

Transient strain accumulation and fault interaction in the Eastern California shear zone

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ABSTRACT

Satellite synthetic aperture radar interferometry reveals transient strain accumulation along the Blackwater–Little Lake fault system within the Eastern California shear zone. The surface strain map obtained by averaging eight years (1992–2000) of Earth Resource Satellite (ERS) radar data shows a 120-km-long, 20-km-wide zone of concentrated shear between the southern end of the 1872 Owens Valley earthquake surface break and the northern end of the 1992 Landers earthquake surface break. The observed shear zone is continuous through the Garlock fault, which does not show any evidence of left-lateral slip during the same time period. A dislocation model of the observed shear indicates right-lateral slip at 7 ± 3 mm/yr on a vertical fault below ~ 5 km depth, a rate that is two to three times greater than the geologic rates estimated on northwest-trending faults in the eastern Mojave area. This transient slip rate and the absence of resolvable slip on the Garlock fault may be the manifestation of an oscillatory strain pattern between interacting, conjugate fault systems.

Keywords: strain transient, synthetic aperture radar interferometry, Eastern California shear zone.

INTRODUCTION

Tectonic faults are zones of localized deformation that accommodate plate motion by creeping aseismically at depth and by earthquakes or episodic creep in the upper crust (e.g., Savage and Burford, 1973). It is generally assumed that creep on the deep section of faults and the far-field plate motion remain steady over long time periods, implying a stable rate of stress loading in the elastic part of the crust. This picture seems appropriate to describe the behavior of faults occurring at plate boundaries (Lisowski et al., 1991; Petersen and Wesnousky, 1994). Within the interior of continental plates, however, the coexistence of faults of various nature, orientation, and direction produces unstable mechanical systems, leading to unsteady kinematics over geological time scales. The time constants involved in processes governing interacting fault systems depend on the geometry of the system, the rates of slip on individual faults, and the amount of distributed strain the crust can accommodate before yielding new faults. Synthetic aperture radar interferometry (InSAR) data covering the 1992–2000 time period bring new insights into the interseismic surface strain field of the area of the Mojave Desert, California, where the Garlock fault and the Eastern California shear zone intersect. The data reveal, in particular, rates and a spatial distribution of the strain that are inconsistent with long-term fault-slip rates determined from geological data, suggesting unsteady kinematics in the northern Mojave.

GEOLOGIC SETTING

The Eastern California shear zone is a 100-km-wide zone of deformation trending approximately N24°W from the eastern end of the compressive fault-bend jog in the San Andreas into the region of east-west extension that bounds the Sierra Nevada block to the east (Dokka and Travis, 1990a, 1990b) (Fig. 1). In the Mojave Desert, the shear zone is formed of several parallel, discontinuous segments bearing evidence of late Cenozoic right-lateral slip. North of the Garlock fault,

the shear zone encompasses the Owens Valley Little Lake, the Hunter Mountain Panamint, and the Death Valley fault systems (Fig. 1). Geologic (Dokka and Travis, 1990a) and geodetic (Savage et al., 1990; Sauber et al., 1994; Gan et al., 2000; Miller et al., 2001) data concur to indicate that the shear zone accommodates 6–14 mm/yr of right-

