FORUM

Late Quaternary uplift and earthquake potential of the San Joaquin Hills, southern Los Angeles basin, California: Comment and Reply

COMMENT

E. E. Bender*
Department of Geology, Orange Coast College, 2701 Fairview Road, Costa Mesa, California 92626, USA

Grant and et al. (1999) rather unequivocally demonstrated that the San Joaquin Hills, located in Orange County, California, have risen at a rate of 0.021–0.027 mm/yr over the past 122 k.y. Based largely on geomorphic evidence, they attribute this uplift as a fault-bend fold above a southwest-dipping blind thrust fault. The main structural feature in the San Joaquin Hills area has often been described as a complexly faulted, northerly plunging anticline with the Capistrano syncline bordering it on the east (Vedder, 1970; 1975; Vedder et al., 1957). However, this "anticlinal" structure is generally based on the relative regional arrangement of bedding attitude in the Topanga Formation, which was created by faulting rather than by folding (Bode, 1934; Miller and Tan, 1976; Tan and Edgington, 1976). In fact, the dominant structure in the area is faulting, most of which is subparallel to the regional northwesterly fabric of the San Andreas fault zone and other parallel fault zones to the west. Within the San Joaquin Hills, these include the Pelican Hill, Shady Canyon, and the southern part of the Laguna Canyon fault zones, as well as the offshore Newport-Inglewood fault zone. North-trending faults such as the northern portion of the Laguna Canyon fault, and east-trending faults, such as the Temple Hill fault, are also present. Of these, the dominant fault in the area is the Shady Canyon fault, which nearly bisects the area in a northwesterly direction, and has a stratigraphic throw of approximately 5,000 feet (1,524 m) (Bode, 1934; Vedder, 1970; Morton et al., 1974). The Shady Canyon fault is nearly vertical and clearly separates the area into an upthrown block exposing early Miocene and older rocks on the east, and a downthrown block exposing rocks of middle Miocene and younger age to the west (Bode, 1934; Duggan, 1961; Sullwold, 1940). One of the more interesting aspects of the displacement along the Shady Canyon fault is that the Topanga Formation and most of the Vaquers Formation are missing on the uplifted northeast block (Duggan, 1961), suggesting that this side may have been emergent as far back as the middle Miocene. The entire area appears to be defined by a combination of fault blocks, each with homoclinal structure (Miller and Tan, 1976; Tan and Edgington, 1976), that form overall anticlinal-synclinal patterns, essentially without folding. The lack of overall folding and the predominance of faulting in the area appear to make a blind thrust model unattractive.

Alternatively, the nearby Newport-Inglewood fault zone is a broad structural zone of en echelon, northwest-trending folds and vertical faults extending from the southern edge of the Santa Monica Mountains southeastwardly across the Los Angeles basin to the offshore area near Newport Beach. Faults having similar trends and projections occur offshore of San Clemente and in San Diego (the Rose Canyon and La Nacion faults). Harding (1973) suggested that the Newport-Inglewood fault zone was a classic example of a wrench fault. Typically, wrench faulting consists of a relatively narrow, subvertical principal displacement zone at depth, and, within the sedimentary cover, of braided splays that diverge and rejoin both upward and laterally (Christie-Blick and Biddle, 1985). These arrays of upward-diverging fault splays are "flower structures" (Harding and Lowell, 1979). Indeed, such structures have been shown to exist along the Newport-Inglewood fault zone (Harding, 1979; Wright, 1991), and the extensive, nearly vertical faulting observed in the San Joaquin Hills is suggestive of such a structure extending off of the fault zone.

It appears more likely, on geologic grounds, to suggest that the uplift within the San Joaquin Hills is generated by squeezing upward along the Newport-Inglewood fault zone in shortening deformation accompanying northwest-southeast horizontal shear or transpression.

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*E-mail: ebender@lib.occ.cccd.edu.

REPLY

Lisa B. Grant
Department of Environmental Analysis and Design, University of California, Irvine, California 92697-7070, USA
Karl L. Mueller
Department of Geological Sciences, University of Colorado, Boulder, Colorado 80309, USA
Eldon M. Gath
Department of Environmental Analysis and Design, University of California, Irvine, California 92697-7070, USA, and Earth Consultants International, 2522 N. Santiago, Suite B, Orange, California 92867, USA
Rosalind Munro
Leighton and Associates, 17781 Cowan, Irvine, California 92614, USA

We welcome the opportunity to further discuss the Quaternary tectonics and earthquake potential of the San Joaquin Hills in response to Bender's comments about our paper. We summarize and address each of his main points below.

