Annual Project Summary
DEEP BOREHOLE TENSOR STRAIN MONITORING, SOUTHERN CALIFORNIA

NEHRP Grant 01-HQ-GR-0156

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seismology, geodesy, borehole geophysics

Project Objectives and Approach

This project provides field observations critical to an understanding of fault processes associated with earthquakes along the San Andreas and Sierra Madre faults. Continuous high precision and high resolution borehole tensor strain data provide an essential complement to long baseline interferometry studies, GPS studies, and seismic characterisation of faults.

The project continues a program of maintenance and analysis of deep borehole tensor strain instrumentation initiated at Pinon Flat in late 1983, and a further deployment in the San Gabriel mountains region (Coldbrook) in 1996. These instruments consist of a three component plane strain module operating at strain sensitivity of 10^{-10} and support data logging systems. They provide data sampling at 30 minute intervals for transmission via satellite to permanent archive. The instruments provided by this project are unique in the program in that they provide continuous tensor strain data of quality and sensitivity not achievable by any other instrumentation. These data form a critical complement to studies assessing strain rates and consequent earthquake risk, fault processes associated with earthquake preparation and postseismic relaxation. Archived long term baseline data are openly available from *http://www.cat.csiro.au/dem/msg/straincal/straincal.html*. Data are also provided in near real time in the USGS Menlo Park computer system (***thecove:/home/mick/QUICKCHECK***). These data permit real time monitoring for short term strain phenomena.

The **immediate objectives** of the project are

- Maintenance of uphole system integrity at 2 Southern Californian sites, with repair or production of replacement uphole electronics as necessary.
- Manual preparation of raw instrument data for permanent archive.
- Analysis of continuous unique low frequency shear strain data (30 minute samples) and modelling studies based on the constraints of these data
- Near real time alert response to the earthquake studies community when necessary.
- Archive of processed data for access by the earthquake studies community, and provision of near-real time automatically processed data for inclusion in publicly accessible web pages linked to the USGS web datasets.

The project is carried out in parallel with maintenance of five further sites (San Juan Bautista, along the Hayward fault and near Parkfield) in Northern California.

Investigations & Results

Long Term strain data

One of the three channels (gauge 2) in the Pinon Flat BTSM instrument suffered abnormal degradation in gain from 1999 onwards, due to component ageing in the downhole preamp (after 20 years of continuous operation). The internal gain compensation system ran out of dynamic range in mid-2000. In December 2000 an additional gain compensating circuit was installed on this channel. Normal operations have resumed, allowing the 19 year dataset baseline to be continued. The gauge component data are shown in the lower traces of Figure 1, and calculated strain in the upper panel.

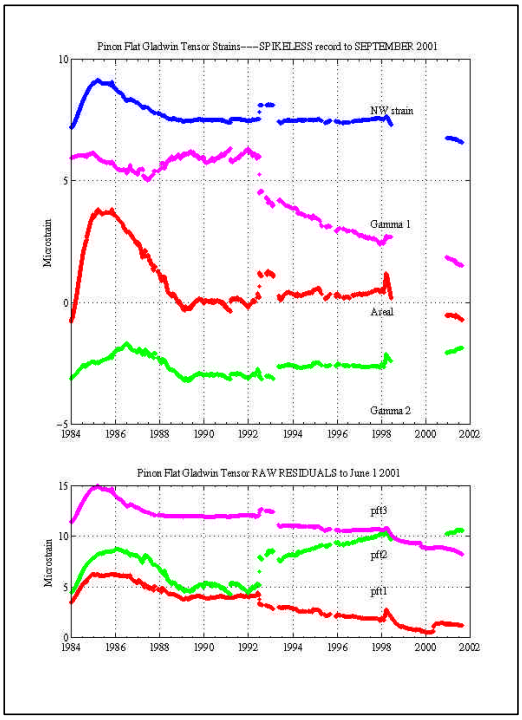


Figure 1. Pinon Flat tensor strainmeter data. Lower panel shows each raw component since installation in 1983. Component 2 downhole failure in 1998, and successful uphole electronics compensation to recover this component in late 2000 are shown. Upper panel shows the computed strain components.

