Plate Boundary Observatory Working Group
Plan for the San Andreas Fault System

Introduction

This document puts forward a draft implementation plan for the San Andreas Fault component of the Plate Boundary Observatory. We begin by describing scientific questions that motivate the program. A key goal of the PBO is to record fault related deformation at time scales ranging from seconds to decades. Emphasis is therefore given to problems that require temporal resolution. There are many compelling and important questions that can be well addressed by determining the velocity of geodetic sites over interseismic (decadal) time scales. Such problems could undoubtedly be answered more rapidly and with greater precision with continuous measurements than with episodic campaign surveys. Nevertheless, they are given a lower priority here in comparison to first order problems that require greater temporal resolution.

Following discussion of the scientific goals, we consider general implementation issues, including the types of instruments to be used, modes of deployment and so forth. We then consider the geographic localities that are best suited to addressing the scientific goals of PBO. Specific instrumentation requests are identified with each area. These requests are based on collective scientific judgement given past experience along the San Andreas. Careful simulation and forward modeling should be conducted for each area before actual installation begins.

Scientific Goals

- *What controls the time scale of inelastic stress transfer between fault segments?* There is compelling evidence that rupture on one fault segment changes the probability of an earthquake on neighboring fault segments. The Joshua Tree – Landers – Big Bear – Hector Mine earthquakes are excellent examples, as is the sequence of quakes on the North Anatolian Fault initiated by the M7.9 Ercincan earthquake. The times between events range from hours, to years and even decades. Elastic stresses are transmitted at seismic wave speeds. Static (and to a lesser extent dynamic) stress changes are easily computed. Coulomb stress changes correlate well with future activity. Yet, we do not understand the processes that control the time scales between events. It seems unlikely that background loading, or simple clock-advance, can explain the range of observed times between events. There is good geodetic evidence for accelerated strain following large earthquakes. Borehole strainmeters have also recorded unexpectedly large transient strains following earthquakes. The processes generating the transient signals are not well resolved. The spatial resolution of borehole strain measurements from one or two instruments is low, leaving open the question of whether such strain transients occur at seismogenic depths where they could play a role in earthquake interactions. Viscoelastic relaxation of the lower crust and upper mantle, afterslip on or near the mainshock rupture, poroelastic stress alterations, and rate-state friction, have all been suggested as possible mechanisms for transient deformation and for controlling the time between triggered events. One of the few ways of discriminating between competing processes is to compare observed deformation with model predictions. If the model accurately predicts spatial and temporal variations in strain or displacement then the time dependent stresses computed from the model should be reliable. From this we seek an improved understanding of how stresses are redistributed, the mechanical properties of the lower crust and upper mantle, and the constitutive behavior of active faults.

- *How common are transient fault slip episodes, deformation events, or slow earthquakes? and how do they evolve in space and time?* Discrete strain events related to individual creep events have been observed, as well as “slow earthquakes” accompanied not only by surface creep, but also by small-to-moderate earthquakes near the ends of the creeping segments of the San Andreas at San Juan Bautista and Parkfield. Due to the paucity of instrumentation we have very little information about how common these events are. Similarly, we have limited constraints on the spatial and temporal evolution of slow slip events, and how they relate to high-frequency earthquakes. Ultra-high-precision relative earthquake locations have revealed remarkable spatial and temporal structure in the patterns of seismicity that provide important information about fault behavior. Imaging the evolution of slow earthquakes in space and time should allow us to constrain physical processes active on major faults.

- *How do earthquakes nucleate?* In particular, what are the spatial and temporal scales involved in earthquake nucleation and do these scale in any way with the size of the ultimate rupture? Theoretical models of the nucleation process well describe laboratory behavior but are poorly constrained by field observations. These models suggest small strain signals due to very localized aseismic slip at depths of 8 to 10 km. Field measurements limit the moment released during nucleation to a small fraction of the final seismic moment, yet few near-field recordings are available and none from dense arrays of instruments. Indeed, no earthquake of $M>7$ has had its epicenter within less than 10 km of a strainmeter. Thus, an important goal of the San

Andreas component of PBO is to record near-field measurements of deformation prior to earthquakes, to lead toward a better understanding of the earthquake nucleation process. The probability of actually measuring the nucleation phase of an earthquake during the lifetime of the PBO may not be great. Nevertheless, the consequences of successfully doing so are so high that we retain this as a scientific goal of PBO.

- *What is the deep architecture of fault zones?* The structure of fault zones, along with boundary conditions and rheology governs how faults are loaded. The structure of faults within the seismogenic zone is often well illuminated by microseismicity. The structure of faults beneath the seismogenic zone is poorly understood, yet critical for understanding the mechanics of faulting. Two possible end-member models involve faults that cut through thick elastic lithospheres vs. faults that splay into zones of distributed shear in the lower crust. For very long strike-slip faults, deformation measurements alone can not uniquely discriminate between these end member models. Surface deformation in combination with geologic mapping and geophysical imaging can improve our understanding of fault zone structure. A somewhat related goal is to better constrain the extent to which compliant fault zone materials, or other elastic heterogeneities alter the strain-rate field and otherwise bias interpretations of fault structure and slip distribution.

