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Re-Evaluation of Fault Slip, Geodetic Strain, and Seismic Hazard in the Light of Active Subsidence, Compaction, and 3D Fault Geometry

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Abstract

The highest rates of measured geodetic shortening in southern California occur across the Los Angeles and Ventura basins. This surface deformation is inferred to represent a significant seismic hazard, and is presumed to be largely accommodated by active hanging-wall faulting, folding, and tectonic uplift. In southern California, however, these deep, subsiding basins are often bounded by oblique reverse faults that thrust early-Cenozoic and older rocks over young unconsolidated sediments. This suggests that footwall deformation, subsidence, and compaction may play an important role in contributing to the apparent high rates of observed crustal strain. Although often neglected, effects like compaction can be significant. Even in the absence of active crustal shortening, sediment compaction alone can produce surficial motions that mimic deep fault slip or elastic strain accumulation. 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. Such effects would contribute to net horizontal and vertical motions in both geologic and geodetic data, and—if not properly accounted for—would result in incorrect estimates of the inferred seismic hazard.

More importantly, subsidence and compaction can increase the potential for gravity-sliding towards the basin and the development of significant non-planar 3D fault geometry. A prime example occurs along the San Cayetano fault that bounds the eastern Ventura basin. Detailed structure contour maps and cross sections of the fault surface derived from industry subsurface well data reveal a fault geometry reminiscent of thrust nappes in the western Alps. At shallow levels, a thin-skinned thrust sheet (the Modelo Lobe) with low dip extends out in front of the deep, steeply-dipping fault segment by over 4 km, is nearly 2 km thick, and occupies over 60 cubic km. This geometry is strongly indicative of gravity-driven (sackungen-type) failure resulting from hanging-wall uplift and basinward tilt enhanced by footwall subsidence and compaction. Failure of this mega-slide off the hanging-wall block most likely occurred within the Rincon Formation, a ~400-m thick ductile shale sequence that often accommodates bedding-plane or detachment slip. Further reactivation of the slide may have been accommodated by additional shale layers within the Modelo Formation, and augmented by the presence of overpressured fluids trapped below the base of the slide as a result of continued sediment compaction and overburden loading.

The thrust-nappe geometry of the San Cayetano fault has significant implications for how the fault might behave during dynamic rupture. Dynamic slip may be inhibited at shallow levels by the presence of the slide and the change in fault dip with depth. However, if the shallow thrust sheet does fail, the shallow slip may or may not be related to tectonic slip on the deep fault segment. If the thrust-nappe geometry is the result of an ancient gravity slide, the slide can be reactivated independent of slip at depth and/or aseismically. Large ruptures may reactivate the slide, either by dynamic triggering of the weak slide surface or by statically pushing the thrust wedge from behind. In either case, observations of near-surface slip or large slip events at the toe of the slide may not be indicative of tectonic slip or large earthquakes at depth on the fault. The hazard associated with such deep-seated slides is increased by their possible occurrence in oversteepened terrain, their large potential slip (unrelated to accumulated elastic strain), and by the high accelerations that may be produced if dynamic rupture is abruptly terminated at shallow depth when it encounters the slide.

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Non-technical Summary
High rates of geodetic shortening occur across the Los Angeles and Ventura basins. These deep basins are bounded by faults that thrust older rocks over young unconsolidated sediments. This suggests that footwall deformation, subsidence and compaction may play an important role in producing the apparent high strain rates. Even in the absence of active shortening, sediment compaction alone can produce surficial motions that mimic deep fault slip. Subsidence and compaction can also increase the potential for gravity-sliding and the development of non-planar 3D fault geometry. Such effects have significant implications for how the fault may accommodate slip, or behave during dynamic earthquake ruptures, and thus on estimates of regional seismic hazard.