RECEIVED MAY 0 1 1991

Finite Element Modeling of Fault-Related Deformation in Southern California

Award No. 14-08-0001-G1780

Eugene Humphreys and Ray Weldon
Department of Geological Sciences
University of Oregon
Eugene, Oregon 97403

The southern California deformation field, and associated uncertainties, are estimated by finite element modeling of a faulted elastic plate. Most significantly, this provides slip rate estimates of the major faults. The faulted plate is driven by (1) the NUVEL Pacific-North America velocity at the model margins, (2) VLBI line-length rate of change data, (3) geologically-estimated fault slip rates, and (4) the fault geometries. An important property of this modeling is that is provides a kinematically consistent solution. A perfect (i.e., strain-free) solution is not possible; rather, we find the deformation field that minimizes the strain energy within the elastic blocks. As such, our use of finite element modeling is solely for kinematic purposes; calculated stresses are simply indications of kinematic misfit. (This is similar to cutting a southern California map into crustal blocks and sliding the pieces so as to best account for the displacement data listed above while minimizing overlap and underlap of the pieces.)

We address the uncertainties associated with our estimated velocity field by driving many simulations, each with a perturbed data set, and then examining the resulting velocities. The perturbed data are obtained by Monte Carlo sampling over the velocity distribution of each datum, using the cited uncertainties in their values.

Geodetic models (with slip-rate data given very low weight) and geologic models (with no VLBI data) are mutually consistent within 95% confidence at most locations. However, the geodetic models have velocities east of the San Andreas fault that are 2-5 mm/yr greater than the geologic models (velocities with respect to North America). Near VLBI sites at Jet Propulsion Lab and Pearblossom, both located in major fault zones, motion is better explained by present-day accumulation of elastic strain related to the earthquake cycle than to steady-state fault slip.

The best-fit velocity field is shown in Figure 1. This solution has: the Sierra Nevada-Great Valley block moving at 10±1 mm/yr N44°W±6°; oblique convergence (N8°W±8°) across the central California coastal region at 7½±1½ mm/yr; relatively rapid north-northwesterly motion of the Mojave (9±1 mm/yr N22°W±16° at Roger Lake); and significant rotation of crust south of the big bend of the San Andreas fault, consistent with 10-15 mm/yr of right-lateral slip west of the Elsinore fault. This figure also shows the variance in the velocity of each element; owing to uncertainties in San Andreas fault slip rate in the Mojave and convergence rates across the western Transverse Ranges, the Transverse Ranges velocities are the least well constrained. Figure 2 shows the resulting fault slip rates. Figure 3 shows the uncertainty in velocity of a few selected points.

An aspect of southern California kinematics that has not been well investigated is the consequence of a more westerly orientation of the Pacific plate than allowed by the uncertainties admitted by NUVEL. However, a Pacific orientation 5° more westerly than NUVEL reduces the overall strain energy of the model, and results in significantly different velocities of some regions (such as a more westerly Sierra Nevada-Great Valley block and less crustal rotation south of the Transverse Ranges). What the presented deformation maps show is that under the constraint of NUVEL relative Pacific-North America motion, a kinematically reasonable solution is available. All such solutions are similar to that shown in the included figures.

Important aspects of this modeling capability are: new data are incorporated easily, and the kinematic consequences of various assumptions (such as assumed fault activity in a region) can be tested easily.

