Measurements in the Creeping Section of the Central San Andreas Fault

Duncan Agnew, Andy Michael

Introduction

We propose the PBO instrument, with GPS and borehole strainmeters, the creeping section of the San Andreas fault in central California, to enhance our understanding of the mechanics of how a major transform fault can slip aseismically. This area was studied in the 1970's, but has been neglected more recently, since the seismic hazard is thought to be low and the risk even lower—though at Parkfield, south of the area we discuss here, there is a high density of measurements. We believe that studies of the creeping section can help resolve key issues currently unclear about how transform faults, of which the San Andreas is one of the most accessible, in fact work.

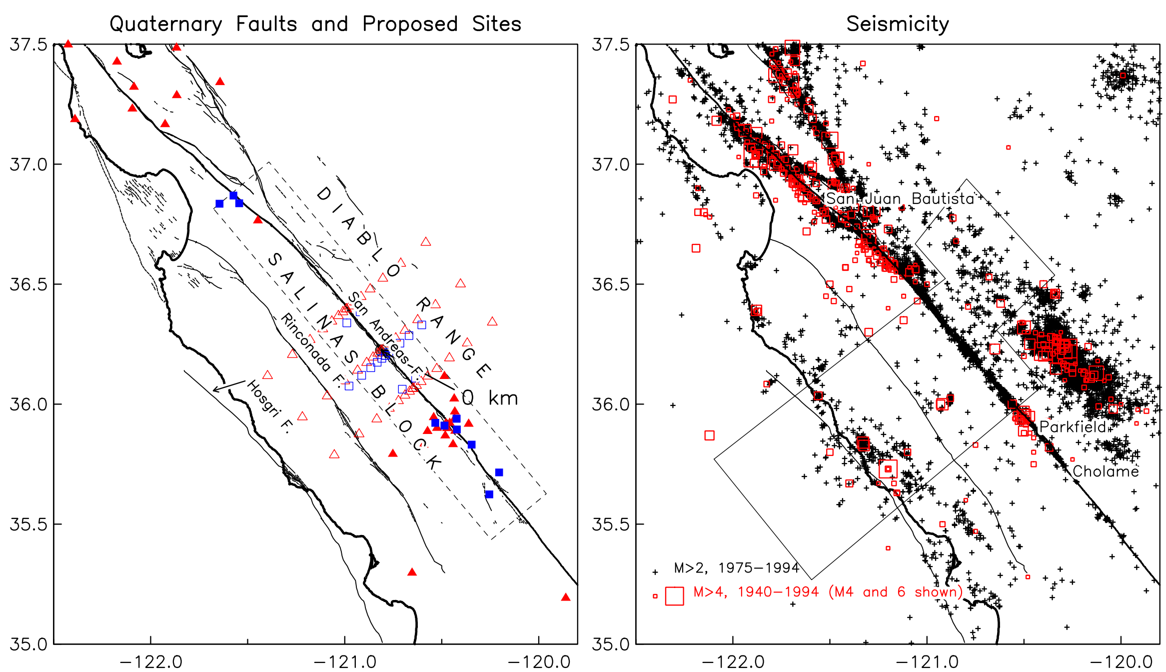

Figure 1. On the left, red triangles are CGPS, and blue squares borehole strain: in both cases, solid for existing or planned, open for proposed here.

Seismotectonics of the Central San Andreas

Figure 1 shows the region of central California around the San Andreas fault (SAF). The seismicity associated with the SAF occurs in a very narrow band, but there are significant amounts off the fault, most notably the Coalinga/Kettleman-Hills earthquake sequence. To show off-fault seismicity uncontaminated by this event, we have defined the box shown in the right panel; Figure 2 shows earthquakes in this box in cross-section. The SAF bounds different seismic regions: the Diablo Range to the NE shows diffuse seismicity down to considerable depths, while the Salinas Block is nearly aseismic, with the seismicity increasing again in the region of the Hosgri fault.

