Fault Processes on the Anza section of the San Jacinto Fault

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SUMMARY

We propose to instrument the Anza slip gap and transition areas of the San Jacinto fault zone with sites including borehole tensor strain meters, seismometers and accelerometers to complement the planned GPS arrays in the area. The array will cover a part of the most seismically active fault system in southern California, and provide:

- **Measurement of stress accumulation around locked fault patches**
- **Integration of microseismicity mapping with aseismic slip observations**
- **Information on nucleation processes leading to instability**
- **Information on stress accumulation near fault intersections**

BACKGROUND

The San Jacinto fault zone is the most seismically active strand of the San Andreas fault system in southern California, with a succession of moderate sized earthquakes (6 < M < 7) over the period since 1890. The Anza slip gap is a 40 km segment of the San Jacinto fault that separates fault segments ruptured during magnitude 6.8 earthquakes in 1918 (San Jacinto to the northwest) and Borrego Mountain to the southeast.

Within this 40 km segment, a 20km section of the fault is relatively aseismic (the Anza seismic gap, see Figures 1 and 2), and is not known to have ruptured during the historic record since at least 1890 (*Sykes & Nishenko*, 1984). It has been suggested (*Sanders and Kanamori*, 1984) that the locked nature of the fault in this region may be due to high normal stresses resulting from the convergent geometry's of the local Buck Ridge and Coyote Creek faults, and the oblique orientation of the regional maximum compressive stress.

Aseismic fault creep within the Anza segment is negligible, and strain rate estimates of 0.35 to 0.4 microradians per year indicate that the upper 5km of locked crust is undergoing loading in preparation for an earthquake likely to rupture this segment. This portion of the fault is bounded by seismically active regions, with the seismogenic zone extending to depths of 22km to the northwest, and 15km to the southeast (*Hartse et al*., JGR, 1994).

The upper 5km of fault represents a fault region with a high rate of microseismicity on a locked fault segment typical of much of the plate boundary in the U.S.. This segment is competent rock, and an ideal candidate for addressing issues such as the character of precursory processes that may lead to instability, and fault behavior during fast rupture. There is some evidence of small repeating earthquakes on this segment (Aster & Scott, 1993), and techniques developed for precise location of these events in transitional regions such as Parkfield may provide very different scientific results in this type of fault zone. The existing laser strainmeter array at Piñon Flat and the local Anza network of seismic stations provide a historical baseline for the region that this new array will build upon.

SCIENTIFIC JUSTIFICATION

Measurement of stress accumulation around locked fault patches:

In the Anza region, there is evidence of stress heterogeneity from microearthquake focal mechanism invevrsions (*Hartse et al.*, 1994) and possible evidence (though perhaps controversial) of temporal variations in stress accumulation as inferred from changes in shear wave splitting (Peacock et al., 1988). Stress accumulation around a locked portion of fault will result in significant strain rate changes around the boundaries of the locked region, and the Anza gap region provides an ideal laboratory to examine the detailed processes of strain accumulation in the case of a relatively large (20km length) section of locked fault.

Integration of microseismicity mapping with aseismic slip observations:

High resolution locations of microseismicity along the San Andreas Fault system are providing an image with sharp details of fault zone structure, and a wealth of new information on rupture processes (*Waldhauser et al.*, 1999; *Ellsworth et. al.*, 1999; *Rubin et al*., 1999; *Nadeau and Johnson*, 1998; *Nadeau et. al*., 1997, *Nadeau and McEvilly*, 1995). Studying the scaling properties of these very small earthquakes (1m-100m) can help provide a link between laboratory studies of faulting and friction and these natural field laboratories. There is evidence of repeating microearthquakes in the Anza region (Aster & Scott, 1993). A combination of constraints from of detailed strain observations, together with identification of the precise relative locations of these microearthquakes, will provide detail of fault processes to complement the larger scale measurements provided by GPS arrays. Figure 3 is an example of the resolution of aseismic processes obtainable from borehole strainmeters.

Imaging of earthquake nucleation and precursory processes leading to instability

The Anza gap has been previously identified as a likely candidate for a moderate sized M6+ earthquake. Whilst a number of previous studies have reported no evidence of strain precursors in the hours to minutes preceding moderate earthquakes, there are far too few observation sites to make definitive conclusions of precursive activity in the medium periods of days to hours prior to moderate sized earthquakes. A well-instrumented Anza network of strainmeters and co-located high resolution seismometers and accelerometers will provide an ideal laboratory to examine this question in detail in a seismically active fault region in competent rock.

