Resolving the Effects of Rotation, Subsidence and Sediment Compaction on Geodetic Strain: A Dense Cluster for the Ventura Basin, Western Transverse Ranges

A 'Notice of Intent' Mini-Proposal Submitted to the 2nd PBO Workshop

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PROJECT

The problem: *One of the highest rates of crustal shortening measured in southern California occurs across the Ventura Basin. The Ventura Basin also exhibits elements of tectonic rotation and has the highest rate of regional subsidence and sediment compaction. How are these observations related, and what influence do these largely aseismic processes—such as subsidence and compaction—have on measured geodetic strain rates?*

Geologic and geodetic data indicate that the Ventura Basin currently accommodates high rates of oblique crustal strain [*Donnellan et al.*, 1993; *Huftile and Yeats,* 1995] including components of regional tectonic rotation. This deformation is inferred to represent a significant seismic hazard, and is presumed to be largely accommodated by active faulting, folding, and tectonic uplift. Most models used to infer subsurface fault geometry, or used to resolve geodetic strain or geologic data into fault slip typically presume rigid footwall blocks, non-deforming planar fault surfaces, and deformation that is largely restricted to the hanging-wall. In California, however, deep, subsiding basins are often bounded by oblique reverse faults that thrust early-Cenozoic and older rocks over young unconsolidated sediments (**Fig.1**), suggesting that footwall deformation, subsidence and compaction may play an important role in accommodating regional tectonic strain. Although often neglected, effects like compaction can be considerable (**Fig.2**). Even in the absence of active crustal shortening or fault slip, sediment compaction alone can produce surficial motions that mimic deep fault slip. Differential subsidence, pressure solution, and 3D compaction of footwall sediments relative to hanging-wall basement rocks can lead to increased vertical separation and fault rotation about horizontal axes (e.g., **Fig.3A**). Such effects would contribute to net horizontal and vertical motions in both geologic and geodetic data, resulting in *overestimates* of the inferred seismic hazard.

As part of an on-going study of active faulting, folding, and basin development, we have been evaluating a unique 3D subsurface dataset for the Ventura basin provided by the Ventura Basin Study Group (VBSG) derived from nearly 1200 correlated deep-penetration wells. The wells vary in depth from 1 to 5 km. Many of these wells drill active fault and fold structures associated with major fault systems, including the San Cayetano, Oak Ridge, and Santa Susana faults (**Fig.1**). We have been using the VBSG dataset, in combination with seismicity, seismic reflection, and offshore well data, to develop improved 3D structure contour maps of specific stratigraphic (time) horizons that extend across the basin and into the Santa Barbara Channel (**Fig.3B**). Map restoration in 3D of these faulted and folded surfaces provides an independent estimate of the finite strain field, and by evaluating different horizons, the evolution of the strain field with time can be determined. Preliminary results indicate that—in addition to uplift, folding, fault offset, and block rotation—significant crustal shortening is accommodated by isostatic subsidence, sediment compaction, and other types of footwall deformation (**Fig.3B**). Moreover, this subsidence is not necessarily restricted to just footwall blocks in the basin, but also affects hanging-wall blocks above active oblique-reverse faults as well. In the Ventura basin (as is likely in the Los Angeles basin), subsidence and compaction are significant, and may locally reach a maximum of ~3 mm/yr. The net effect is one of the thickest deposits of Plio-Pleistocene deposits in the world, and a basin that has subsided nearly 7 km (most of this in the last 3 Ma) with an equal deflection of the Moho.

The question is: How do these effects of regional subsidence, rotation and sediment compaction influence geodetic strain data? If the modulus of the basin material evolves with time due to compaction, how does this effect influence measured geologic and geodetic rates of crustal deformation? What is the mantle process that accommodates or sustains this basin subsidence and Moho deflection? How are rotations about both horizontal and vertical axes accommodated, and are these motions resolvable with currently available techniques?

The solution: *A dense cluster of geodetic stations around the Ventura basin region to better resolve spatial and temporal components of horizontal and vertical motions, integrated with a multidisciplinary study of basin compaction effects, and the evolution of basin subsidence, faulting, folding, and small-scale rotations in 3D.*

We propose to augment the existing geodetic arrays around and within the Ventura basin to better resolve the horizontal and vertical components of crust and mantle strain. Because the primary effects of both mechanical and chemical compaction appear to be vertical, even in the presence of a strain field whose axis of maximum principal stress is horizontal, this proposed array of geodetic measurements must be able to resolve both vertical and horizontal motions to a high degree of precision. Station spacing must also be sufficient to resolve rotations, some of which are occurring by small blocks caught within zones of distributed shear.