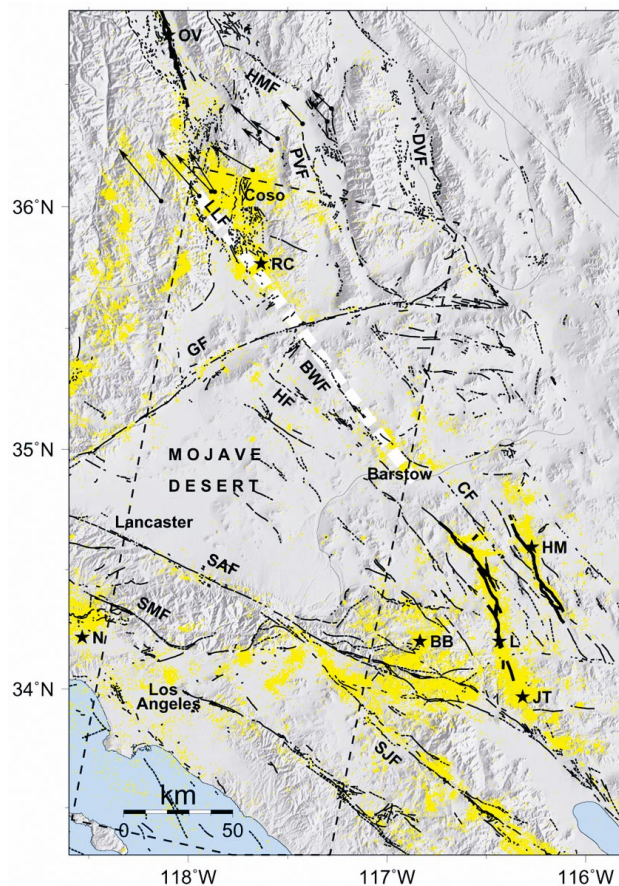


Figure 1. Tectonic map of southern California. Solid lines are active faults (Jennings, 1975). Yellow dots are relocated earthquakes between 1981 and 2000 (Hauksson, 2000). Dashed-line box is area covered by Earth Resource Satellite (ERS) data used in this study. White dashed line shows location of concentrated shear observed in synthetic aperture radar (SAR) data. Black stars indicate epicenters of recent earthquakes: OV—1872 Owens Valley, JT—1992 Joshua Tree, L—1992 Landers, BB—1992 Big Bear, N—1994 Northridge, RC—1994 and 1995 Ridgecrest, HM—1999 Hector Mine. Heavy solid lines depict surface ruptures of Landers (Sieh et al., 1993), Hector Mine (U.S. Geological Survey and California Division of Mines and Geology, 2000; Peltzer et al., 2001), and Owens Valley (Beanland and Clark, 1994; only southern half of rupture is shown) earthquakes. Black dots and arrows show locations and observed velocities of 11 stations of Yucca GPS array (Gan et al., 2000). Faults: SAF—San Andreas, GF—Garlock, BWF—Blackwater, CF—Calico, HMF—Hunter Mountain, PVF—Panamint Valley, DVF—Death Valley, HF—Harper, LLF—Little Lake, SMF—Sierra Madre, SJF—San Jacinto.

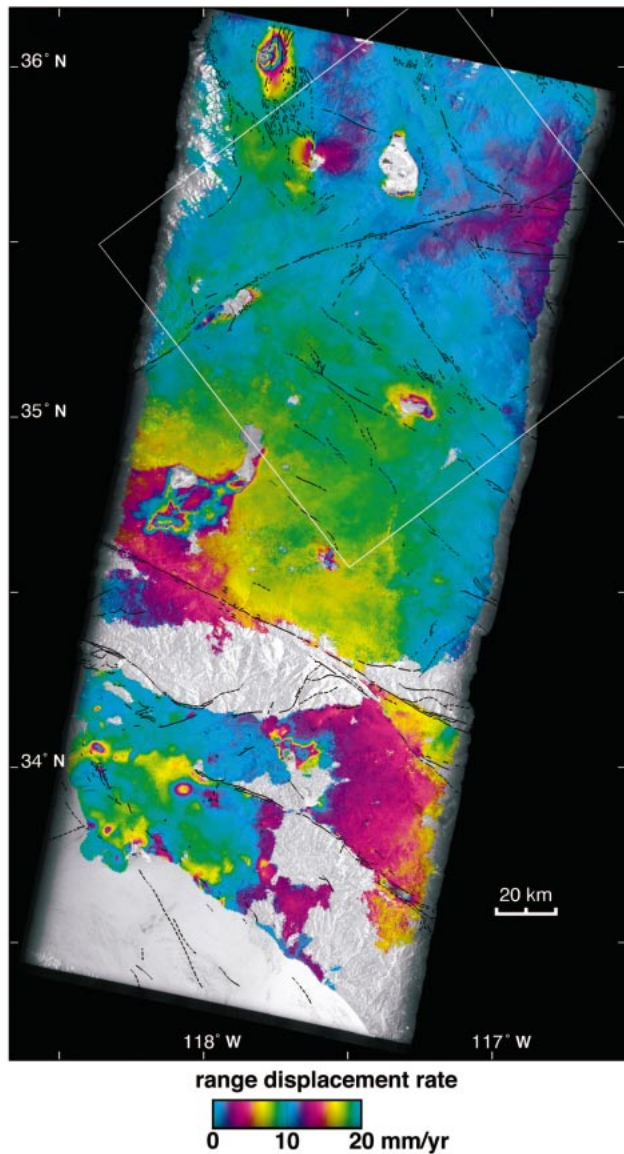


Figure 3. Surface velocity map obtained by averaging 25 interferograms of Los Angeles–Mojave region. One color cycle depicts 10 mm/yr of surface displacement along radar line of sight (at lat N34°; ERS [Earth Resource Satellite] descending track trends S13.6°W, radar looking westward at 23° off vertical incidence angle in middle of imaged swath). Gray areas are zones of low phase coherence that have been masked in processing. Black lines are active faults (Jennings, 1975). White box indicates subset of synthetic aperture radar (SAR) data that was used for profile in Figure 4. Note conspicuous shear strain along San Andreas fault and shear zone parallel to Blackwater–Little Lake fault system. Large deformation signal in northwest corner of frame is ground subsidence related to Coso volcanic and geothermal field (Fig. 1). Surface displacement associated with 1994 and 1995 Ridgecrest earthquakes is visible south of Coso area. Other patterns of surface deformation include ground subsidence due to groundwater withdrawal in Los Angeles and Lancaster areas (Fig. 1) and to seasonal change of water table level around dry lakes.

irregular return periods (McGill and Rockwell, 1998; Dawson, 2000). Dawson (2000) suggested a correlation between the occurrence of six well-determined events on the Garlock fault and the clusters of seismic activity observed in the southern section of the shear zone. Four of the six Garlock events fall in the most recent cluster; the two other events occurred at 5.1 ka and 6.8 ka—i.e., slightly postdating and pre-dating

