3):

fault	mechanism	average dip	fault	mechanism	average dip
S. Fernando thrust	reverse	35° N	*Northridge thrust*	reverse	43° SW
FLA1	reverse/LL	53° S	*FLA2*	reverse/RL	83° S
FLA4	reverse/LL	80° SSE	*FLA5*	reverse/LL	80° S
FLA6	reverse/LL	60° NNW	*FV1 (Oak Ridge)*	reverse/LL	47° S
FV2	reverse/LL	80° SE	*FV3*	reverse/LL	65° SE
FV6	reverse	75° SSW	*FV7*	reverse	82° S
S, Cayetano thrust	reverse	48° NNE	*S. Ynez Fault*	reverse/LL	84° SSE

2) San Gorgonio Pass. We mapped over 70 faults in the San Gorgonio Pass-San Bernardino Mountains region to depths of 20 km. We were able to constrain the 3-D geometry of the San Andreas fault near San Gorgonio Pass from the 3-D geometry of the fault network surrounding it. Our findings suggest that the existence of a through-going vertical or near-vertical San Andreas fault between Yucaipa and North Palm Springs is highly unlikely. Only complex 3-D geometries are possible. The most likely configuration is the one where the San Andreas fault merges into the shallow-dipping San Gorgonio Pass thrust W of North Palm Springs. Strike-slip motion is taken up by both the thrust and by a series of NW striking faults in the footwall of the thrust (fig. 5). Considering the 3-D geometry of the San Andreas fault system in this region, the only rupture possible for the San Andreas is a complex rupture. The present-day stress field allows for such a rupture, involving both strike-slip and reverse faulting, to occur between the Coachella Valley and Banning. However, both 3-D geometry and stress field are an obstacle to further rupture propagation towards the W, between Banning and Cajon Pass. One application of our fault models is shown in fig. 5, where we map the Coulomb stress change on the San Gorgonio Pass thrust system caused by a hypothetical M_W 7.4 event that ruptures the San Andreas between Cajon Pass and Banning.

Non-technical Summary

We imaged and mapped in 3-D a total of about 100 active faults in the San Gorgonio Pass and Ventura basin regions using earthquake locations and focal mechanisms. The majority of these faults are previously unknown or unnamed, and some are as large or larger than the rupture area of the Northridge earthquake.

Reports published

Carena S., and Suppe J., 2002, 3-D Imaging of Active Structures Using Earthquake Aftershocks: the Northridge Thrust, California. *J. Struct. Geol.*, 24, 887-904.

Carena S. and Suppe J., 2002, Continuity of the San Andreas fault at San Gorgonio Pass. *EOS, Transactions*, in press. Abstract.

Carena S., Suppe J., Kao H., 2002, Active Detachment of Taiwan Illuminated by Small Earthquakes and its Control of First-Order Topography. *Geology*, 30, 935-938.

Data availability

The original earthquake hypocenter locations and focal mechanisms are available from the Southern California Earthquake Center database (http://www.scecdc.scec.org/catalogs.html). ASCII files of the clustered locations and all the Gocad files (earthquake hypocenters, focal mechanisms, and fault surfaces) are available from Sara Carena (scarena@princeton.edu, (609) 258-1515). We plan to make digital maps available through the *SCEC Community Fault Model*, currently under development.