This augmented geodetic study of the Ventura basin must be coupled with an integrated, multidisciplinary analysis of basin compaction, subsidence, faulting, folding, and rotation. This includes documenting the contributions to subsidence of both mechanical and chemical compaction, as well as studies of the crust and mantle interaction that continues to drive (or sustain) the regional component of subsidence and the downwarping of the Moho. Compaction histories can be developed from porosity versus depth data. This will allow decompaction of sediments in both basin and fault evolution models, and help resolve how inferred fault slip rates derived from geologic and geodetic data are potentially affected by these largely aseismic processes of isostatic subsidence, compaction and diagenesis. These results will then provide a better understanding of the relationship between faults and fault-related folds, as well as help clarify the differences in seismic and aseismic processes, and how each may influence the geometry, behavior and seismic hazard estimates of major active fault segments in southern California.

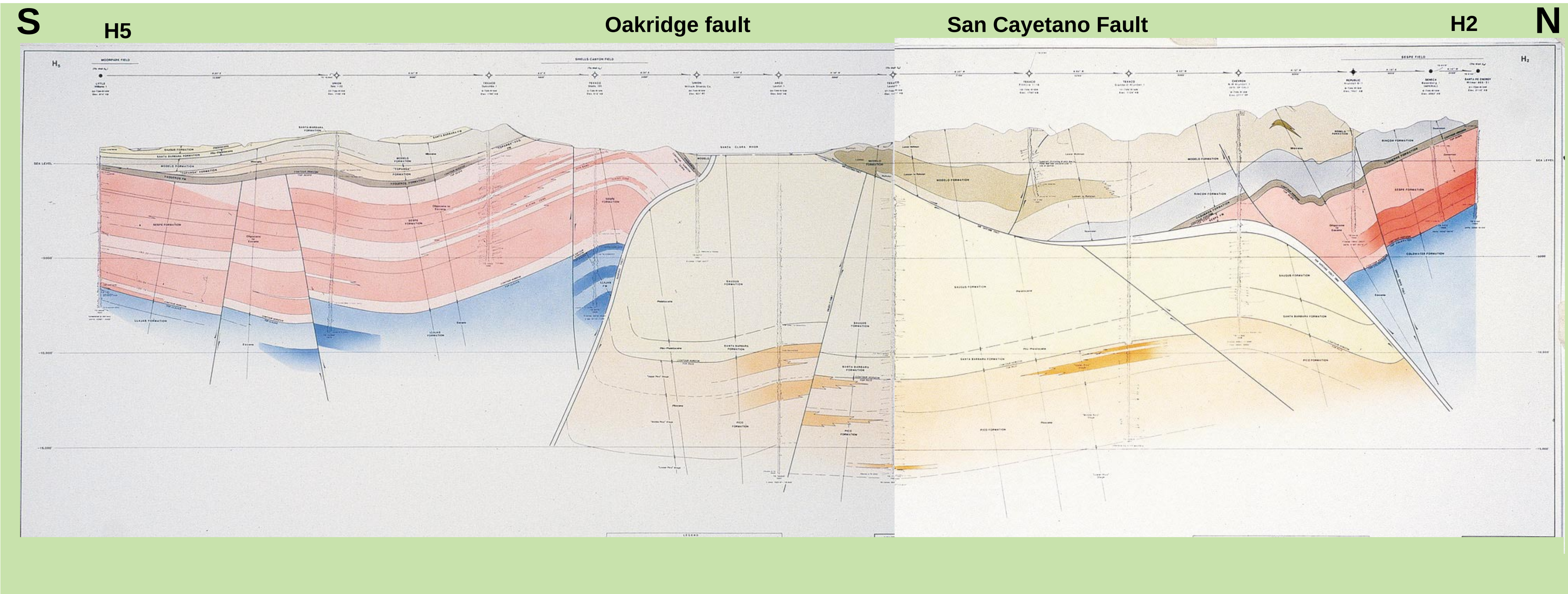

Figure 1. Vertical structural cross section across the Ventura basin and Oakridge and San Cayetano faults produced by the Ventura Basin Study Group (VBSG) (Hopps et al., 1992). This section shows how oblique-reverse faults overthrust early-Cenozoic and older rocks over mostly Plio-Pleistocene and younger sediments. Note the rotated and non-planar geometry of the faults. Also note the folding, differential compaction and other aspects of footwall deformation within the basin. Compare with schematic model in Fig.3A. Red - Sespe Formation (~30 Ma); Yellow - Saugus Formation (~0.5 Ma).