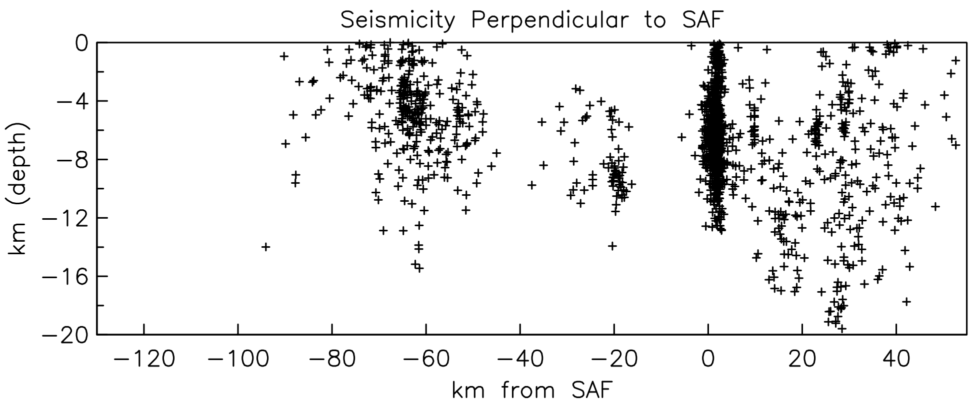

Figure 2

In **Figure 3** we show the the different kinds of behavior along the San Andreas. The fault geometry (top) is as simple here as anywhere. The seismicity plots show that the central part of the fault has, for the last 55 years, been free of any earthquakes larger than magnitude 4. Of course, this is also true of parts of the SAF that have broken in great earthquakes; what is remarkable about this section is what is shown in the bottom panel, namely that the fault here creeps continuously at the surface, with slip extending to the surface in a very narrow zone (~100 m wide). The rate measured over this zone is nearly equal to the full rate of slip for the San Andreas of 34 mm/yr (Burford and Harsh, BSSA, 1980; Lisowski and Prescott, BSSA, 1981) which suggests that there is no depth at which the fault is locked; the motion seems to just be two blocks sliding past each other, with no deformation in either one, and no earthquake cycle. Except for one zone of complexity near Monarch Peak, even the rate of small earthquakes is low. Except perhaps for one part of the North Anatolian fault, in Turkey, such behavior is known nowhere else.

What are the mechanics at work to produce these effects? It was thought that the fold belts near the San Andreas were produced as byproducts of the shearing stresses that drove the fault motion in a classic example of ‘‘transpression’’. However, stress measurements near this portion of the fault showed that the principal axis of compression was nearly normal to the SAF, which was interpreted as showing that the SAF was ‘‘weak’’, in the sense that little shear stress was needed to cause it to slip (a conclusion in consonance with the long-known lack of a heat-flow anomaly along the fault). The stress state would thus be dominated by a large compressional stress nearly normal to the fault: the small part not normal to the fault would provide the shear stress needed to make the fault slip The transpression is then effectively two independent processes (of compression and shear) which are largely decoupled. This decoupling might be accommodated mechanically by a mid-crustal detachment. Such a detachment might change form at the San Andreas; this could provide an explanation of the otherwise puzzling question of why folding (and seismicity) occurs only east of the fault.