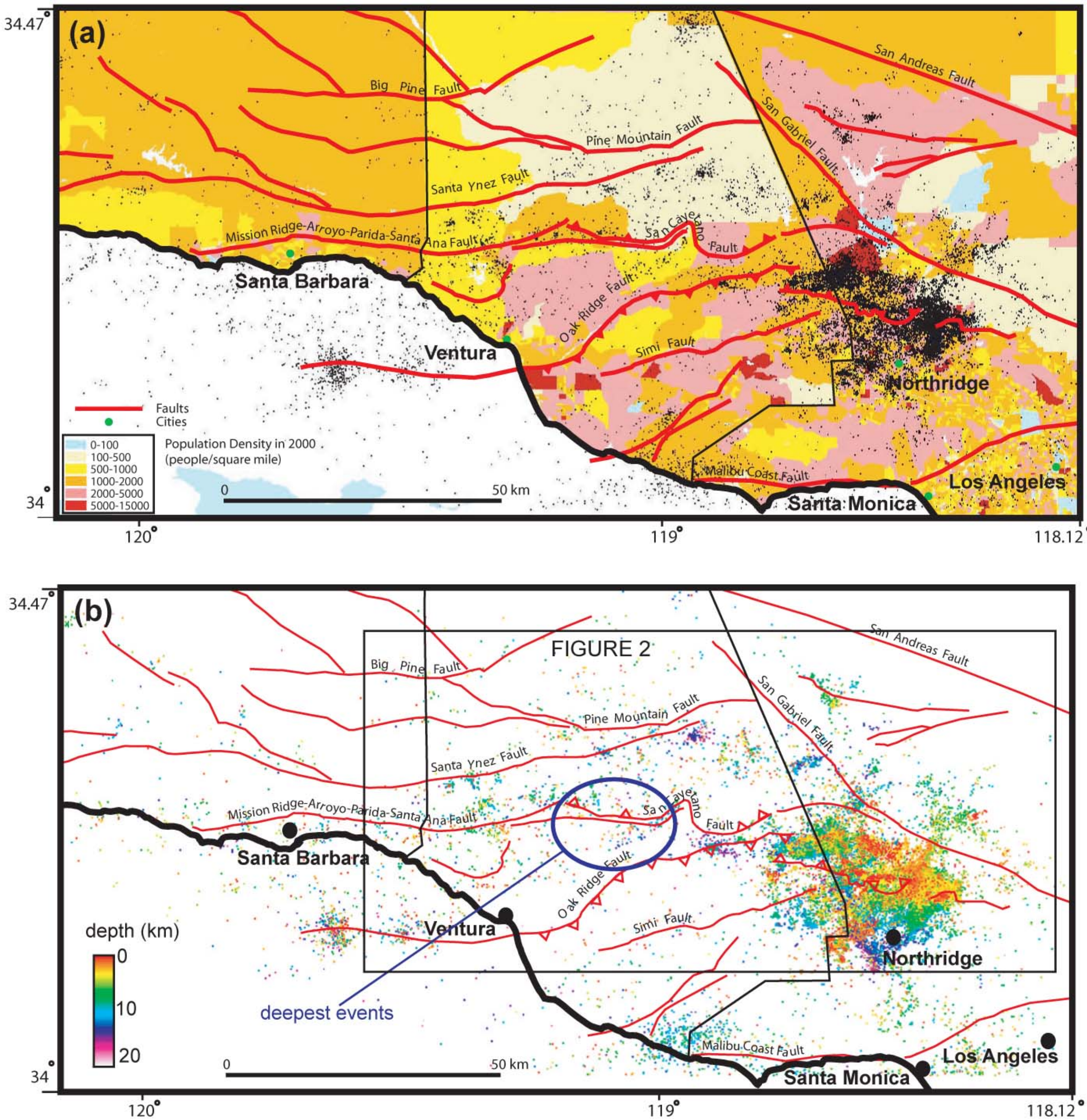

Figure 1. (a) Population density map. (b) Earthquake hypocenters from Richards-Dinger and Shearer [2000] (for the period 1975-1998) and from the California Tri-Net network (for the period 1999-2002), totaling about 21,000 events (quarry blasts have been removed).