COMPACTION

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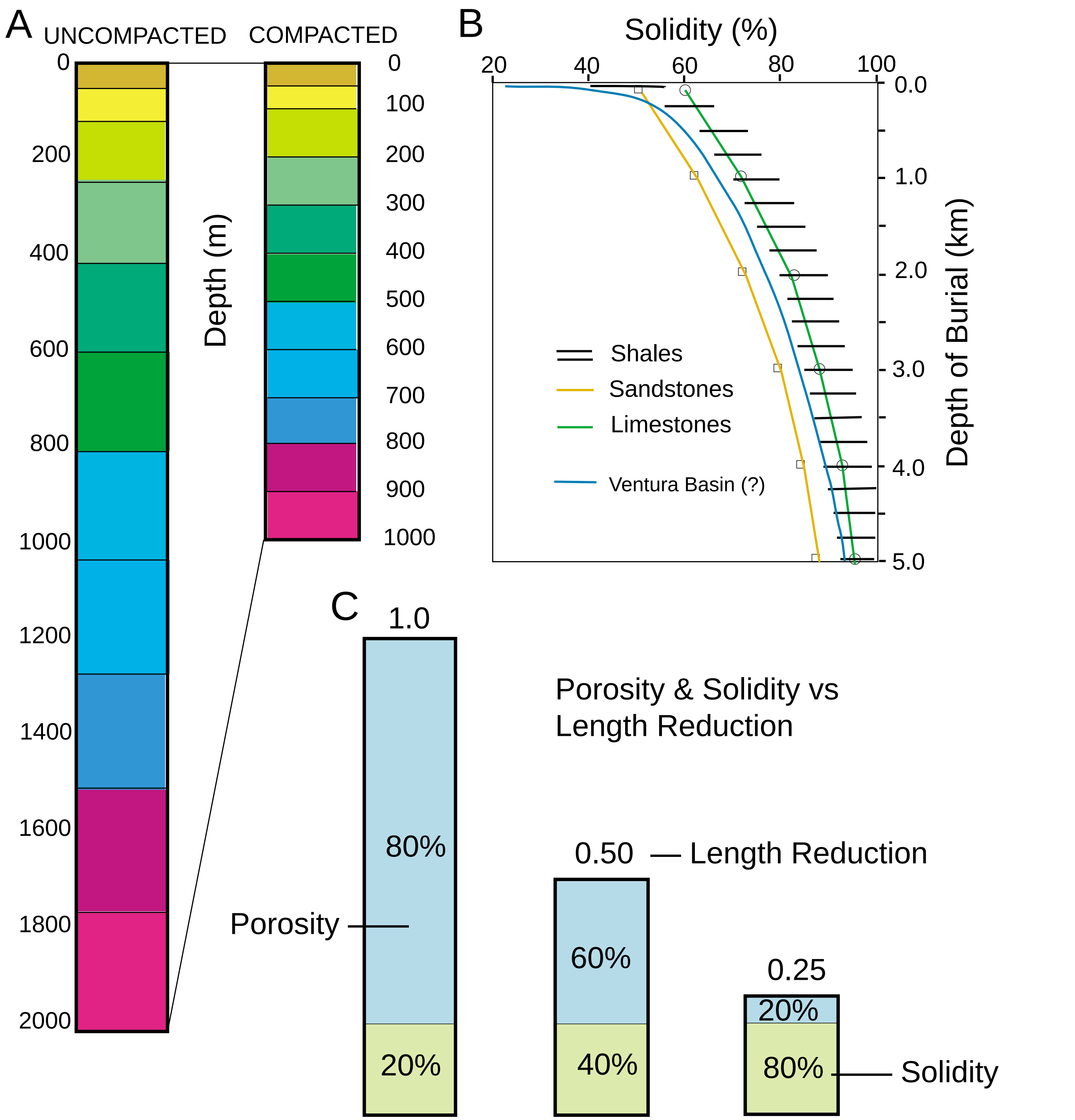
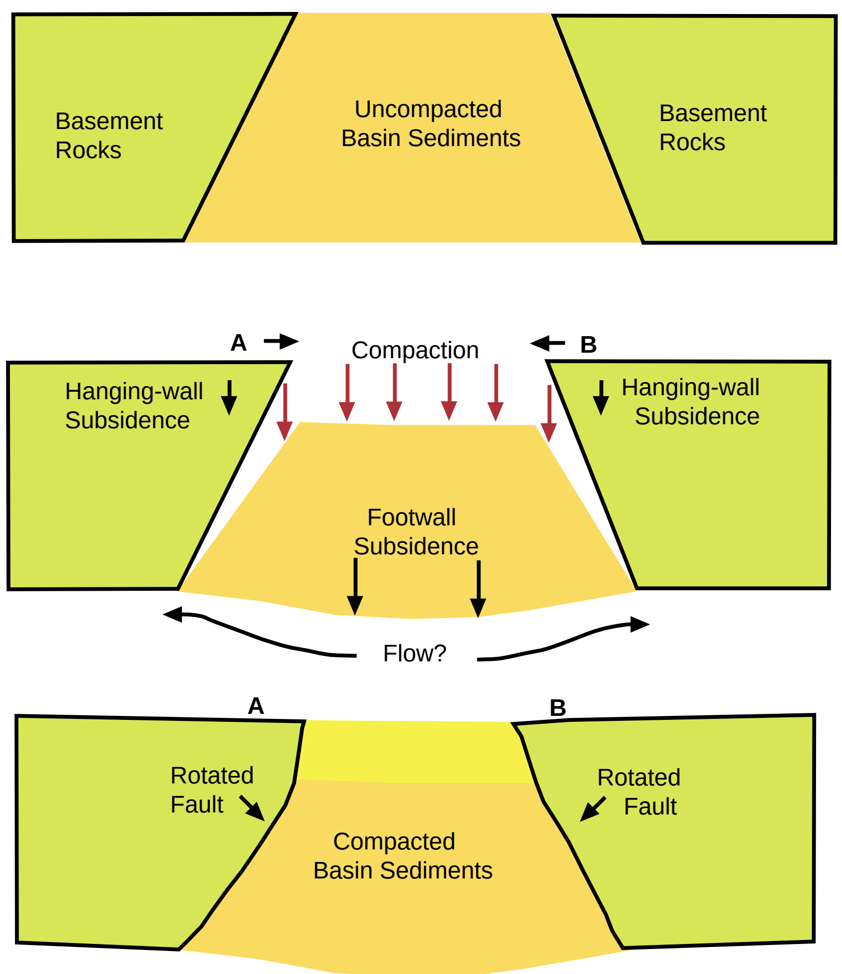


