Extension of the Parkfield deformation array

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SUMMARY

We propose an extension of the array of instruments at Parkfield to enable detailed investigation of strain processes at depths in theseismogenic zone of the fault, with an array of **15 borehole tensor strainmeters**, (some including downhole seismometers) and **40 permanent GPS sites**. These arrays will enable:

- Identification of aseismic fault slip and constraints on the depth of aseismic slip, in a transition region of the San Andreas fault
- Identification of constraints on fault slip processes associated with repeating microearthquakes
- Characterise propagating fault slip episodes
- identification of aseismic slip localised around the SAFOD experiment

Background

The earthquake monitoring experiment at Parkfield began in earnest in 1985 after a forecast with a 95% confidence that a M6 earthquake would occur near Parkfield before 1993 near the site of the 1966 M6 earthquake shown in Figure 2. The primary goals for deploying instruments around Parkfield were to record geophysical signals that accompany the earthquake process., to measure ground motion in the near-field of the forecasted earthquake, and to issue a warning 3-days prior before the anticipated M6 event if seismicity and/or fault creep reach pre-defined threshold levels (*Parkfield Working Group*, 1987 and *Michael and Jones*, 1998).

The basis of the forecast was simply an extrapolation of an apparent 22 year period between moderate sized earthquakes that have occurred at Parkfield since 1857. Although there are a variety of statistical models that attempt to capture the phenomena of repeating, moderate sized earthquakes, clearly the one employed by *Bakun and Lindh* (1985) does not allow for the real variability in the earthquake process. Other statistical models which use earthquake statistics from around the world imply an annual earthquake probability for a M >6 of roughly 10% (*NEPEC working Group*, 1994).

The current distribution of instruments deployed to measure the earthquake process is shown in Figure 2. The types of instruments yield measurements of displacements and strains, velocity and acceleration, and electrical and magnetic variations (*Roeloffs and Langbein*, 1994). Most of these instruments were installed in the mid-1980s in response to the earthquake forecast. Currently, most field efforts have been simply to maintain these instruments; many that use obsolete technology and are becoming increasingly difficult to maintain.

The Parkfield experiment has addressed several observational questions on the general topic of earthquake physics. The results have been summarized with appropriate references in *Roeloffs and Langbein* (1994) and *Roeloffs* (2000). However, listed below are one-line summaries of some of these findings:

- Monitoring of micro-earthquake activity shows that many events have identical seismograms, recur in exactly the same location, and account for a high proportion of the recorded seismicity.

- Both resistivity surveys and seismic velocity analysis suggest that the fault zone beneath Middle Mountain has high fluid content.
- The rate of micro-earthquake activity, changes in the rate of lengthening of several two-color EDM baselines, and changes in the rate of shear strain beginning in late 1992 suggest that the rate of fault slip beneath Middle Mountain increased. These rate changes also correspond to a period when the 4 largest earthquake (all M >4) occurred since the initiation of monitoring.
- Possible pre-earthquake signals were detected at Parkfield when water-level and strain changes occurred prior to the 1985 M5 Kettleman Hill earthquake located about 30 km east of Parkfield.
- A catalog of surface creep, strain, and water-level changes has been compiled; the inference is that creep events that are recorded by creepmeters are shallow with a depths of less than a few hundred meters.
- High precision EDM measurements reveal that geodetic time-series have temporally correlated noise which is due to localized motion on the monuments; the impact of this fact is degradation of long-term precision. Installation of deeply braced monuments have better stability and can improve the precision of geodetic measurements.
- Many creepmeters not only respond to fault slip, but they respond to rain, too.
- Even though there is aseismic slip at depth, there is more than enough strain-energy accumulating for another M6 earthquake at Parkfield. Large scale aseismic strain changes in 1993 (which continued until at least 1997) were observed on both borehole strainmeters and EDM two-color instrument and are shown in Figure 1.
- Their now exists an upper bound on the moment of premonitory slip prior to M4 to M5 earthquakes.