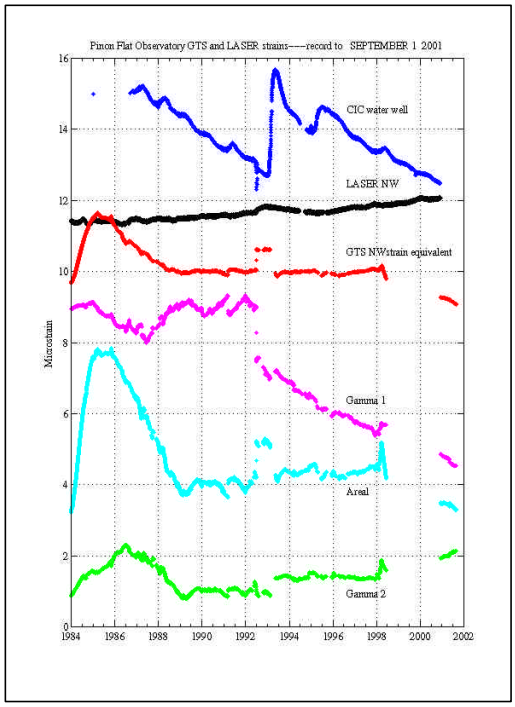


Figure 2 Data from Pinon Flat tensor strainmeter compared with the laser strain meter since installation in 1983. *Traces in order from top, show*: aquifer level in nearby water well; nearby laser strainmeter NW data, calculated NW strain from tensor strainmeter data, and three tensor strainmeter components gamma1, areal and gamma 2.

Shown in Figure 2 for comparison are aquifer level in water well CIC, and north-west laser strain data. The anomaly in strain in early 1998 is correlated with an anomalous change in aquifer level, and probably is caused by precipitation during that period. The large changes in 1992 were caused by the Landers earthquake.

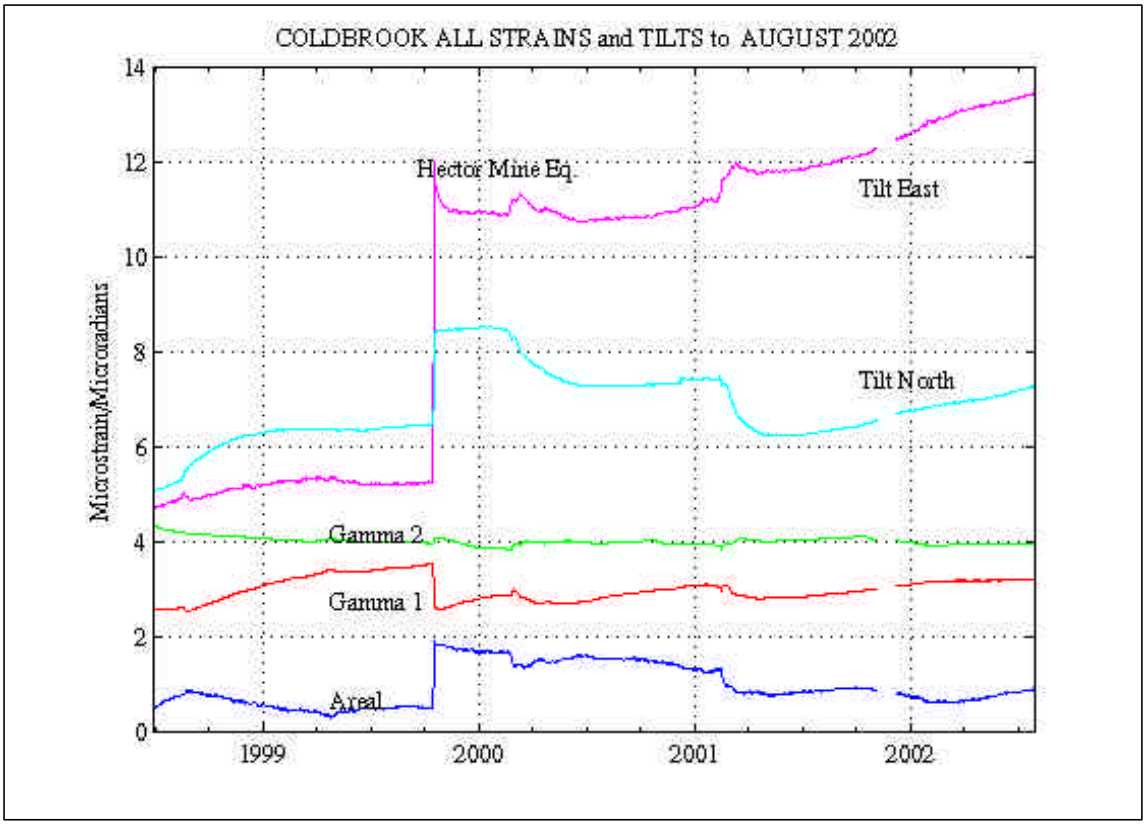
September 1, 2001 produced a massive electrical storm during which all instruments at PFO were disabled. Initial repairs were implemented during the December 2001 field trip, but further repairs were necessary and were completed in late May 2002.