- *How slip is partitioned among the major faults of the San Andreas System?* In particular, how does slip on the full complement of faults act to accommodate the Pacific North America plate motion? Some segments of the fault system are relatively simple and characterized by a single major fault, whereas other areas contain multiple parallel strike-slip faults. The Big Bend in the San Andreas and the Transverse Ranges are zones of compressional deformation. These structures act kinematicaly to accommodate imposed plate motions. The dynamics of the interactions are not well understood. San Andreas normal motions, responsible for fault parallel folds and thrusts, are just beginning to be resolved geodetically; indications are that this deformation is very localized. Improved understanding of fault normal deformation will help elucidate the stress state near the San Andreas and the mechanics of faulting. Improved understanding of the structure of fault systems, the manner in which faults are loaded, and the rheology of the lower crust, upper mantle, and fault zones, is necessary to have a mechanically based predictive capability of future behavior.

- *What is the depth and along-strike distribution of interseismic slip-rate?* It is common to assume that the slip-rate is uniform along individual fault segments, yet there is little information to support this. The central creeping zone of the San Andreas is also assumed to slip uniformly in rigid block fashion. Precise measurements will allow for the mapping of along-strike variations in slip-rate, the existence of locked or slowly slipping patches in otherwise creeping stretches of the fault, and the depth distribution of shallow fault creep. Tighter bounds on the depth distribution of aseismic slip will help constrain rheology of fault zone materials, and the transition from stable to unstable fault behavior.

Implementation

The occurrence of frequent moderate earthquakes on well identified faults within 10 km of the surface affords the opportunity to obtain near-field source information. Deformation along the San Andreas Fault system in the region is spread over a ~100 km broad zone. In the north there are three principal faults, SAF, Hayward, Calaveras (and their northern extensions) plus numerous smaller faults. At the Mendocino Triple Junction subduction and strike-slip faulting are juxtaposed and the San Andreas transform is “born”. In central California the deformation is localized on the SAF. South of the Carrizo Plain the San Andreas enters the Big Bend and deformation is partitioned between strike-slip faults and thrusts in the Transverse Ranges. Slip is partitioned on the San Jacinto, Elsinore, and other faults before deformation is again localized on the Imperial fault in the southern Salton Trough, an area of incipient crustal spreading.

Permanent Global Positioning System (GPS), Borehole Strain (BHS), Long Baseline Strain (LBS), and creepmeter instrumentation are proposed. GPS provides long term stability and vector displacements at selected sites. Borehole strainmeters provide much greater sensitivity at periods from minutes to months, but are highly susceptible to local noise and hydrologic effects at longer periods. Longbase strainmeters provide high sensitivity and stability, but at a much greater cost and therefore lost spatial resolution. Creepmeters constrain surface creep, which is crucial data for interpreting transient strain information. Other monitoring methods including sea-floor geodetic methods, InSAR, pore-pressure monitoring, and others are not explicitly addressed in this plan. The instrument request here totals the equivalent of 400 new GPS stations and 75 BHS installations. Inclusion of other types of instrumentation reduces the number of BHS or GPS sites.

Design philosophy

This plan is developed under the understanding that MRE proposals are for NEW instrumentation only. Thus, we do not address the important issue of support for operation of existing instrumentation. Furthermore, the plan sticks to that delineated in the white paper in terms of total number of GPS and borehole strain sites. We do believe that some flexibility is warranted in terms of sea-floor geodesy, and long baseline strain, but save that discussion for the workshop.

There are tradeoffs between redundancy and spatial coverage in any field experiment. There is a general consensus that, particularly for strain instruments, the best experimental design is one that includes multiple instruments at relatively dense spacing. The suggestion is to install strainmeters in clusters of 5 instruments minimum. Spacing within each cluster will vary depending upon logistics and geophysical objectives, but will be on the order of 2 to 10 km. With each borehole strainmeter there would be borehole seismic sensors as well as auxiliary sensors sensors (i.e. barometric pressure and pore pressure at high enough sampling rate) to ensure unambiguous interpretation of the strain records. The spacing of the GPS stations will be optimized in each area to address the primary scientific objectives for each region. The spacing will vary from dense profiles with stations every 5 km, to broadly spaced arrays with a distributed spacing of 25km. Although the total number of instruments that will be available from PBO is large relative to previously available resources, it will still not be adequate to optimally instrument the entire San Andreas fault system. Therefore, the requests described below represent a compromise between a thin distribution of instruments that would sparsely cover the entire region without adequately covering any region, and a dense instrumentation in just a few areas.