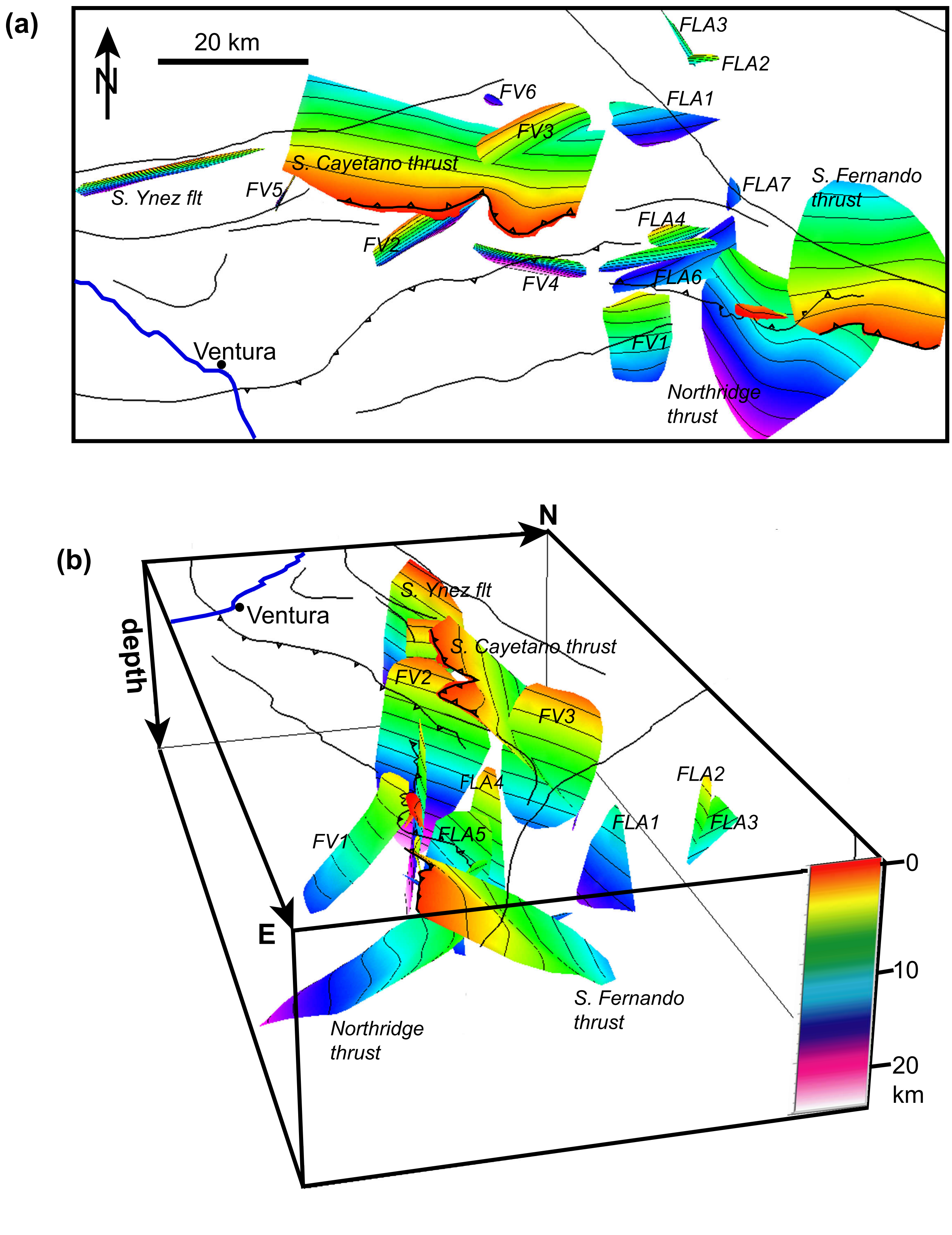

Figure 2. (a) Map view and (b) perspective view of 25 faults imaged in the area. Names indicate county: FV = Ventura, FLA = Los Angeles.