Subsequent to this, data in late July and August indicate that further degradation is occurring on Channel 2, and more action was undertaken in December, 2002. The

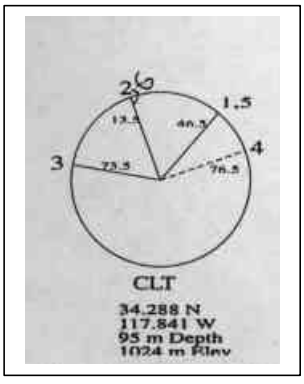
cable is now on 20 year expected service life limit, so progressive deterioration is to be expected.

Propagating event in San Gabriel

The Coldrook site is situated in the San Gabriel mountains, and together with three USGS operated borehole dilatometers ***puba*** (20km NW), ***cnts*** (15 km SW) and ***bdts*** (15 km SE) forms a 4 instrument array in the region between the Sierre Madre and San Andreas faults. The Coldbrook instrument was installed in late 1996, and borehole recovery processes evident in the data in the form of exponential signals have been removed.



The site is showing very little change in gamma2 through the whole record, yet significant fluctuation in both areal strain and gamma1. There is a change of strain rate prior approximately six months before the Hector Mine Earthquake showing also in the tilt data. This is early in the site lifetime so should be treated with reserve. It is clear that all fluctuations on the strain components are accompanied by tilt fluctuations. The azimuthal orientation of the various instrument components is shown to the right. Channels 1 through 4 are strain, and 5 and 6 are tilt. The major driver of the strain and tilt variation at this site is on channel 2 and channel 6. The exponential grout curing models removed from the data have now been reviewed and are now in final form in all archived data.



A hard disk failure occurred in August 29, 2002, and was repaired in December, 2002.

Small anomalous strain changes were observed on all of the strainmeters in the Sierra Madre array sites in late October 2001 (see Figure 3 below). There was no precipitation recorded during this period. This is the first time that a wide area effect has been seen in this array. The tensor strainmeter (Coldbrook) indicates a changes of gradient of greater than 200 nanostrain per year predominantly in the gamma2 shear strain component. Strain offsets were observed at **puba** on 12 October, and at both **cnts** and **bdts** on 19 October, with smaller offsets on 25 October. The puba signal also indicates a change of strain gradient following the offset event. The correspondence of these strain changes across the array suggests a strain signal propagating from north (on the San Andreas fault) towards the south (Sierra Madre fault) at an approximate rate of 5 km per day.