Existing borehole strainmeters are installed at maximum depths of about 300 m. Part of the instrument's good performance is due to the noise-free, stable borehole environment. The 300 m depth is a small step closer to shallow earthquake nucleation depths. Yet, even at depths of 10-12 km, several cm of accelerated aseismic fault slip occurring over a period of a few days would be barely detectable by a borehole strainmeter a few km from the fault trace. To obtain data that can illuminate the scientific issues of non-elastic earthquake interaction, the depth-dependence of transient aseismic slip episodes, and earthquake nucleation, it would be highly desirable to seek greater sensitivity to strain at depth. Three possible approaches should be tried:

- It is essential that the instruments be distributed in distance from the source. A fault-perpendicular profile of strainmeters, at distances of +/-2, +/-5, and +/-10 km from the fault trace would facilitate detection and identification of deep signals. An additional instrument 15-20 km from the fault can help localize signals to the fault plane.
- Possible advantages of installing strainmeters in somewhat deeper boreholes should be explored. In non-geothermal environments, temperature should not be a problem at depths of 1 km. It is possible that this further removal from the surface could somewhat reduce noise, and the added depth will be a slight

advantage in terms of proximity to the source. The relative benefits of deep installations in terms of signal to noise ratio and ability to resolve source depth should be considered.

- Improved signal-to-noise ratio can be achieved by processing data from several closely-spaced instruments together. Groups of instruments possibly combined with somewhat deeper borehole installations should improve sensitivity and resolution. Signals originating at depth might be expected to have similar time histories at all instruments, but with larger amplitudes at the deeper instruments.

Borehole strainmeters are connected to the surrounding rock by means of an expansive grout. This gives good coupling but at the expense of coupling coefficients which are site dependent. Calibration of the instrument is currently done using earth tides. Model calculations for the ocean-loaded tides generally give the calibrated strain to better than 10%, although in some areas the errors may be as large as 30% for some components.

Three disadvantages of borehole strainmeters relative to surface strainmeters are: (1) their inability to measure absolute strain; (2) the necessity of calibrating them using earth-tide signals, whose absolute amplitude can only be measured by a tidal-sensitive absolute strainmeter, and which may provide inadequate calibration for short-wavelength signals; (3) the difficulty in demonstrating their stability over periods of time longer than about one month. Long baseline strainmeters measure the change in distance between end points and so determine directly the amplitudes of strain changes. Long-baseline surface strainmeters are extremely expensive relative to borehole strainmeters (by a factor of ~40 for a three component installation!), but have none of these disadvantages. In particular, a long-baseline strainmeter provides an absolute measurement of tidal strain that can be used to calibrate nearby borehole strainmeters, and co-location of a long-baseline strainmeter with a borehole strainmeter network can shed light on the long-term stability of the borehole instruments. Long baseline strainmeters (with the longer averaging length) give better stability at long periods but secure recognition of long period transients (months and longer) depends on obtaining spatial coherence independent of the type of instrumentation. The high cost of the long baseline instruments (and the difficulties in obtaining suitable sites) may limit the number of such installations.

Instrumentation Plan

This section describes an instrumentation plan to address the scientific problems outlined in the first section of the report.

1. Time scale of inelastic stress transfer.

The best places to study transient deformation and inelastic stress transfer are regions that have recently experienced large earthquakes. With reference to Figure 1, it is clear that the optimal localities are the central Mojave (Landers - Hector Mine source regions), the Loma Prieta region, and the Mendocino Triple Junction. The Landers and Hector Mine area experienced the greatest moment release along the greater San Andreas system within the last 50 years and was well instrumented soon after the 1992 and 1999 shocks. Longer term monitoring with high precision is needed to determine the spatial and temporal behavior of post-earthquake deformations. The Loma Prieta quake was smaller and deeper than Landers, and showed little evidence for deep relaxation within the first 5 years after the quake. Early GPS measurements lack the precision routinely achieved today, yet they provide a vital comparison for possible future changes in deformation rate. The 1992 Cape Mendocino earthquake provides the only opportunity to study transient motion following a large thrust event adjacent to the San Andreas. Like Loma Prieta, previously collected data provide the necessary baseline for comparison of deformation rate changes with time. All three regions are interesting from other perspectives, so that no attempt is made to identify the specific instrumentation requests for this component. Expected signals are long period so that continuous GPS measurements are preferred over strainmeters. Roughly speaking 25 new permanent GPS stations are requested for the Landers-Hector Mine area, 15 new permanent GPS stations for the Loma Prieta region, and 20 for the Mendocino Triple Junction.