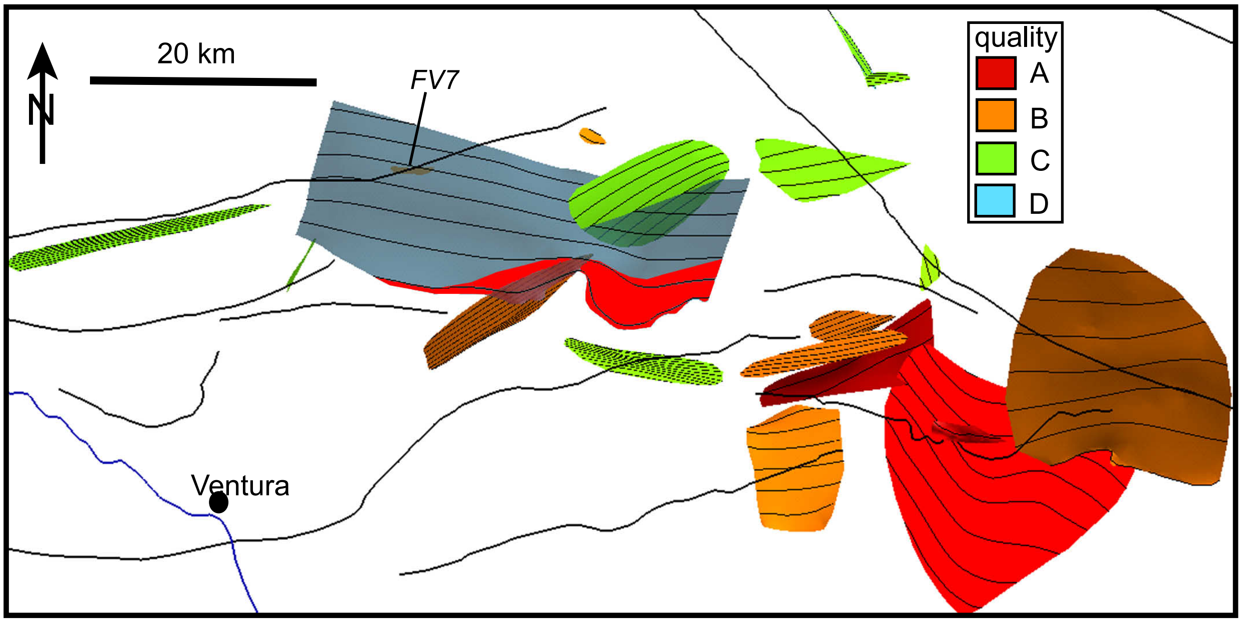

Figure 3. Quality index. **A** = fault obtained from dense earthquake clusters with strong preferential orientation, and/or large number of consistent focal mechanisms. It is possible to identify details of the geometry like undulations and changes in dip easily. Alternatively, the fault has been imaged from a network of seismic reflection profiles and/or wells combined with a mapped surface trace. **B** = fault obtained from clusters of earthquakes with well-defined preferential orientation, though not as dense as in A. When available, focal mechanisms are consistent. Details of the geometry are less well defined. **C** = fault obtained from earthquake clusters which show weak preferential orientation, and fewer or generally inconsistent focal mechanisms. Some faults in this category represent the average orientation of a series of fault segments. **D** = No easily identifiable clustering of earthquakes. There are only a few focal mechanisms with nodal planes and slip similar to those predicted for this fault at depth. Contour interval on all faults is 2 km.

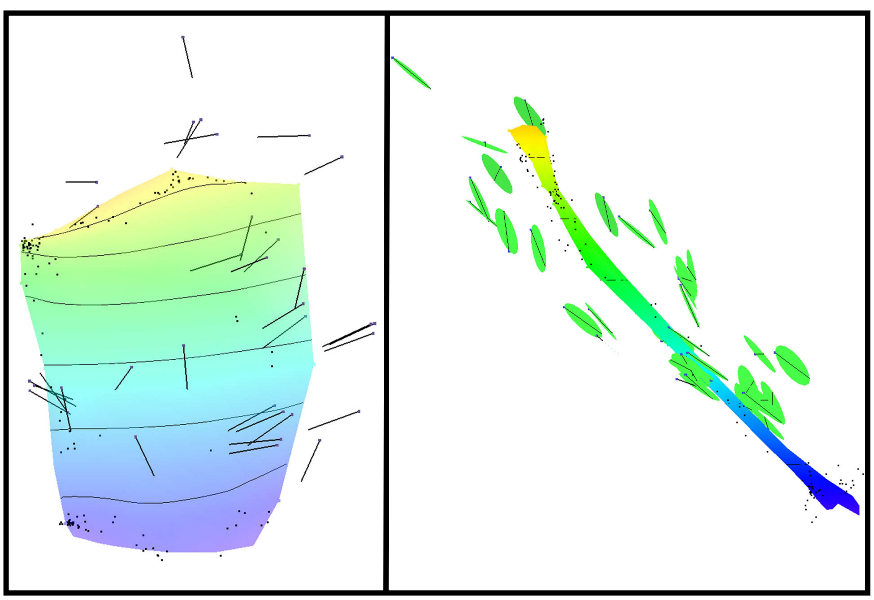

Figure 4. An example of a B quality fault: FV1 (fig. 2) in map view (a) and in view parallel to strike (b). Defined by 157 earthquake hypocenters with a donut-like distribution (black dots) and by 34 focal mechanisms. Green discs represent preferred nodal planes, and black lines with dot at one end represent the corresponding slip vectors. As shown in (a), slip on FV1 is a combination of mainly reverse and left-lateral motion. When the fault plane is projected to intersect the Earth's surface, the line of intersection is very close in position and orientation to the easternmost mapped trace of the Oak Ridge fault. Colors on fault surface indicate depth (see fig. 2 for scale). Contour interval is 2 km.