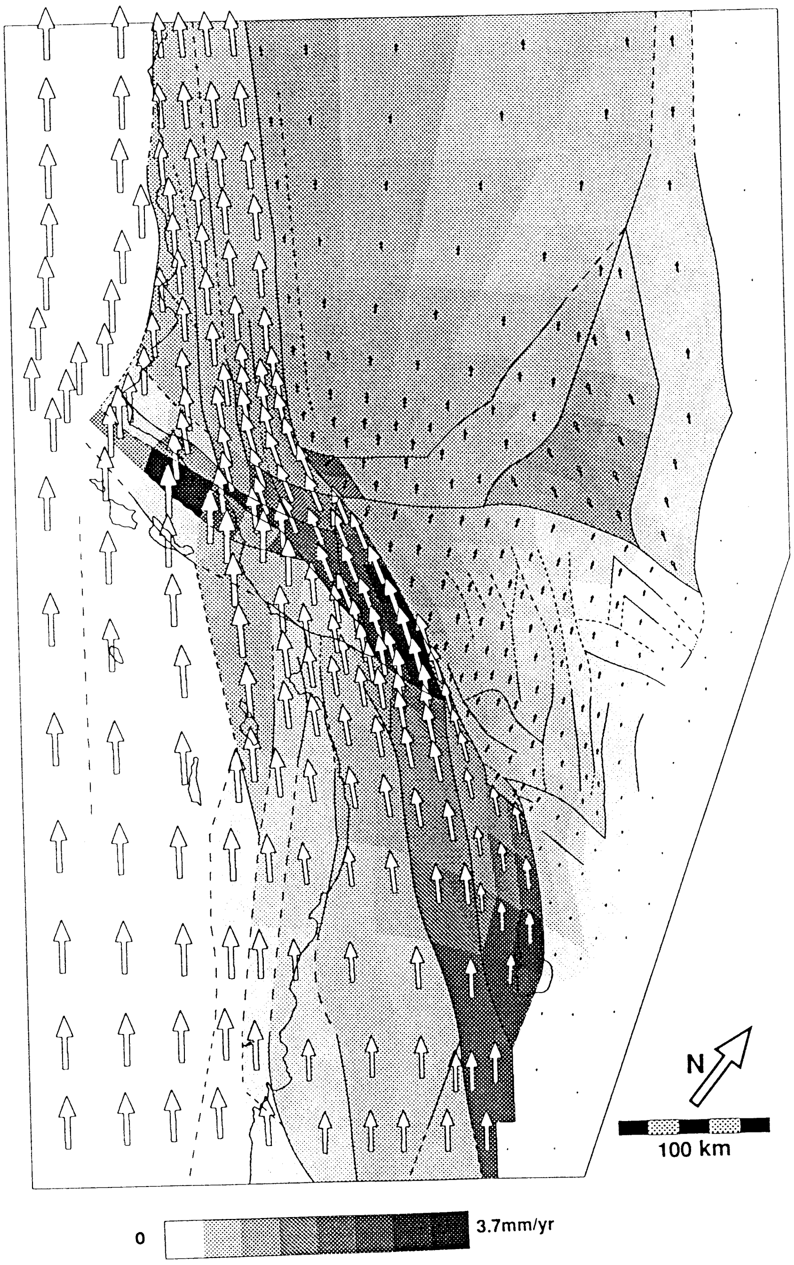

Figure 1. Velocities and uncertainties of joint geologic-geodetic model of southern California kinematics. Velocities are with respect to North America, and maximum values are the NUVEL Pacific-North America value of 49 mm/yr. Gray shading indicates the variance in velocity of the shaded element, as indicated with the scale.

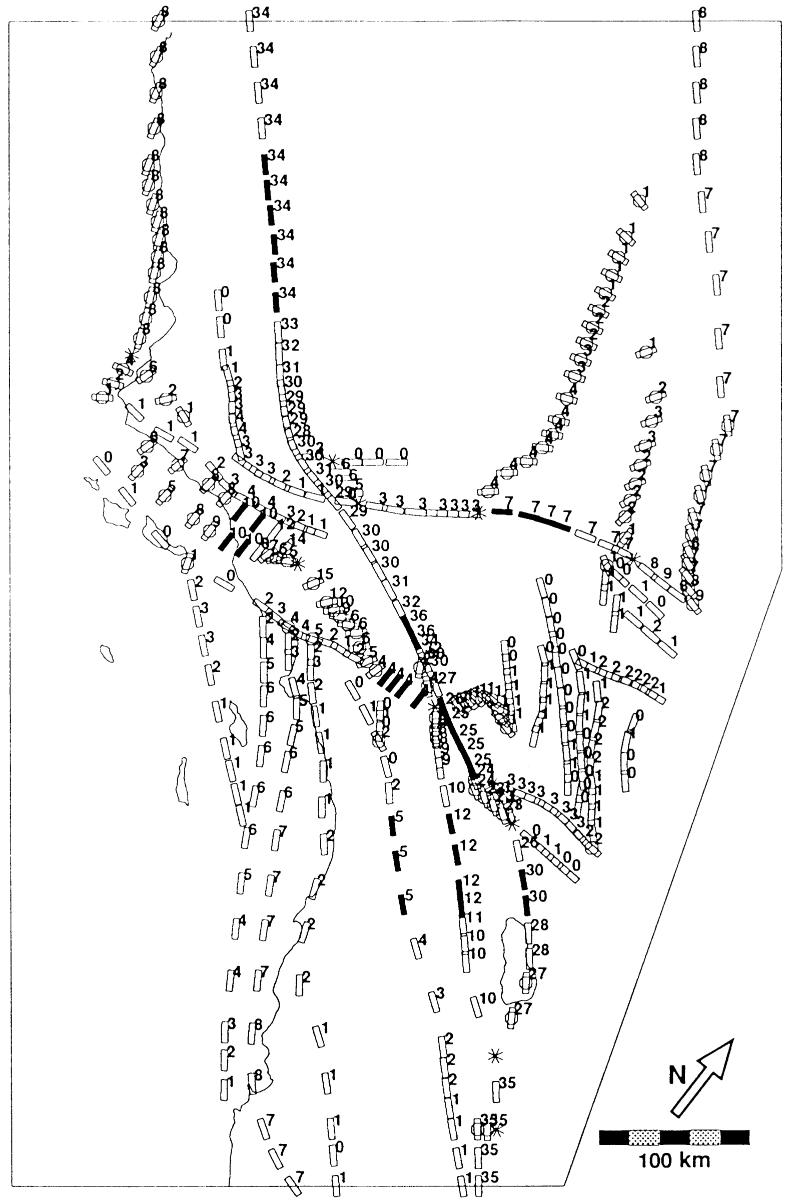

Figure 2. Fault slip rates of joint geologic-geodetic model of southern California kinematics. Values are in mm/yr. Open rectangles are "slippery nodes", which allow free slip in the direction indicated by the rectangle orientation; the rate is model determined. Solid rectangles are "split nodes", which imposes a rate of the indicated amount in the indicated direction. Rectangles with circles represent a "cut", which allows complete freedom in rate and orientation; rectangle orientation is model-determined slip orientation. Stars represent triple junctions, which allow freedom of motion.