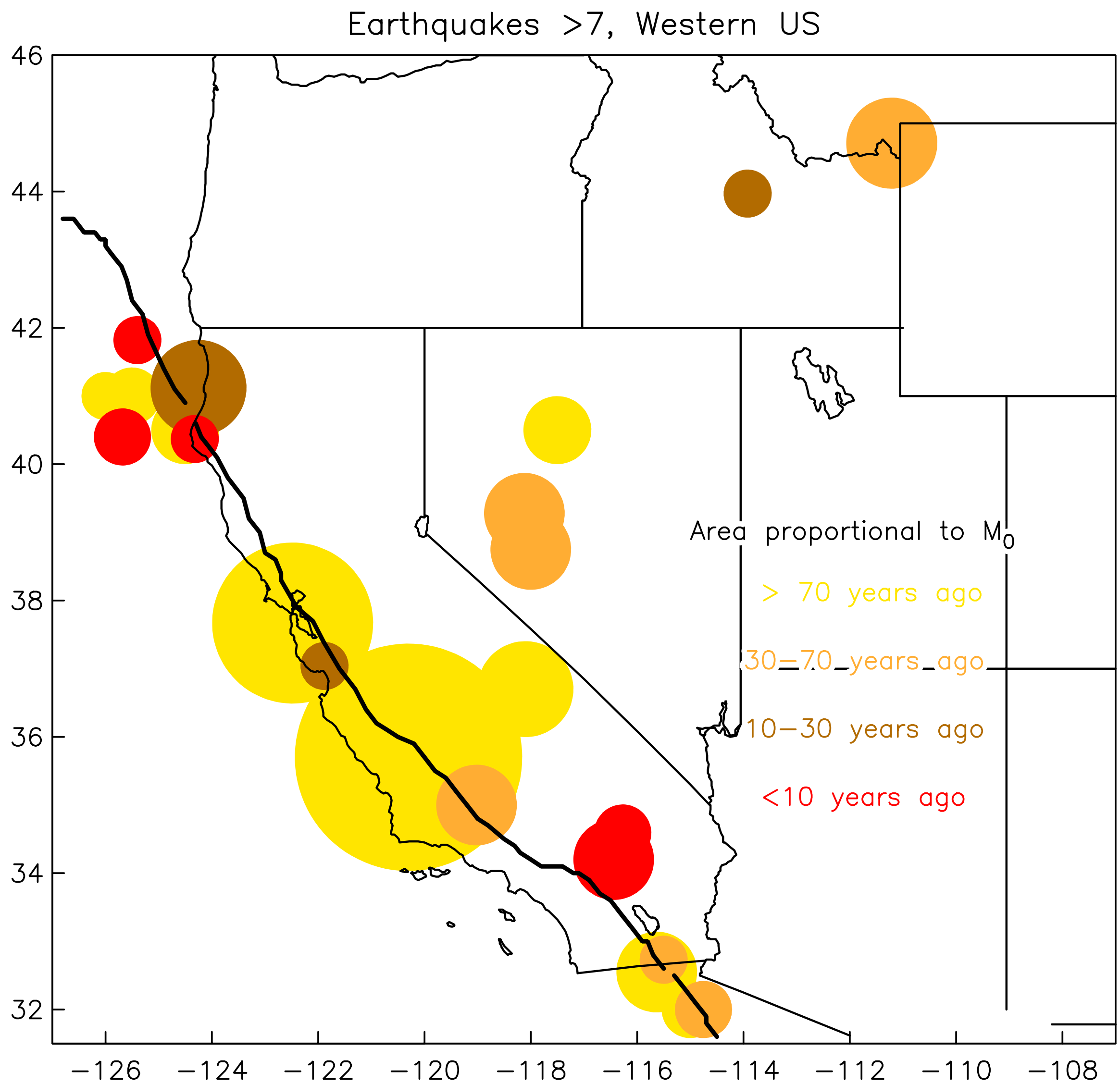

Figure 1.Magnitude 7 and greater earthquakes in the western US. From proposal by Agnew.

2. Transient slip events.

The best localities for studying transient slip phenomena are places where such events are documented to have occurred in the past: San Juan Bautista and Parkfield. Both areas are transitional between creeping and locked segments of the San Andreas. This suggests that other creeping faults are potential loci of slow or silent earthquakes. Accordingly, the Hayward-Maacama fault,s the Brawley Seismic Zone and Imperial faults are also identified as important targets for studying transient slip. The Salton/Coachella Valley segment of the San Andreas itself has exhibited evidence of transient deformation (both in long baseline strainmeter records and InSAR observations). The central creeping zone of the San Andreas exhibits episodic creep events, although it is commonly assumed to be in steady-state rigid-block motion below a shallow depth. There is some evidence suggesting interactions between earthquakes at either end of the creeping zone, including north-south propagation of earthquakes between 1838 and 1857. Thus the creeping zone itself is an important target for transient slip phenomena. The time scales of transient slip and deformation events is poorly understood, indicating a mix of strain and continuous GPS measurements. We propose 25 GPS receivers and 30 strainmeters for San Juan Bautista area, a similar number for the Parkfield area. The Hayward, Rogers Creek, and Maacama faults get approximately 30 GPS receivers (depending how one counts) and 20 strain instruments. Roughly 30 GPS stations are slated for the Imperial Valley and Brawley Seismic zones. Relatively few strainmeters in the Salton trough due to the thick sedimentary cover. Strain clusters are allocated for the Salton Sea segment of the San Andreas. 20 GPS receivers and 15 strainmeters should record and allow study of transient events along the central creeping segment of the San Andreas.

In addition to the transient slip events discussed above, some workers have suggested regional transients or "strain waves" on decadal scales not related to local postseismic deformation. If such events exist, they would be well captured by the regional distribution of continuous GPS stations.