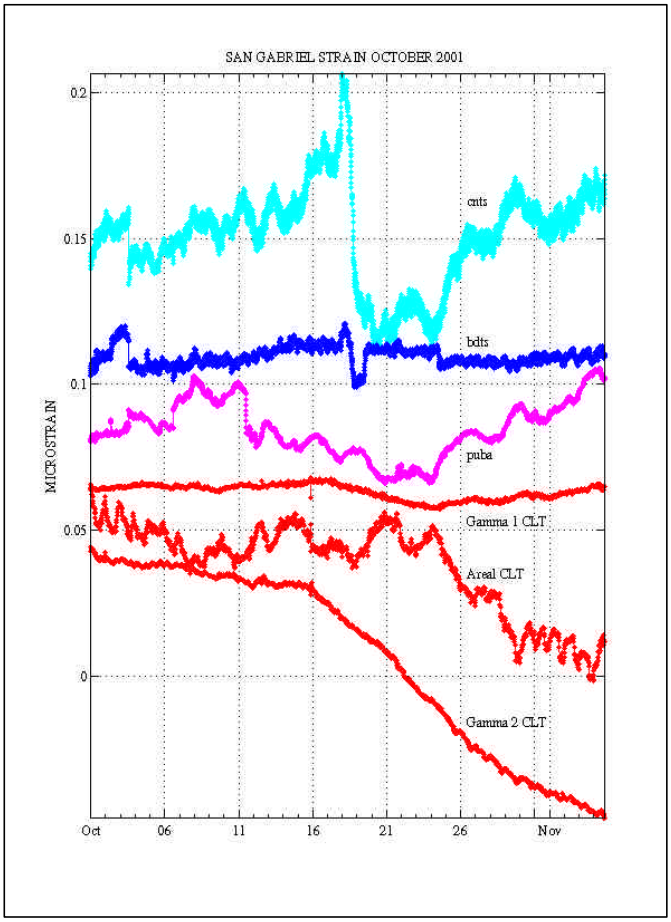


Figure 3. Initiation of strain gradient changes at **pub**, **clt** and **cnt** occurred during October 2001. Events occur at pub (12 October, clt (16 October, and cnts, bdts (19 October), and then again at each site on 25 October.. The temporal progression of the initial events may indicate a strain propagation at 5 km per day.

Data Product Availability

Archived strain data from the Californian sites are stored in both raw component form, and as processed areal and shear strains. A regularly updated archive of data has been maintained in the USGS Menlo Park computer system since 1988. This data is stored in binary files with appended header information (USGS "*bottle*" format).

CSIRO home page for direct access to data from all borehole tensor strain instruments in open format is *http://www.cat.csiro.au/dem/msg/straincal/straincal.html* ***This page includes facilities for download of raw or processed data from our primary archive***.

Automatically processed near-real time data is always available in *thecove:/home/mick/QUICKCHECK* for users with access to USGS plotting software "*xqp*", and via the USGS crustal deformation web pages in graphical form.

Scientists requiring other access to the archived data should contact Dr. M.T. Gladwin (+617 3327 4562, email *mike.gladwin@csiro.au*).

Publications

Recent Publications

Gwyther,R.L , Gladwin,M.T, & Hart,R.H.G. &M.Mee Focussed Study of Aseismic Fault Processes, *Workshop Abstracts, Earthscope Workshop: Making and Breaking a Continent, October 2001. p 157-160, 2001*

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Gladwin,M.T., Gwyther,R.L., & Hart,R.H.G., Addition of Strain to Targeted GPS Clusters-New Issues for Large Scale Borehole Strainmeter Arrays, *Proc. 2nd Plate Boundary Observatory Workshop*,1.17a-1.17e, *2000*

Langbein, J., Gladwin, M.T., & Gwyther,R.L., Extension of the Parkfield deformation array,*Proc. 2nd Plate Boundary Observatory Workshop*,2.45-2.49,2000

Thurber,C., Gladwin,M.T., Rubin,A., & DeMets,D.C., Focussed Observation of the San Andreas/Calaveras Fault intersection in the region of San Juan Bautista, California, *Proc. 2nd Plate Boundary Observatory Workshop*,2.75-2.79, 2000

Roeloffs,E., Gladwin,M.T., & Hart,R.H.G., Strain monitoring at the bend in the Cascadia Subduction Zone, *Proc. 2nd Plate Boundary Observatory Workshop*,4.36-4.40 2000

Steidl,J., Gladwin,M.T., Gwyther,R.L., & Vernon, F., Fault Processes on the Anza section of the San Jacinto Fault, *Proc. 2nd Plate Boundary Observatory Workshop*,2.70-2.74, 2000

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Selected Previous Journal Publications

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Gwyther R.L., M.T. Gladwin and R.H.G. Hart Anomalous Shear Strain at Parkfield During 1993-94 *Geophys. Res. Lett. V 23 (18)* p 2425-2428, 1996

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Gladwin, M.T., Gwyther, R.L., Hart, R.H.G. and Breckenridge K.(1993) Measurements of the strain field associated with episodic creep events on the San Andreas fault at San Juan Bautista, California (1994*). J. Geophys. Res*. Vol 99 (B3), 4559-4565.

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Gwyther R.L., Gladwin M.T. and Hart R.H.G. (1992) A Shear Strain Anomaly Following the Loma Prieta Earthquake. *Nature* Vol 356 No.6365 pp 142-144.

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Non-Technical Summary

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