MAINTENANCE, DATA ARCHIVE AND ANALYSIS OF EXISTING LOW- FREQUENCY GTSM INSTALLATIONS IN CALIFORNIA.

NEHRP Grant 04-HQ-AG-0116

August 1, 2004 to February 28, 2007.

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seismology, geodesy, borehole geophysics

Project Objectives and Approach

This project provides **maintenance and analysis of now five deep borehole Gladwin Tensor Strainmeters (GTSM)** in California for a bridging period to ensure continuity of observations into the early PBO era. The remaining sites, (SJT (1983), CLT (1996), DLT (1986), FLT (1986) and CHT (1992)) operate at a sensitivity of better than 10^{-9}, with data sampling at 30 minute intervals. They provide the NEHRP program with a tensor strain data base which needs to be maintained at least until key PBO arrays are established to ensure continuity of these long term data sets. The project provides open access to quality assured data archive, identification of strain events and anomalies, correlation with datasets from other instrumentation, and maintenance of all pre-PBO GTSM sites

Archived long term baseline raw data are available from http://www.ncedc.org and for processed data at http://quake.wr.usgs.gov/research/deformation/monitoring.data.html in the USGS open archive Data are also provided in near real time for internal USGS staff within the USGS Menlo Park computer system at ***thecove:/home/mick/QUICKCHECK***, Full archive quality component data is also available within the USGS at thecove:/home/mick/BASEDATA/RAW_FOR_BERKELEY/ .

The **immediate objectives** of the project were initially

- *Provision of data for understanding* of stress accumulation and relief processes, and aseismic fault interactions.
- *Operation and Maintenance* of six instruments in California to continue the 20 year-long baseline of data.
- *Detailed editing and archive maintenance* of a permanent archive of instrument data at Berkeley, Menlo Park, and in on line user-friendly form.
- *Ongoing analysis* of continuous unique low frequency shear strain data, *identification and modeling* of significant strain events, and *publication as appropriate of modeling studies* based on the constraints of these data.

Archived Data

The servers listed above for the formal archive data are in some instances not user friendly so that we are also maintaining a specialist archive at our GTSM instrument production facility. We also provide overnight turnaround of any data sets requested to marie@gtsmtechnologies.com as noted on the strain download form at http://gtsmtechnologies.com/NEHRP/strain_download/strain_form.html This archive is now open for direct access.

- **Parkfield**
    - Long term data plots for the **Donnalee** site are shown below.