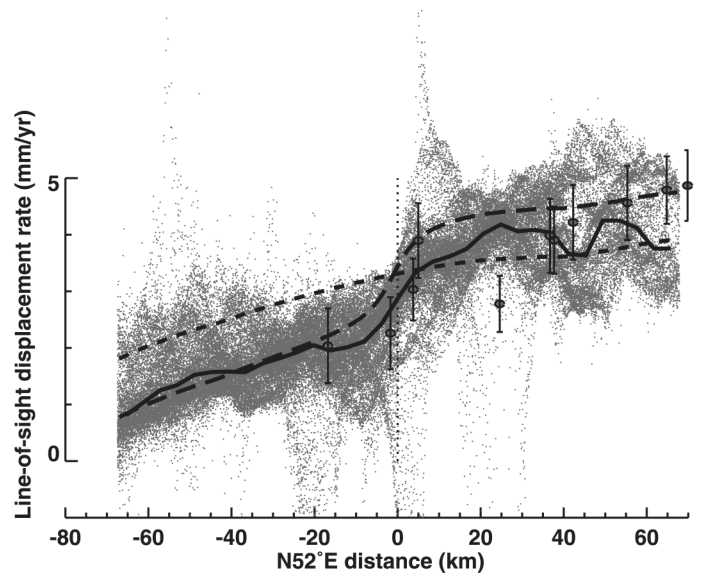


Figure 4. Profiles of observed and modeled line-of-sight displacement projected on vertical plane perpendicular to shear zone. Gray dots are individual data points for all radar-image pixels included in box shown in Figure 3. Solid line shows 2 km running mean of observed displacement along profile length. Note that apparent standard deviation of projected data relative to average profile reflects in part displacement gradient parallel to fault strike and not only error in data. Groups of dots that deviate from dense part of profile are due to ground subsidence near lake shores and to surface displacement associated with Ridgecrest earthquakes (Figs. 1, 3). Short-dash line is profile predicted by long-term velocity model used to estimate interferometric baseline (Shen et al., 1996). Long-dash line is profile predicted by velocity model, including additional buried dislocation along Blackwater–Little Lake fault system. Parameters of added fault are given in text. Black dots and error bars (2σ) are line-of-sight projections of horizontal velocities observed by GPS at stations of Yucca transect (Gan et al., 2000).

the penultimate shear zone cluster centered at 5.5 ka. A similar pattern is observed in eastern Turkey, where the sequence of large earthquakes during the past three centuries suggests that the locations and periods of occurrence of seismic moment release alternate between the East Anatolian fault and the North Anatolian fault (Ambraseys, 1973). Using Coulomb stress models, Hubert-Ferrari (1998) interpreted this pattern as the result of the mechanical interaction between the two conjugate fault systems.

Another, nonexclusive way to explain the present rapid shear strain on the Blackwater–Little Lake fault system is to advocate a postseismic process subsequent to the recent large earthquakes in the Eastern California shear zone. The observed shear zone links the southern end of the 1872 Owens Valley surface rupture (Beanland and Clark, 1994) in the north to the northern end of the 1992 Landers surface break in the south (Sieh et al., 1993) (Fig. 1), defining a section of the shear zone that can be viewed as a seismic gap. Coseismic slip and viscoelastic relaxation in the lower crust and upper mantle following these events may have increased the shear stress along the Blackwater–Little Lake fault zone, leading to accelerated fault creep at shallow depth during the past decade. A trend of triggered seismicity was observed after the Landers earthquake from the northern end of the rupture to the southern Owens Valley (Roquemore and Simila, 1994). Furthermore, the sharp displacement gradient observed near the southern end of the imaged section of the shear zone is collocated with the swarm of seismicity that occurred near Barstow after the Landers earthquake (Hauksson et al., 1993; Price and Sandwell, 1998).

CONCLUSIONS

The surface velocity map of the Mojave area obtained by averaging 8 yr of ERS interferometry data reveals that ~50% of the right-lateral motion of the Eastern California shear zone is sharply concentrated along the Blackwater–Little Lake fault system continuously across the Garlock fault. This anomalously fast slip rate and the absence of detectable left-lateral motion along the eastern section of the Garlock fault during the same time period may be the manifestation of an oscillatory strain pattern caused by stress transfer between the two intersecting faults. The absence of Quaternary fault trace across this section of the Garlock fault may indicate that the connection between the Blackwater and the Little Lake faults has never been established in the past; the observed shear would then reveal the birth of a new fault.

The rapid strain accumulation observed along the Blackwater–Little Lake fault system indicates that the fault is currently accumulating stress in the shallow crust at a rate that exceeds the long-term rate inferred from geological data by a factor of about three. Concerns about a potential earthquake on the Calico–Blackwater fault were raised after the 1992 Landers earthquake by the Working Group on the Probabilities of Future Large Earthquakes in Southern California (1992). Should this section of the fault system break in a single event, it would generate an earthquake of magnitude >7 and a surface break exceeding 100 km in length. Such a break would link the gap between the 1872 Owens Valley and 1992 Landers surface ruptures.

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