Investigation of stress accumulation processes near fault steps and intersections

The influence of fault geometry on mechanisms of stress transfer between earthquakes is an issue yet to be resolved by observational studies. The Anza region we propose to instrument includes a discontinuity of 4 km between the Hot Springs and San Jacinto faults, and the intersection between the San Jacinto and Buck Ridge faults, with a change from strike slip to reverse structures at the surface, and change in principal horizontal stress orientations of 25^{o} across the discontinuity (*Sanders & Magistrale,* 1997). This region forms a good laboratory to investigate this question.

PROPOSED CLUSTER DEPLOYMENT AT ANZA

Each borehole tensor strainmeter is installed at a typical depth of 200m, enabling observations of strain which are unaffected by local surface effects. The resulting data sample the surrounding strain field in the immediate vicinity of the instrument, and accurate local tidal calibration ensures that this sampled strain observation is representative of strain in the locality. Typical strain field patterns arising from slip around a locked patch of fault at depth are shown in Figure 4. The extent of such strain fields, and the rate of change of these fields with distance, are very dependent on the size and depth of the source region. Thus borehole instrument arrays which are located close to the fault (say 3 km) will image processes in the upper few km of the fault. Instruments at further distances of say 10 km will enable imaging of deeper processes.

We propose a cluster of **20 borehole sites** each with a **tensor strain meter, high resolution seismometer and accelerometer**, with an indicative spacing as indicated in Figure 4. Borehole cluster stations must contain both high-resolution seismometers and also accelerometers if we are going to be able to image both the small (M0) events all the way to the large (M6+) events.

There are relatively few SCIGN permanent GPS sites along this region, and we propose installation of a significant permanent GPS array together with some monuments for campaign GPS. Placement of this array will be discussed in other proposals. Together these instrument types will provide the full temporal spectrum of observations necessary to identify and provide modeling constraints on fault processes.

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Figure 1: Map of the Anza section of the San Jacinto fault. Historical seismicity from 1975 to 1998 is shown with filled circles (0-5km depth red, 5-10km depth yellow, 10-15km depth magenta, <15km depth blue). The relatively aseismic region of the Anza gap is evident in the central section.

Figure 2: Cross section of seismicity within 5km on either side of the main fault trace (A-A' box in Figure 1).

Figure 3: A typical data plot of borehole strain data from a two instrument array, showing a slow earthquake observed in northern California in 1992 near San Juan Bautista. The top trace is data from a dilatometer at SRL, whilst the next three traces are the three strain components from a tensor strainmeter at a distance of 4 km. Instruments are at a distance of 1 to 2 km from the fault trace.

Figure 4: The white contour lines indicate contours of a Gamma 2 shear strain field arising from slip equivalent to a magnitude 6 event on a surface 10 km in lenth and 5 km in width, at a depth of 5 km, and centred near one end of the Anza gap section of fault trace. Countours are in intervals of 3000, 1000, 300,100,30 nanostrain, all of which are readily observable on a borehole strainmeter. Our **suggested array deployment** is indicated by the filled white circles. There are three categories of sites: (a) those at a distance of approximately 3km from the fault trace, which are staggered either side of the fault to gain maximum scientific benefit at minimum cost (b) stations at a distance of approximately 10 km from the fault trace, designed to image processes at depths of 5-10 km along the fault; and (c) two stations situated at 15 km from the fault trace, to image processes at the northwest section of the fault where seismicity is concentrated at depths of 20km - 15 km.