3. Earthquake Nucleation.

This is certainly the most difficult scientific goal to plan for. The geophysical community's track record in predicting the most likely sites to instrument for future earthquakes is less than stellar. The best we can do in this regard is allocate a small number of instruments to areas with high current rates of seismicity. In most cases these are areas that are of interest for other reasons (eg, Parkfield, San Juan Bautista, Eastern California Shear Zone, the Imperial Valley, and the Mendocino Triple Junction). Given the fact that the seismic moment associated with the nucleation process must be small, the most sensitive instruments at our disposal are required: borehole and long-baseline strain meters. We propose 15 borehole strain instruments in the seismically active Mendocino Triple Junction, 16 sites in the SF Bay area (excluding the San Juan Bautista area), 17 strain meters in the southern California Shear Zone, 5 near the Anza gap, and at various fault junctions in southern California that could be potential nucleation sites.

4. Deep structure of fault zones.

In all likelihood the deep structure of the San Andreas is somewhat variable. It makes sense to tackle this problem in a number of places where the fault is relatively simple, consisting of a single major trace, such as the Carrizo Plain segment. The plan allocates 20 GPS sites to the Carrizo Plain. Other localities are of interest due to their contrast with the archetypal San Andreas. The Salton trough contains active spreading zones as well as transform segments. On the order of 35 permanent GPS receivers are devoted to the Salton Trough. The Mendocino triple junction offers an opportunity to study the initiation of transform faulting; 40 permanent GPS sites are allocated to the triple junction. A possible way to discriminate between thin and thick lithosphere models of the San Andreas is to focus on regions that deviate most from an infinitely long vertical fault. This argues for careful investigation of the two ends of the San Andreas and the Big Bend region. The plan allocates 10 new GPS sites near the Gorman area and the intersection of the Garlock fault, as well as the aforementioned sites near the Salton trough and the Mendocino triple junction.

5. Partitioning of slip and 6. Along-strike and depth distribution of slip.

North of the creeping zone the San Andreas bifurcates into the sub-parallel Hayward-Rogers Creek-Maacama Faults, and the Calaveras-Green Valley- Bartlett Springs Faults. The branching of the Calaveras and Hayward faults is well covered by GPS sites for a variety of reasons, including the transient slip events at San Juan Bautista. The plan calls for one dense profile across the entire San Andreas System at the latitude of Pt. Reyes. Combined with an existing site on the Farallon islands this provides the best coverage west of the San Andreas. In southern California the San Andreas branches into the San Jacinto and Elsinore faults. The plan calls for additional GPS sites in the San Gorgonio pass area. The complex system of strike-slip and reverse faults in the Los Angeles area is well covered by existing instrumentation. Although the interseismic deformation field can place constraints on fault slip-rates, the slip-rates on sub-parallel faults are highly (negatively) correlated. In addition, the slip-rates are positively correlated with depth of locking, which is often not well resolved. Better constraints on the kinematics of fault slip throughout the entire San Andreas system can be achieved by combining improved estimates of the interseismic velocity field with paleoseismic estimates of slip-rate. In addition to the specific areas discussed above, the GPS deployment plan allocates a reasonable density of sites throughout the San Anderas Fault system (a San Andreas backbone). The along strike distribution of fault slip is generally addressed in the same manner as slip partitioning. The depth distribution of slip is addressed by having sites at different distances from the fault. In general, sites are more closely spaced near the faults where velocity gradients (strain-rates) are high and more widely spaced where the velocity gradients are low.

Geographic Distribution

This distribution of sites is also indicated on the maps in Figures 2 and 3. To the extent that there are inconsistencies, the maps should be more accurate. Also, note that the numbers do not total to 400 GPS sites and 175 strainmeters. The reason for this is that assignment to regions is somewhat arbitrary and a number of GPS sites in particular are allocated to a San Andreas backbone.

Mendocino Triple Junction

Request: 40 GPS 15 Strain

The Mendocino Triple Junction lies at the intersection of the Gorda, Pacific and North America plates. It is the transition zone where the strike-slip motion typical of the San Andreas system terminates against the subduction to the north. This area is one of the most seismically active areas in California. Magnitude 6+ events are relatively common here, making it an attractive area for investigations of time dependent phenomena. On the other hand, much of the activity occurs offshore, and the geometry of the active faults is not as well known as other parts of the SAF system. Currently there are 39 GPS stations that have been surveyed in campaign mode in this area. (see also proposals by Furlong et al, and Chadwell et al.)

Northern San Andreas Fault System

Request: 40 GPS 9 Strain

The Northern San Andreas fault system extends from the Mendocino triple junction south to Point Reyes. It includes the San Andreas fault zone, which is mostly offshore through the area, and the parallel Maacama and Bartlett Springs fault zones to the east. Most current microseismicity occurs on the Maacama and Bartlett Springs faults. For example, the UC Berkeley catalog contains only one M 3.0 or greater event in 1998 and none in 1999 along the San Andreas fault itself. The San Andreas fault last ruptured in a M 7.7 event in 1906. The long term slip rates and current strain accumulation rates on the faults are thought to be: San Andreas, 20-25 mm/yr; Maacama, 10-15 mm/yr and Bartlett Springs, 3-10 mm/yr. There will not be sufficient resources to properly instrument this entire area. Therefore we are planning to use a few instruments, one strain cluster plus GPS, to fully instrument one section of this area. The strain cluster is focused on the actively creeping Maacama Fault, which could be associated with transient strain events. The northern San Andreas is also a good place to study slip partitioning between parallel faults, along strike variations in slip-rate and the deformation late in the cycle of the 1906 earthquake.