Future Scientific Goals at Parkfield

- **Identify constraints on fault slip processes associated with repeating microearthquakes** at depths of 5 to 15km in a well documented section of the San Andreas fault. *Nadeau and McEvilly* (1999) have identified clusters of microearthquakes in which the seismically active portions of the fault occupy a small percentage of the total surface, and used these observations to infer fault slip rates at depth. *Heimpel & Malin* (1998) have identified a transition from creep-dominated slip to earthquake dominated slip at magnitudes close to M = 0.9.
- **Identify regional fault slip at depth** to compare with previous data observations of significant variations in slip rate in 1993 and 1997 recorded by three independent means - temporal variations in microearthquake clusters (*Nadeau & McEvilly*, 1999), EDM measurements (*Langbein et al*., 1999), and borehole tensor strain measurements (*Gwyther et al*., 1996). There have also been indications in temporal variation in fault properties such as wave propagation (*Karageorgi et al*., 1992).
- **Characterise propagating fault slip episodes** observed repeatedly on the current strainmeter/creepmeter array at Parkfield. The depth and extent of these propagating aseismic slip episodes will only be identified, when an array of instruments spanning larger distances from the fault trace and thus able to identify processes at greater depth than a few km, is installed. There have been previous observations of seismic properties at depth indication the presence of stress diffusion along the fault at Parkfield (*Malin & Alvarez,* 1992).

- Provide a regional deformation measurement and **identification of aseismic slip localised around the SAFOD experiment** near Middle Mountain, which is not currently well instrumented with either GPS or borehole strainmeters.
- Identify **aseismic fault slip and provide constraints on the depth of aseismic slip, in a transition region of the San Andreas fault**. The region of the fault to the southeast of Cholame exhibits insignificant fault creep. The surface measurements of fault creep transition through episodic creep of 23 mm per year in the Parkfield region , to a steady 30mm per year of surface creep to the northwest. This region is the northern boundary of the 1857 rupture surface, and may provide future cluse to processes associated with large inter-plate earthquakes. Instrumenting the southeast section of the Parkfield segment will help to better resolve the boundary between creeping and locked sections of the fault.

Instrumentation proposal

The spacing and placement of the current borehole strainmeter arrays close to the fault (typical distance currently is 2km from the fault trace) has precluded definite identification of fault processes at depths of 5km or greater. Re-establishment of this array on a scale more appropriate for study of aseismic fault processes to depths of 10-15km, will strongly complement current studies of localized microearthquake sources and shallow fault processes. The area is known to experience both slow and normal seismicity processes.

The current deformation array in Parkfield consists of 3 borehole tensor instruments, 5 dilatometers, and 6 continuous GPS sites. We propose to extend this array to cover a 40 km section of the fault, spanning from north of the SAFOD experiment to southeast of Highway 46, and spaced to cover a 20 km transect across the fault. A parallel proposal has been submitted for the PBO to update the coverage of surface creepmeters in the creeping section of the fault between Parkfield and San Juan Bautista.
The new array will require 15 extra borehole tensor strainmeters with an estimated cost each of $50k, and siting costs of $50k each. Co-located with these may be seismometers and FBA's. A further 40 permanent GPS sites will also be required with costs of $25k per site.. Strainmeter sites at the southern end should also include tilt meters at marginally increased cost. Total cost would be of order $2.2m.