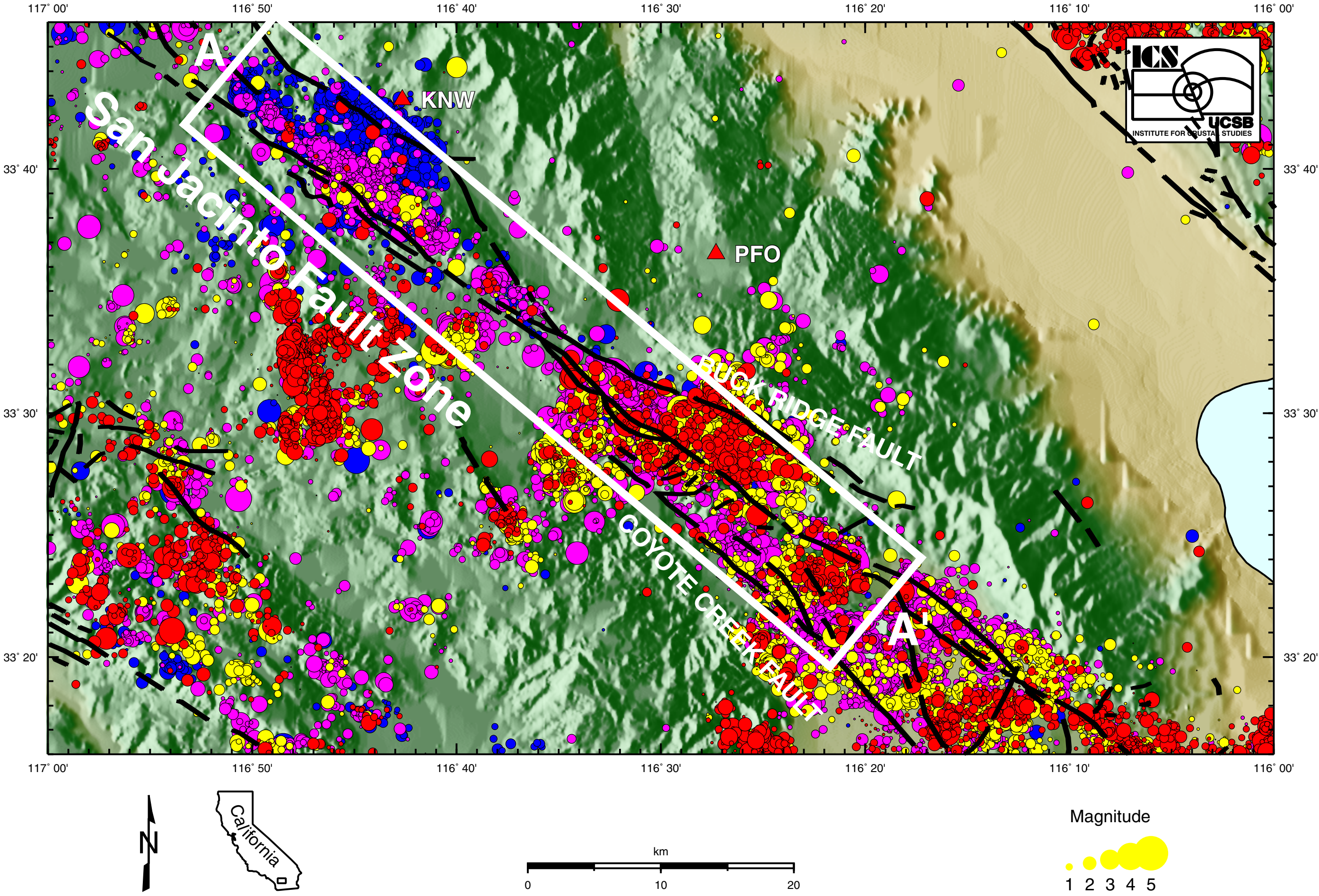

Figure 1. Seismicity from DScat_2000 (1/75 - 3/98)