Bender contends that there is a "lack of overall folding" in the San Joaquin Hills and the "anticlinal structure . . . was created by faulting rather than folding." The structure of the San Joaquin Hills is complex and was created by at least two phases of deformation. Bender carefully describes older structures. As indicated by the title of the paper, our research focuses on younger Quaternary structures, landforms and relief of the San Joaquin Hills, and their significance for seismic hazard. The pattern of Quaternary uplift and folding of the San Joaquin Hills, as evidenced by the distribution of marine terrace deposits and geomorphology, is significantly less complex than the pre-Quaternary structures. Quaternary uplift, as defined by marine terraces, is superimposed on older Cenozoic structures, basin sediments, and intrusive volcanic rocks related to Miocene extension (Crouch and Suppe, 1993; Wright, 1991). Most of the faults Bender mentions were active prior to deposition of the late Miocene-Pleistocene depositional sequence of the Los Angeles basin (Yeats, 1973; Wright, 1991) and their last movements predate development of the seismically active strike-slip Newport-Inglewood fault zone, which initiated movement in the Pliocene (Yeats, 1973). Latest movement of the Shady Canyon fault was in late middle or early late Miocene (Tan and Edgington, 1976). With the exception of the Pelican Hill fault zone, none of these faults is known to have moved during the Quaternary.

The slip rate and significance of the Pelican Hill fault zone has been studied by geotechnical consultants Leighton and Associates and summarized by Clark et al. (1986). Strands of the Pelican Hill fault zone displace Quaternary terrace deposits. We have observed approximately 8 m of vertical separation of terrace 7 (age 900–1000 k.y.) at Pelican Hill, approximately 1 m of vertical separation of terrace 3 (age 212–340 k.y.) immediately north of Laguna Beach, and no deformation of terrace 2 (age 122 k.y.) anywhere along the coast. At the head of upper Newport Bay, meter-scale displacements were mapped in the terrace 2 deposits (122 k.y.), but they were overlain by undisturbed Holocene deposits (Clark et al., 1986). (Terrace numbers and ages from Grant et al., 1999.) From these observations, the Pelican Hill fault zone appears to be an abandoned secondary structure that ruptured infrequently in response to uplift of the San Joaquin Hills, movement of the Newport-Inglewood fault zone, or both.

Bender's conclusion that uplift within the San Joaquin Hills is generated by squeezing upward along the Newport-Inglewood fault zone by shortening that accompanies northwest-southeast horizontal shear (i.e., transpression) agrees with our statement that, "We prefer to interpret movement of the San Joaquin Hills blind thrust to be the product of partitioned strike-slip and compressive shortening across the southern Newport-Inglewood fault zone," (p. 1034, Grant et al., 1999). However, we disagree with Bender's assertion that the structure of the San Joaquin Hills and proximity to the Newport-Inglewood fault make a blind thrust model unattractive. His interpretation is based on a model of the Newport-Inglewood fault zone as a classic example of a wrench fault (Harding, 1973). The wrench fault model was defined by Wilcox et al. (1973). In that classic paper, the authors describe the San Andreas fault in central California as an example of a wrench fault with a series of en echelon folds on the eastern side of the fault. These folds (anticlines) are now known to be underlain by seismogenic blind thrust faults (Stein and Yeats, 1989; Stein and Ekstrom, 1992) created by transpressive strain partitioned across western California (Lettis and Hanson, 1991). A similar structural relationship probably exists between the Newport-Inglewood fault zone and the San Joaquin Hills.

Our data and geomorphic analysis do not provide detailed constraints on the geometry of the San Joaquin Hills blind thrust, as we acknowledged in our paper. Research into the structural relationship between the San Joaquin Hills blind thrust, the Newport-Inglewood, or other regional faults is ongoing. Our data do provide strong evidence that the San Joaquin Hills are rising in response to a potentially seismogenic, underlying blind fault, and we suggest that this potential earthquake source should be included in regional seismic hazard models.

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