San Francisco Bay Area

Request: ~80 GPS 40 Strain

The San Francisco Bay area is a transition region between the three locked fault zones to the north and the creeping single San Andreas fault zone to the south. We include the San Juan Bautista-Hollister area as part of the SF Bay. Faults in the SF Bay area display a mix of creeping-microseismically active and locked-aseismic behavior. The creeping-locked transition zone near San Juan Bautista has produced some of the best documented cases of transient aseismic deformation in the world and is a high priority target for PBO. Ultra-high precision earthquake locations reveal fascinating streaks of seismicity and repeating clusters of similar earthquakes. It may be possible to test hypotheses about the distribution of slipping and locked fault areas by combining strain and seismicity data. The Hayward fault also exhibits fault creep, but also experienced a M 7 event in 1868. The distribution of slipping and locked zones there is of intense interest. Finally, the S.F. Bay area is high on the world list of high population density urban areas close to hazardous faults. <u>(see also proposals by Thurber et al).</u>

Central Creeping San Andreas Fault

Request: 20 GPS 15 Strain

Between Hollister and Parkfield, the San Andreas fault is creeping, i.e. slipping continuously and aseismically. It produces abundant microseismicity, but probably rarely produces events above Magnitude 6. At the surface the creep is often episodic, occurring in small jumps of few millimeters or less. It is believed that this episodic behavior transitions to a more continuous motion at depth. Macroscopically, the deformation appears rigid-block like with no evidence of strain accumulation. The principal questions to test in this area would be the transition depth between episodic creep behavior and steady state creep. It has also been proposed that transient deformation events propagate along the creeping zone. Following the 1989 Loma Prieta earthquake surface creep was accelerated in the northern portion of the creeping segment. Measurements are needed to confirm or deny purely steady-state rigid body motion. The association of slow earthquakes with creep, suggests this segment of the San Andreas may be rife with transient slip events. <u>(see also proposal by Agnew et al).</u>

Parkfield-Cholame Area

Request: 40 GPS 25 Strain

Monitoring at Parkfield began in 1966 after the most recent in a series of 5 moderate earthquakes that have occurred there since 1857. The earthquakes have occurred on average every 22 years (with extremes of 12 to 32 years) and have some remarkable similarities. Parkfield became the classic example for repeating earthquakes and the characteristic earthquake model. Parkfield has produced significant strain signals associated with creep events. The SAFOD proposes a 4-km deep hole into the fault zone, which should provide measurements of fault properties both in the creeping zone and areas of small, repeating earthquakes. Parkfield offers PBO a unique opportunity, with an extensive set of complementary instruments (Drill hole, strong motion, creep, other geophysical); a rich source of time dependent signals; and, a high probability of a moderate earthquake during the life of PBO. The Cholame segment (from Hwy. 46 to Simmler) extends the transition from a creeping to fully locked fault. Compared to the other end of the creeping zone, the fault geometry is relatively simple. There is interest in knowing whether transient slip near Parkfield extends into the locked part of the fault. This area exhibited a major change in slip amplitude in the 1857 earthquake and is a possible area for a triggered larger earthquake in the event of a M 6 Parkfield earthquake. Long-baseline strainmeters in the area could provide sensitive measurements at moderate to long periods to improve depth resolution of transient slip. Long base strainmeters also provide tidal calibration for borehole instruments. <u>(see also proposals by Langbein et al, and Agnew et al).</u>

Carrizo Profile

Request: 25 GPS; 6 strain

The Carrizo Plain is perhaps the simplest section of the entire San Andreas Fault system. A single fault accommodates ~35 mm/yr of slip, is locked to near 20 km and experienced ~9 meters of slip in 1857. It is not until one reaches the coastline in the neighborhood of Santa Maria basin that there is another fault, the San Gregorio-Hosgri Fault . Thrust faults and folding to the northeast in the Temblor Range and Elkhorn Hills, but there is little data in this area. This is probably the good place to resolve the deep structure of the fault, and the depth distribution of interseismic slip. There is presumably a transition from locking to creep at a depth of ~15 km. Is that transition steady or does it migrate with time? Is the slip-rate below the locking depth steady or transient. Due to the simple nature of the fault, this is perhaps the best place to address these issues. Is fault normal deformation very localized to the northeast of the fault? It may also be possible to understand the connection between strike-slip and thrust faults in this area. <u>(see also two proposals by Shen et al).</u>

Gorman area

Request: 10 new GPS sites; 5 strain

This area is of interest because of the intersection of the San Andreas fault and the Garlock faults at the western end of the Big Bend in the San Andreas. Right-lateral slip on the San Andreas combined with left-lateral slip on the Garlock should produce local dilatation in the area. It would be interesting to see how the faults respond to the interactions. This area also marks a transition in slip in the 1857 rupture from 9 m to the north along the Carrizo Plain, to less than half that along the Mojave section of the fault. Finally, the San Gabriel range runs along the south side of SAF from this junction to the SE, a marked change in the style of secondary faulting along the San Andreas <u>(see also proposal by Jackson) .</u>