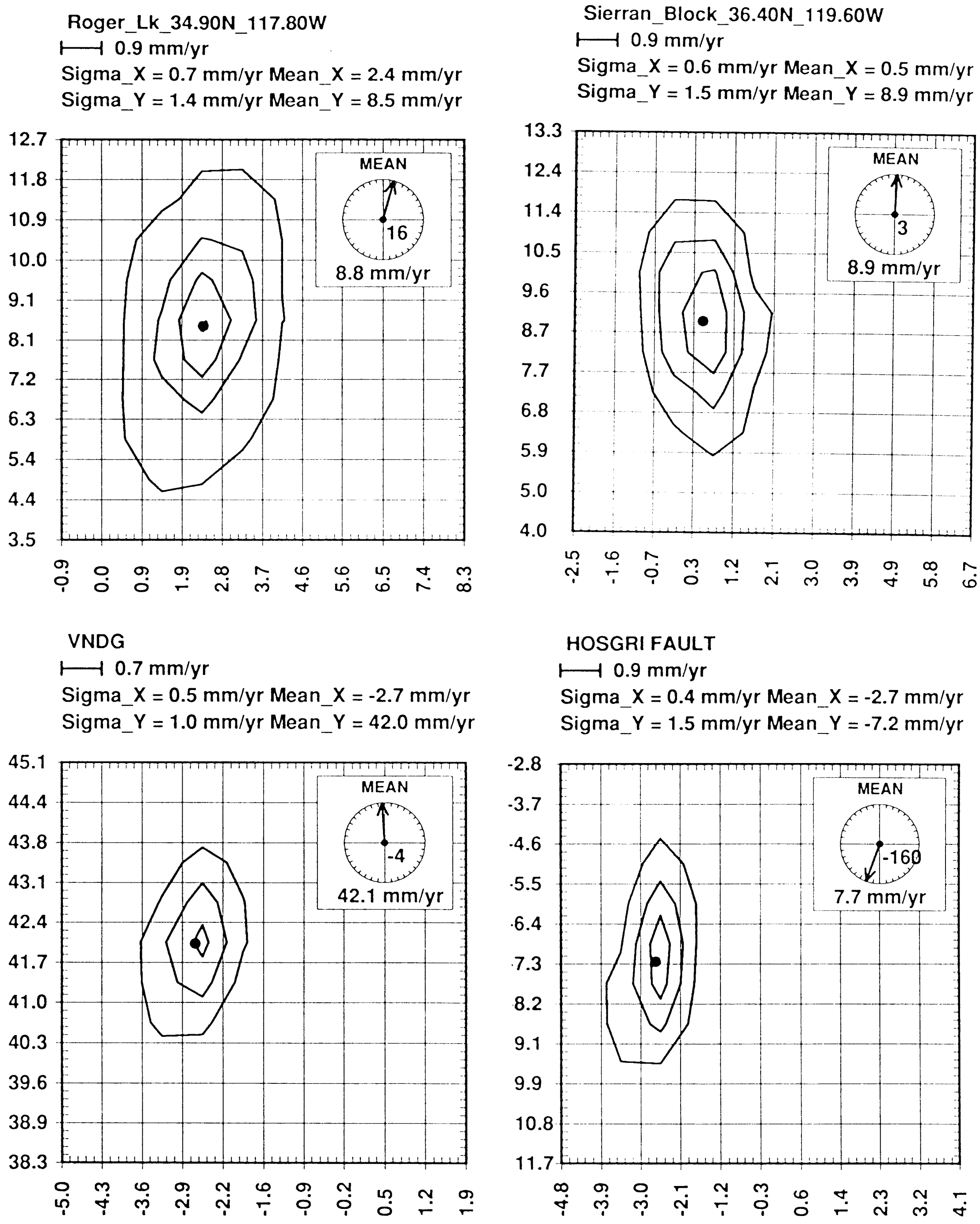

Figure 3. Contoured probability of velocity for selected locations. Rates in mm/yr, probability contours are, 30%, 60% and 90% certainty, and the dot is the probability centroid. Vertical axis is velocity parallel to NUVEL Pacific, and horizontal axis is velocity normal to NUVEL Pacific. Inset shows velocity of the centroid, where up is NUVEL parallel. "VAND" represent the VLBI site at Vandenberg.