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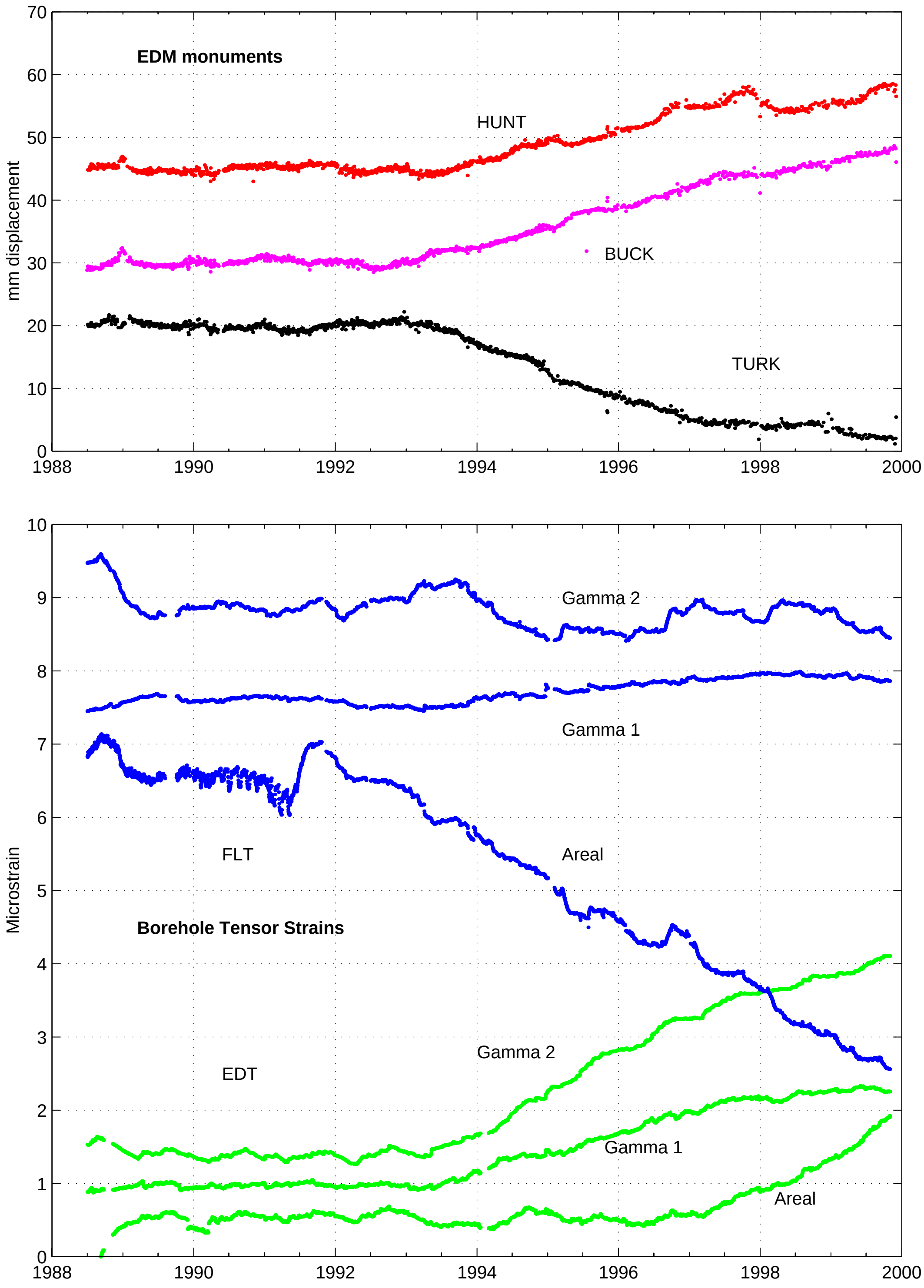

Figure 1. Long term aseismic strain changes observed at Parkfield in 1993 and 1997, which provide good constraints on source slip models. The upper box shows three EDM line length changes, adjusted for motion of the central monument. Lower box shows shear (gamma1 and gamma2) and areal strains observed at Eades site (northeast of the San Andreas and close to the town of Parkfield) and Frolich (southeast of the fault and a distance of 6 km from Eades).