Transverse Ranges and Los Angeles Basin

Request: existing SCIGN sites; 10 strain

Zone of complex interaction between strike-slip and thrust faulting. Possibility of detachment beneath the San Gabriel range suggested by LARSE reflection and refraction data. Deep structure is independently constrained from LARSE profiles. .Possible presence of detached thrust fault system abutting SAF makes for strong possibilities of time-varying interseismic deformation. The Northridge earthquake exhibited post-seismic signals interpreted to result from deformation within the shallow part of the crust, perhaps associated with viscous relaxation at greater depth. It is likely that these signals will have decayed to background by the time PBO is implemented.

San Gorgonio Pass area

Request: 5 new GPS; 8 strain

The eastern end of the Big Bend is an area where the San Andreas goes through a change in behavior associated with the intersections of the San Jacinto fault and also the Pinto Mtn. fault. Resistance to oblique convergent motion here may be the reason why some right-lateral shear takes a path of less resistance, up the eastern Calif. Shear zone and eastern side of the Sierra Nevada. Hence, if PBO will study temporal variations on the ECSZ then it should also observe here, to see if there is an observable trade-off in the strain budget (as is presumed to occur)

Salton Trough

Request: 30 GPS; 10 borehole strain

The Salton trough marks a transition from ridge-transform tectonics in the Gulf of California to San Andreas Fault tectonics. Unlike the transitions at either end of the creeping section, or at Mendocino, here we have a pull-apart fault geometry with anomalous strain pattern, indicating lower crustal NW-SE extension, and distinctly developed secondary cross-faulting between the Brawley Seismic Zone and main bounding faults. There has been abundant seismic activity and associated triggering and relaxation phenomena. Earthquakes, including the 1979 Imperial and the 1987 Superstition Hills-Elmore Ranch sequence, caused triggered slip on other faults in the region. They were also followed by very rapid, mostly shallow afterslip captured in great detail by creepmeter measurements, but less well by strain and surface deformation measurements. The latest phase of SHF creep in the aftermath of the Landers and Hector Mines earthquakes was also captured by InSAR. This complex zone may load the southern San Andreas fault unevenly through time, as evidenced by episodes of temporally varying creep and other deformation, not only associated with large earthquakes and their triggered and postseismic effects, but also associated with regional distant events. What is the depth and significance of the triggered creep seen? Is it shallow and inconsequential, or a deeper and hence more important process? (See also proposals by Agnew et al. And Jackson & Shen)

Eastern California Shear Zone.

Request: 25 new GPS; 20 strain

The Eastern California Shear Zone has been the locus of intense seismic activity in the past decade. The Landers and Hector Mine earthquakes have provided important data on postearthquake deformation. This is the best area in the San Andreas system to monitor long term post-seismic deformation. For this reason 25 new GPS sites are requested for the eastern California Shear Zone. The high rate of seismicity also suggests, somewhat speculatively, that the area may be the site of future significant earthquakes.