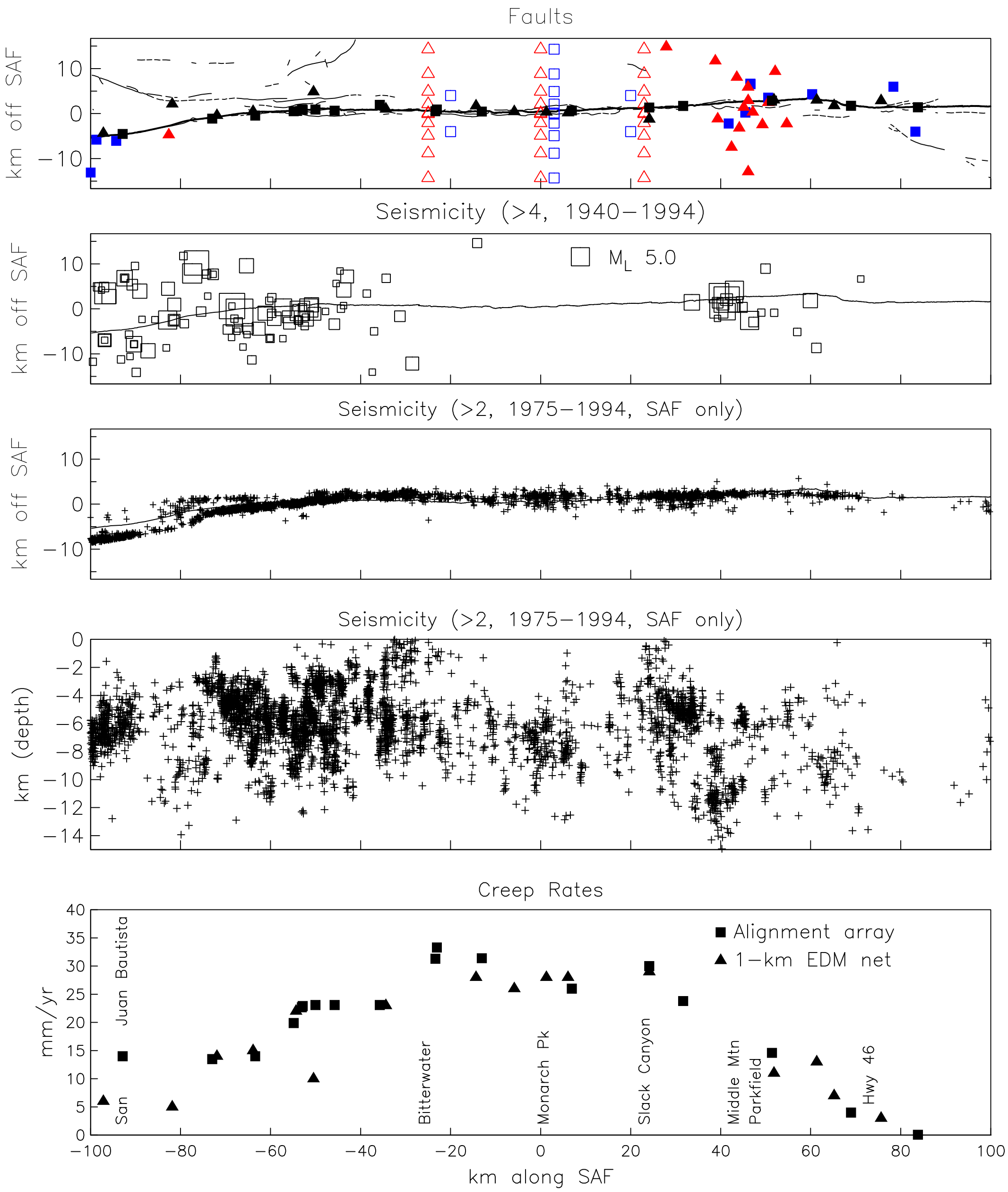

Figure 3

Given deformation measurements around this part of the fault, we can test between two possibilities:

(A) On geodetic time scales, the Diablo Range is deforming while the Salinas side is not. There are then two possible models: (1) the stress field is different on the two sides (because of some structural complexity) or (2) the stress is the same, but different deformation rates result because of differences in the flow laws for the ductile material underneath the elastic lithosphere.

(B) The current deformation is the same on both sides of the fault. Then the difference in long-term deformation would imply that one side responds to the tectonic stress by deforming, while the other side never leaves the elastic regime. This requires two conditions: (1) a difference in strength (failure point) between the materials of the lithosphere (on the two sides of the San Andreas), and (2) tectonic stress which at times reaches a level above the failure stress of one side but always remains below that of the other.

There is some data available on this already, from Thatcher (1979) using a triangulation network SW of the San Andreas, and by Sauber *et al* (1989) using a triangulation network to the NE. On neither side of the fault do the rates differ significantly from zero; given the uncertainties in these determinations (dominated by the low precision of even first-order triangulation), it is difficult to conclude much except that the strain rates are not high.

We note that there is some reason to question this simple picture of a purely creeping fault. Over the last decade, a number of authors (e.g. Michael and Eberhart-Phillips, Science, 1991; Michelini and McEvilly, BSSA, 1991; Eberhart-Phillips and Michael, JGR, 1993; Zhao and Kanamori, GRL, 1995; Hauksson and Haase, JGR, 1997; Eberhart-Phillips and Michael, JGR, 1998) have found a correlation between seismic images of subsurface geologic structure and the seismogenic behavior of faults. Locked fault segments tend to have higher seismic velocity material in contact with the fault and it is often difficult to identify the fault as a velocity contrast. Creeping segments have lower velocity material on one side with a sharp across-fault velocity contrast. Approximately 20 to 35 km north of Parkfield (on Figure 3, from north of Slack Canyon to south of Monarch Peak) there is a 15-km length of fault that has the seismic velocity structure and low background seismicity of a locked fault segment (Eberhart-Phillips and Michael, JGR, 1993). As noted above, common wisdom is that this whole segment is creeping; but there is no direct evidence that this segment is actually creeping throughout the entire depth of the seismogenic crust, as opposed to being locked over part of its depth.

Proposed Measurements

We propose the installation of continuous GPS and borehole strainmeters as shown by the open symbols in Figure 1 and Figure 3. There would be three profiles of GPS, and one of borehole strain, extending on either side of the fault, and with gradually incresing spacing going away from it. The closest stations would be 1 km from the fault to capture most of the motion; we further propose that the Bitterwater profile include a ‘‘GPS creepmeter’’, with two systems 100 m apart, spanning the creeping zone at a place where it is especially narrow. The profile of borehole strainmeters would be supplemented by four additional instruments, about 4 km from the fault and 20 km from the central profile; these would provide a measure of the lateral extent of any signals seen. The increasing spacing along both profiles is designed to give maximum resolution of the motions of the upper few km of the fault, while not putting out more sites than needed: far from the fault, the signals will have a longer wavelength, so there is no point in closer spacing. The total number of GPS installations would be 30 in this plan, with 15 borehole strainmeters.

The questions that could be addressed by these measurements would be:

1. How ‘‘block-like’’ is the deformation off the SAF? This relates to issues (described above) of the local tectonics, and whether locked faults can be detected by their velocity structure. More generally, measurements of off-fault strain accumulation relate to the question of whether the deformation in this region is truly aseismic. This will help to address the question of how much such behavior might occur elsewhere—especially, how much moment could be ‘‘hidden’’ by aseismic slip on other transform faults, notably oceanic ones.
2. From temperature profiling of the boreholes, is there any heat-flow anomaly present? We note that no heat-flow measurements have been made along this part of the SAF, the one place where there would not be lowering of the effective stress during earthquakes (since there are no earthquakes).
3. How steady is the slip on the SAF? Again, this is the one part of the SAF for which we do not think any significant deformation occurs as earthquakes. But, are there stick-slip events with longer time scales—especially events at what would usually be seismogenic depths? If there slip is either seismic or perfectly steady, this would be a strong constraint on possible models of fault friction: so would any departure from steadiness.

Again, we recognize that this is a unique part of the plate boundary, and one with little seismic hazard—but we believe that just because of that uniqueness, it should be a target area for the PBO.