Viscoelastic earthquake cycle models with deep stress-driven creep along the San Andreas fault system

K. M. Johnson and P. Segall
Geophysics Department, Stanford University, Stanford, California, USA

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[1] We develop a two-dimensional boundary element earthquake cycle model including deep interseismic creep on vertical strike-slip faults in an elastic lithosphere coupled to a viscoelastic asthenosphere. Uniform slip on the upper part of the fault is prescribed periodically to represent great strike-slip earthquakes. Below the coseismic rupture the fault creeps in response to lithospheric shear stresses within a narrow linear viscous fault zone. The model is applied to the GPS contemporary velocity field across the Carrizo Plain and northern San Francisco Bay segments of the San Andreas fault, as well as triangulation measurements of postseismic strain following the 1906 San Francisco earthquake. Previous analysis of these data, using conventional viscoelastic coupling models without stress-driven creep [*Segall*, 2002], shows that it is necessary to invoke different lithosphere-asthenosphere rheology in northern and southern California in order to explain the data. We show that with deep stress-driven interseismic creep on the San Andreas fault, the data can be explained with the same rheology for northern and southern California. We estimate elastic thickness in the range 44–100 km (95% confidence level), fault zone viscosity per unit width of $0.5–8.2 \times 10^{17}$ Pa s/m, and asthenosphere relaxation time of 24–622 years ($0.1–2.9 \times 10^{20}$ Pa s) for northern and southern California. We estimate a slip rate of 21–27 mm/yr and recurrence time of 188–315 years for the northern San Francisco Bay San Andreas fault and slip rate of 32–42 mm/yr with recurrence time of 247–536 years for the Carrizo Plain. *INDEX TERMS:* 8107 Tectonophysics: Continental neotectonics; 8159 Tectonophysics: Rheology—crust and lithosphere; 8150 Tectonophysics: Plate boundary—general (3040); *KEYWORDS:* San Andreas, slip rates, GPS

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1. Introduction

[2] Interseismic deformation at the ground surface across major strike-slip faults is characterized by strain rates that are highest near the trace of the fault and decay with distance laterally away from the fault. For example, along the Carrizo Plain section of the San Andreas fault, GPS data provide the contemporary velocity distribution across the section of the fault that last ruptured in 1857 as displayed in Figure 1 (http://www.scecdc.scec.org). The data show high strain rates at the fault trace that decrease to nearly zero within about 80 km of the fault. In the San Francisco Bay area, we have both the contemporary GPS velocity field [*Prescott et al.*, 2001] and longer term deformation rates obtained by repeated triangulation surveys at Point Arena and Point Reyes [*Kenner and Segall*, 2003]. Figures 2a and 2b show the velocity distribution across the 1906 break of the San Andreas fault and the adjacent Hayward-Rodgers Creek and Concord-Green Valley faults. We again see the highest strain rates near the San Andreas and adjacent faults. Figure 2c shows a 90-year record of strain rates following the 1906 earthquake. The strain rate across the 1906 rupture was initially high after the earthquake and has been decreasing since.

[3] Several analytical models of interseismic deformation along strike-slip faults such as the San Andreas fault have been proposed, all based on the premise that the distribution of strain across a strike slip fault is a result of locking of the fault in the upper part of the lithosphere as the plates on either side of the fault move past one another. *Savage and Burford* [1973] proposed a mechanical model of interseismic strain accumulation using a buried screw dislocation in an elastic half-space (Figure 3a). In this model the mechanism by which the plates move past one another is approximated with uniform sliding on a buried vertical dislocation extending from the locking depth to infinite depth. The slip rate is prescribed to be equal to the far-field plate rate.

[4] A presumably more realistic model in which crustal deformation occurs in response to coupled viscous flow in the asthenosphere was first proposed by *Nur and Mavko* [1974]. This so-called viscoelastic coupling model consists

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