GPS Implementation Plan for PBO

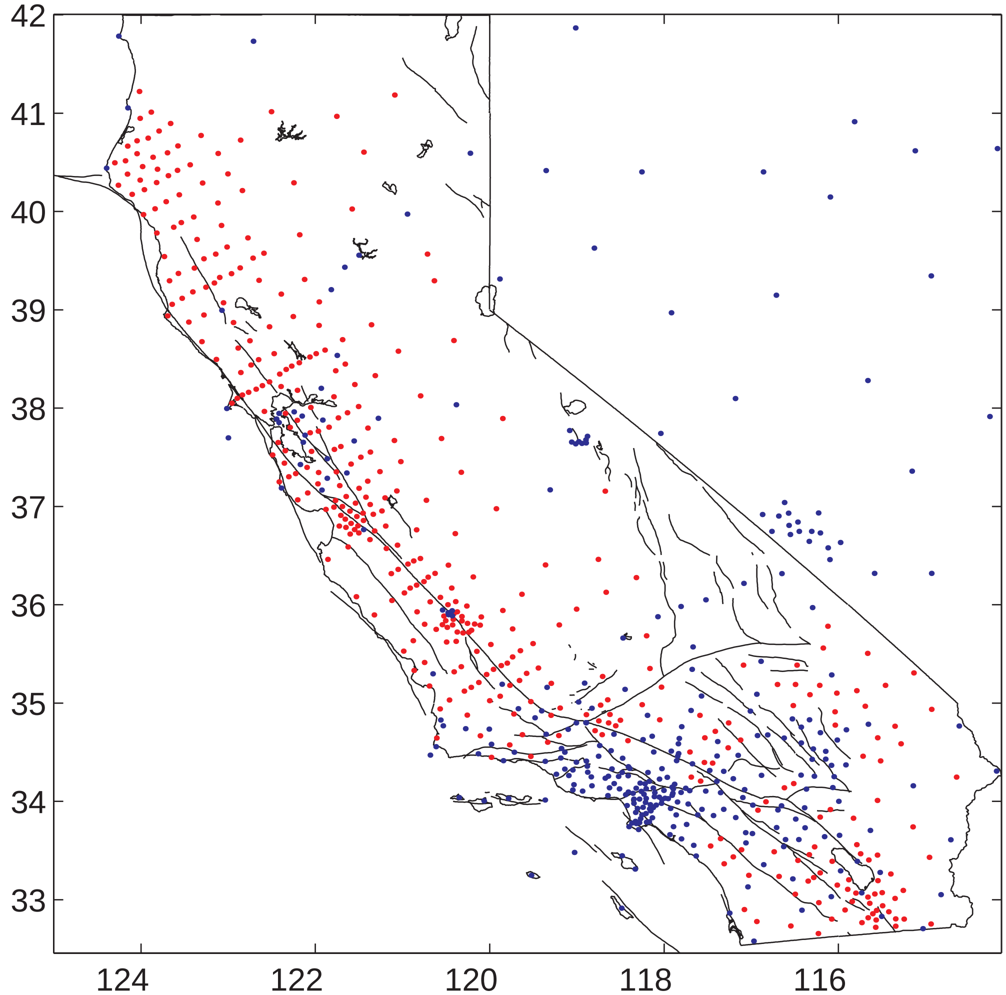

Figure 2. Proposed GPS locations. Blue Existing. Red New PBO Sites.

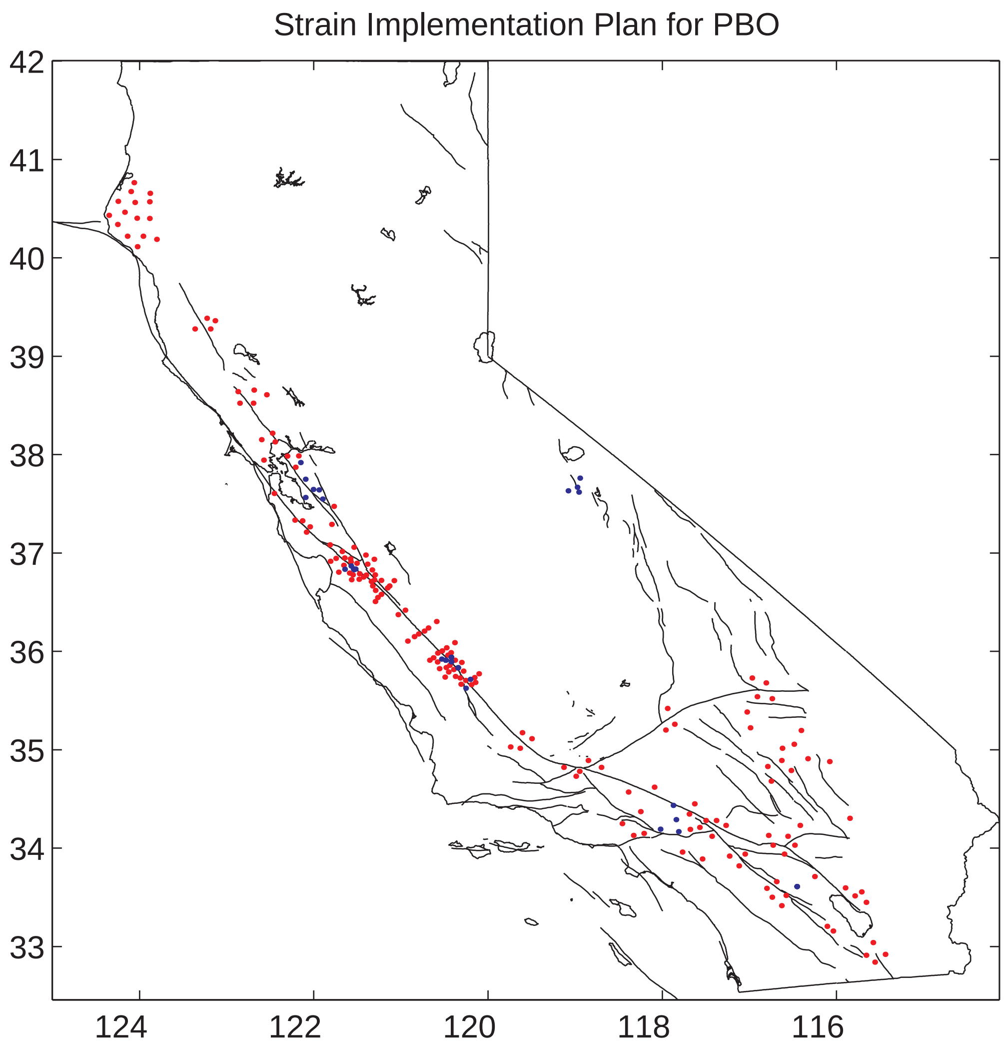

Figure 3. Proposed Strainmeter locations. Blue Existing. Red New PBO Sites.