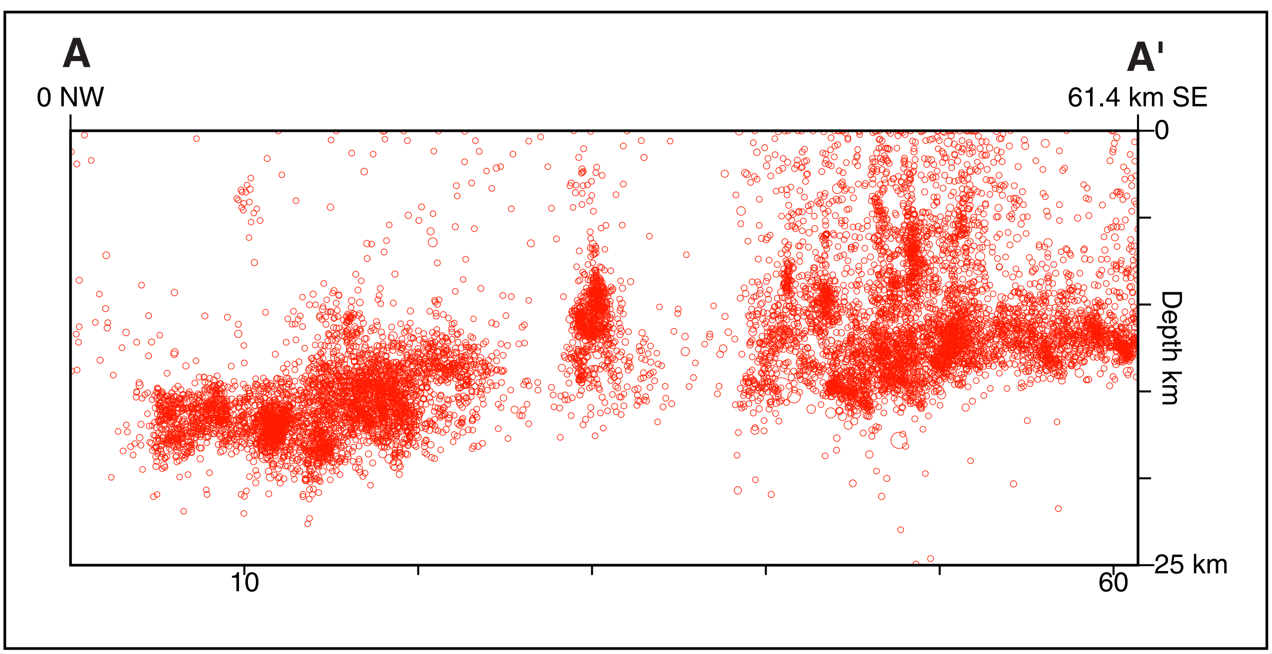

Figure 2. Cross-section along A-A'