Figure 2. Possible extent of the problem: Sediment compaction and its effects on vertical line lengths. **A)** Typical amount of uncompacted terrigenous sediments needed to produce a compacted 1-km section (Hamilton, 1976). **B)** Compaction curves (solidity versus depth) for sandstones, limestones, and shales (from Baldwin and Bulter, 1985). Blue line is a preliminary compaction curve for the Ventura Basin based on porosity well-logs. **C)** Relation between percent solidity (green shaded) versus percent porosity (blue shaded) during compaction. Top ratios are 1D length reductions produced by the vertical compaction.



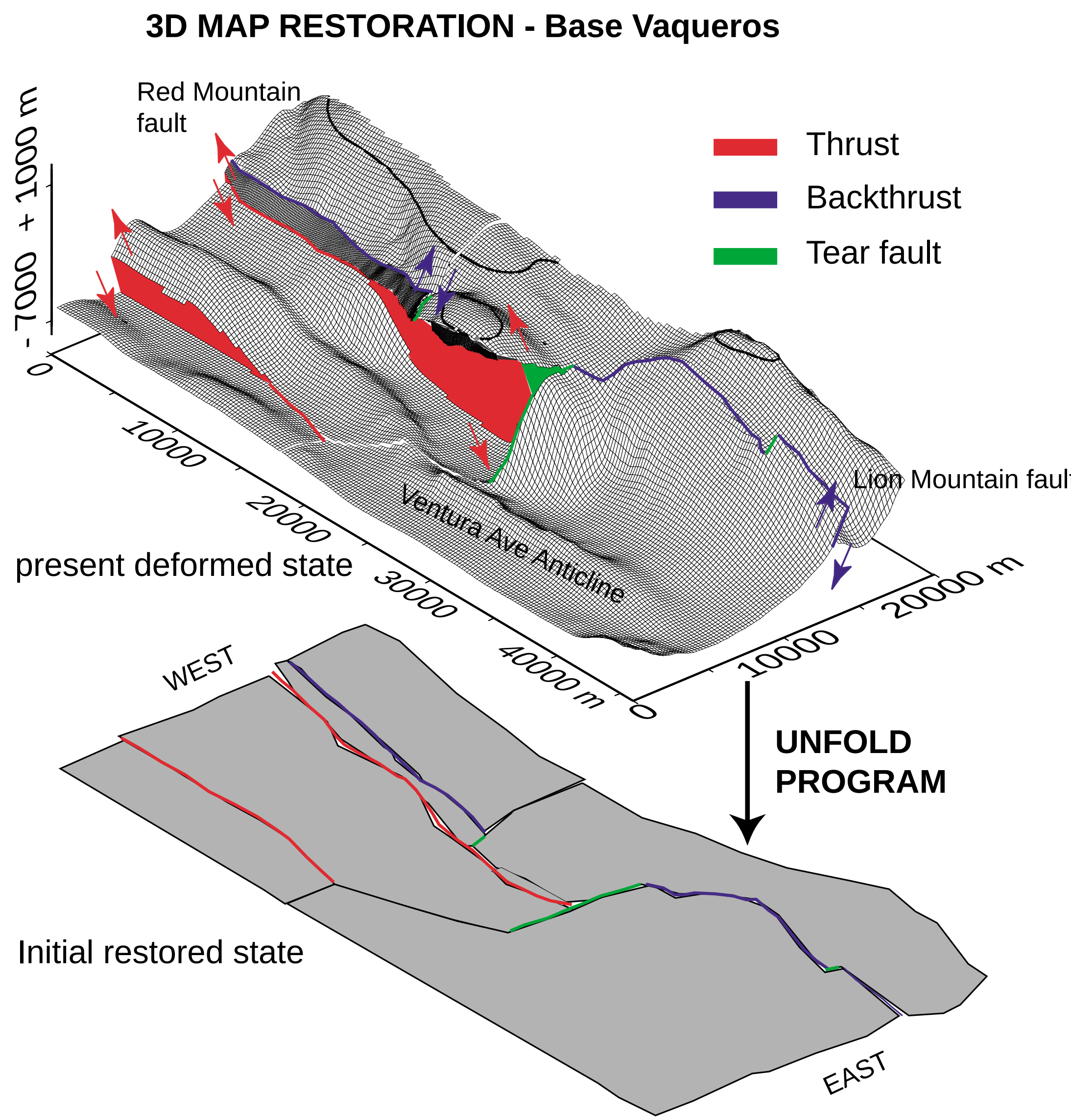


Figure 3A. Simple schematic model suggesting how differential compaction and isostatic subsidence alone can produce: (1) apparent vertical separation across faults; (2) surficial displacements (points A & B moving towards each other) that mimic tectonic shortening; (3) tilting and subsidence of hanging-wall blocks towards the basin; and (4) rotation and deformation of faults into non-planar geometry. All this in the absence of any real fault offset or net tectonic shortening.

Figure 3B. (top) Oblique 3D perspective view of Base Vaqueros. View is towards the northwest across the deep Ventura basin and Red Mountain fault (RMF). Vaqueros is a 22 Ma shallow marine deposit that has since subsided 7 km. (bottom) 3D map restoration of this surface to its initial presumed undeformed state recovers the finite strain field since deposition. The net shortening is nearly uniform along strike whether it is accommodated primarily by fault offset across the RMF (to the west) or by folding as shown farther east. This 3D surface emphasizes that a large part of the regional crustal strain is accommodated by isostatic subsidence.