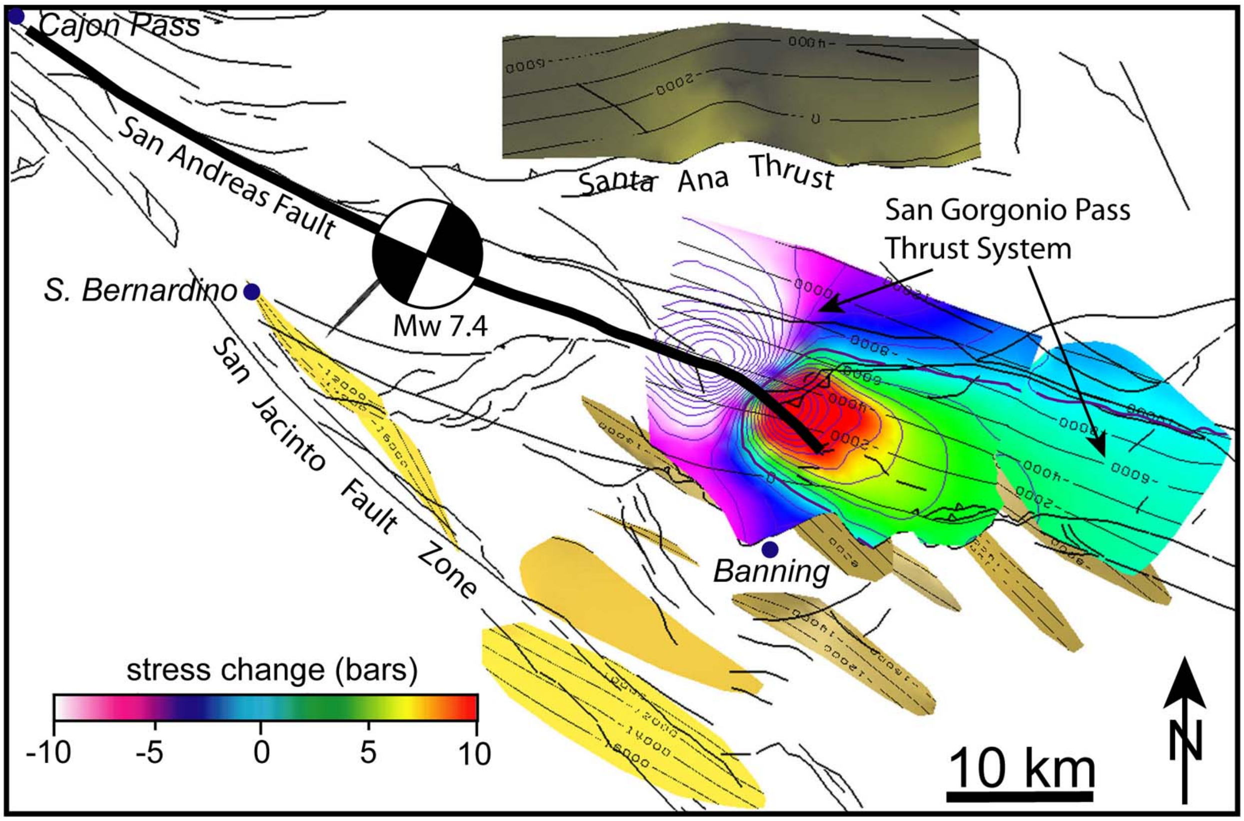

Figure 5. Map showing the Coulomb stress change on the San Gorgonio Pass thrust system due to a hypothetical Mw 7.4 event involving the San Andreas fault between Cajon Pass and Banning. The heavy black line represents the ruptured San Andreas. In this scenario the fault ruptures all the way from the surface down to 15 km depth (15 km is the average depth to the base of seismicity along this stretch of the San Andreas), with a slip of 2-3 m on average. The purple contour lines on the San Gorgonio Pass thrust system represent Coulomb stress change intervals of 2 bars (the heaviest line is the 0 bars value). Depth countour interval on all faults is 2 km.