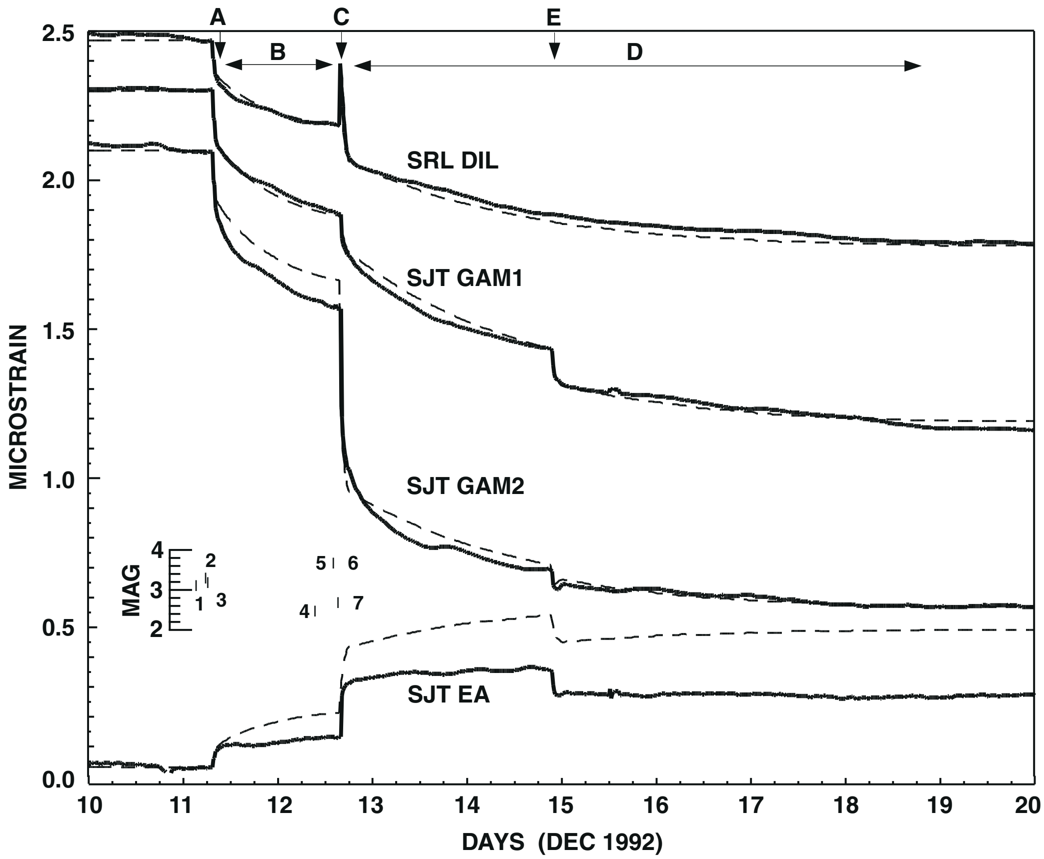

Figure 3. Borehole Strain Data

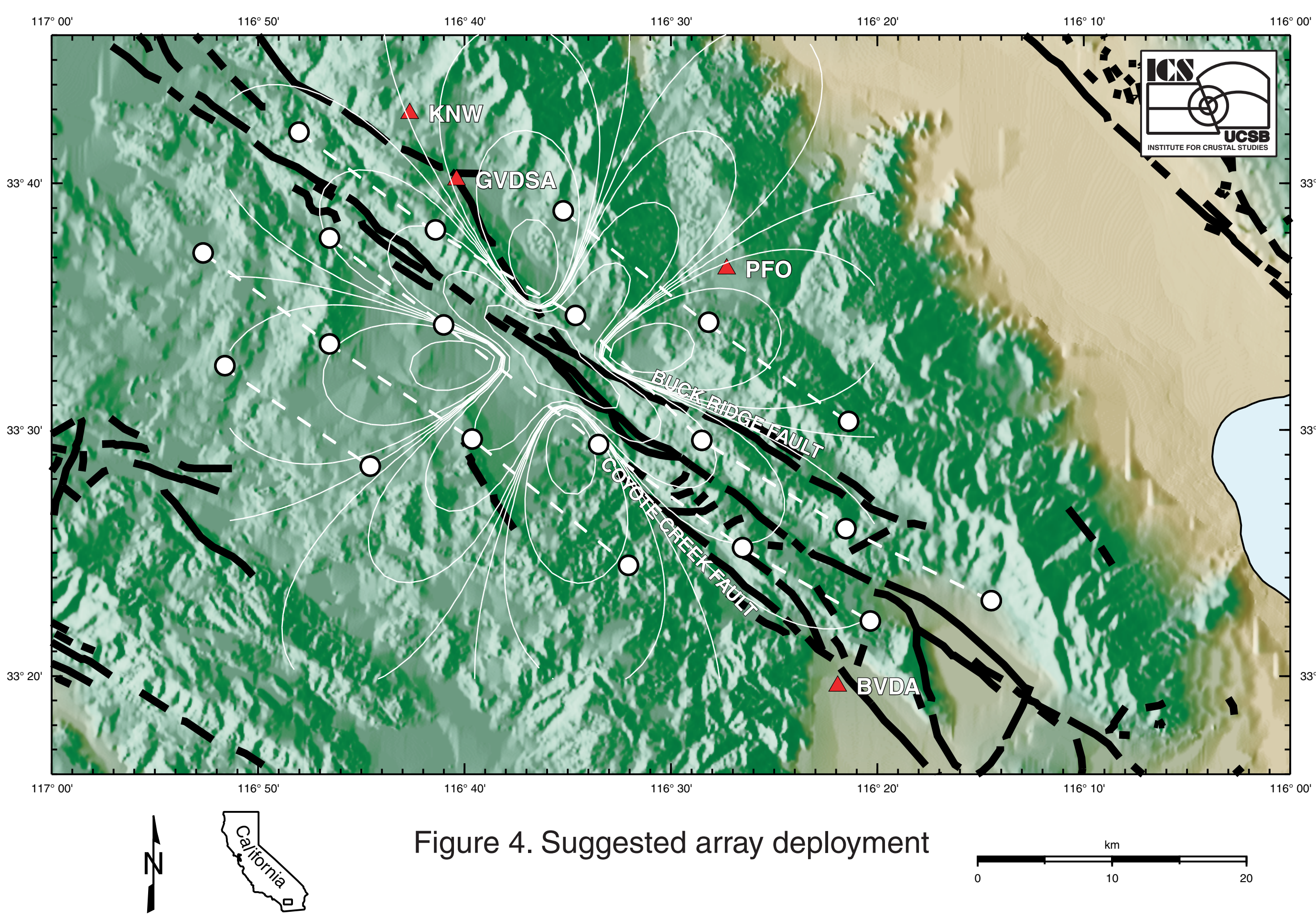

Figure 4. Suggested array deployment