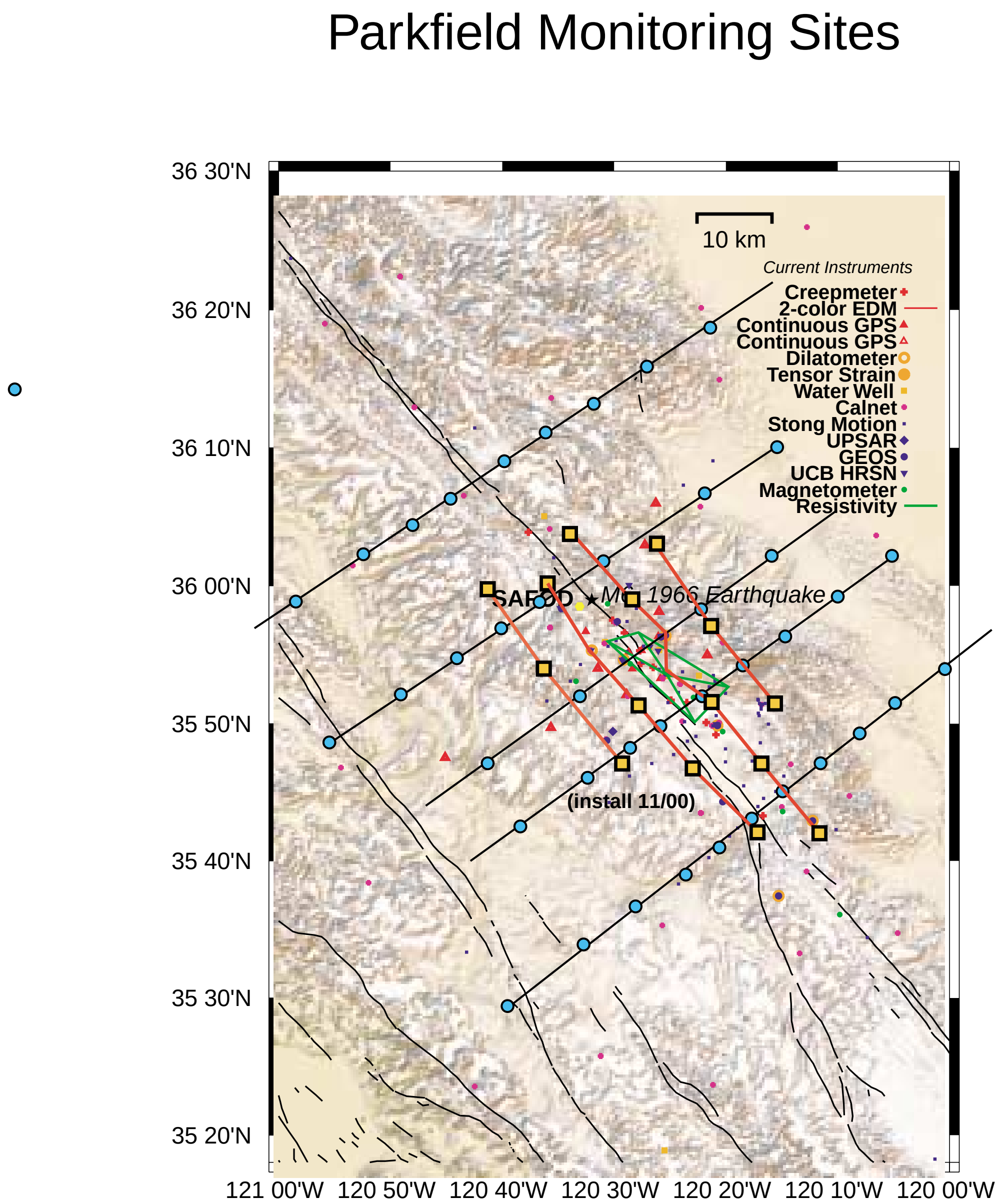

Figure 2. Map showing current Parkfield instrumentation sites, and proposed GPS and borehole tensor array. The **proposed GPS sites** are aligned on five transects crossing the fault as shown, with each site **indicated as a circle**. **Proposed borehole tensor strain sites** are shown spaced along four traces parallel to the fault, with each site indicated as a **square**. Two of these traces are at a distance of approximately 3km from the fault on each side, with stations spaced such as to provide an inter-station along-fault distance of 5 km. The other two traces are at a distance of 8 - 10 km from the fault on each side, enabling observation of fault processes at depths of approximately 10km. Epicentre of the 1966 Parkfield earthquake is shown as a star, and the proposed SAFOD experiment is just to the southeast.