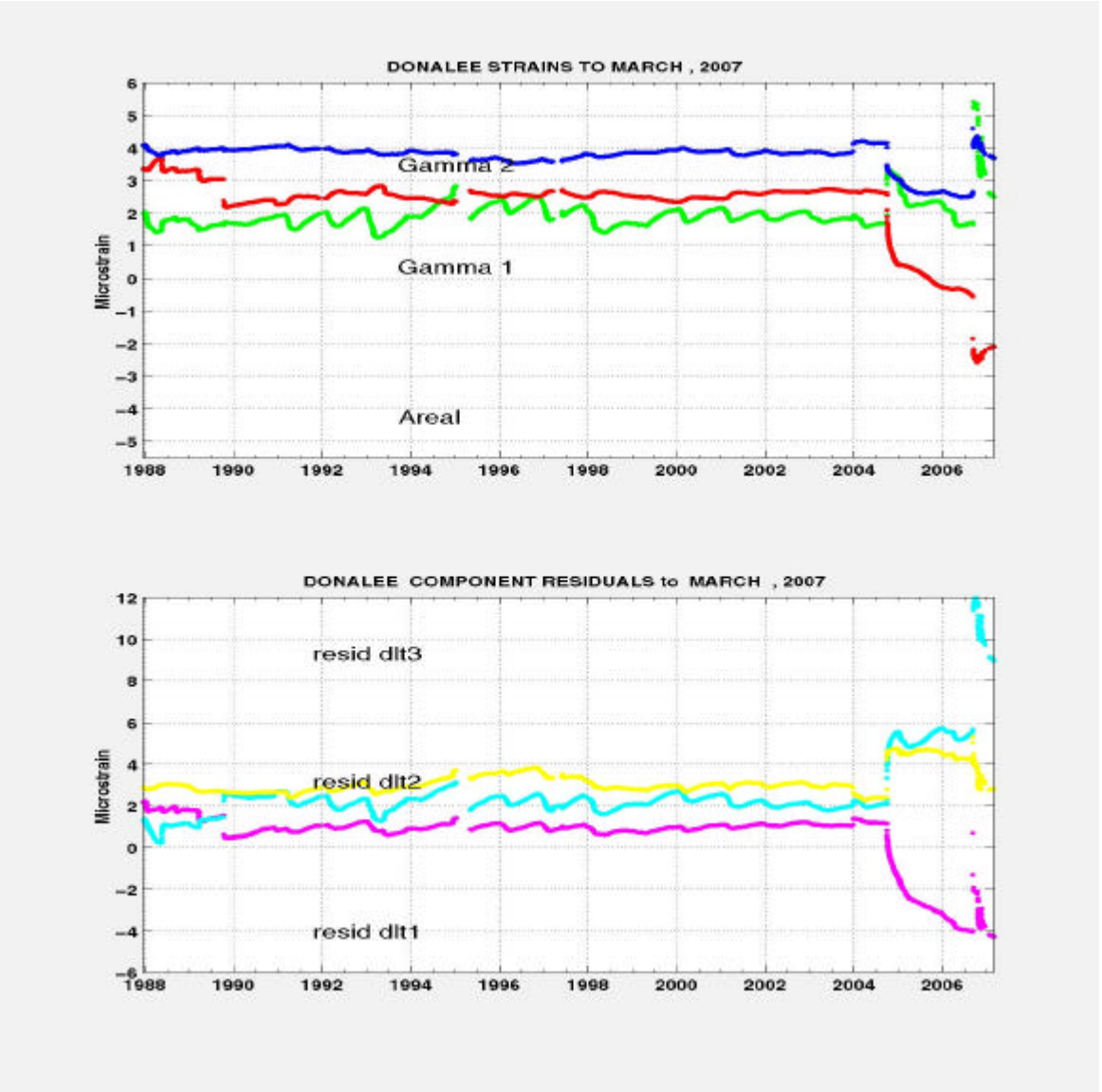

***Figure 1(a)**: Long term tidally calibrated residual strain data from DonnaLee site at Parkfield to March 1, 2007.. The 2004 Parkfield earthquake and its post seismic deformation over more than 18 months dominates the record. The areal strain step from the September, 2004 Parkfield event has almost returned to present values, but the two shears are settling to significantly different offset values.*

The PBO drilling program began in Parkfield in summer of 2006. The new PBO DonnaLee site was drilled on August 30, at a distance of 100m from the NEHRP DLT site installed in 1986. This original DonnaLee site provided excellent data and has always shown an annual signal due to the aquifer replenishment temperature differentials during the rainy season. The borehole was sealed to the surface immediately after installation in 1986 with concrete, thus containing the aquifer as is standard GTSM practice.

PBO 2004 Steering Committee added pore pressure measurement *(extra to the 2002 steering committee decisions)* at most PBO sites and as implemented leaves the borehole open to the atmosphere (so that failing pressure transducers can be replaced). In an attempt to control water flow in the borehole which is a major contaminator to the strain signal measurement, packers are being used to seal the borehole. Release of the aquifer occurred **during drilling** at 161 feet. At 400 feet on September 8, 12 batches of cement were used, and when the borehole reached 654 feet, a 10με signal occurred

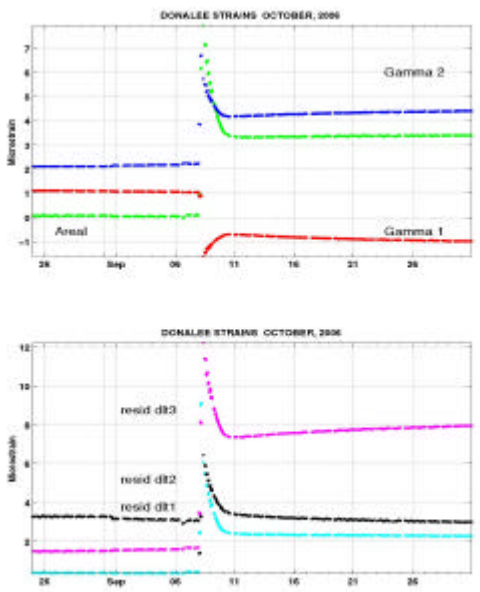

***Figure 1c**:PBO Drilling and installation effects DLT*

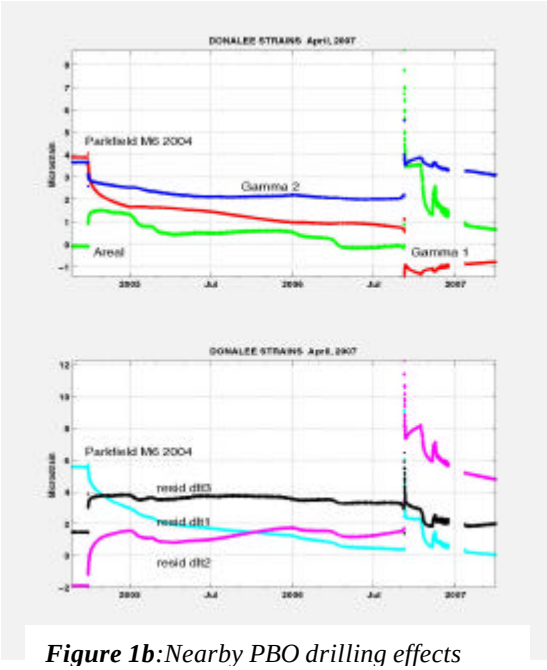

***Figure 1b**:Nearby PBO drilling effects*

(much larger than the Parkfield Earthquake of September 2004)(***Figure 1b***). This major disturbance relaxed over the next 2 days, but has resulted in a **permanent offset on all channels**, a small extension on channel 1, 3 microstrain extension offset on channel 2, and 1.5 microstrain compresson offset in channel 3.

After the disturbance on August 30, attempts have been made to close this new PBO site with packers which have failed several times, (eg Oct 20, Nov 14-17), each time compromising the DLT strain signal.

PBO drilling was carried out at the new DonnaLee PBO site on August 30,2006. The PBO strainmeter **installation** was carried out on October 13, the seismometer installation was carried out on October 14 and was accompanied by up to 100 nε compressional step on all channels at DLT, probably due to high pressure pumping of the cements. This was followed over Oct 14 to Oct 19 by 100 to 160 nε compression on all channels.

It is unclear whether the flow of artesian water from this installation has been halted.

At this stage, March 31, 2007, though the offset caused by the drilling and new installation is unchanged, <u>the rate of strain change</u> established after the rainy season in May 2006 in channel 1 and 3 appear to be resuming, but that of channel 2 (the most affected by the

drilling) has changed from extensional 3.7 nε/yr to compressional 2400 με/yr. Investigations of the data reveal that this is not a normal wet season effect. More likely it is evidence that the aquifer has not returned to its original state and is still in transition, see ***Figure 1c*** above.

This has resulted in overall strain rate changes from 240 nε/yr extensional to 960 nε/yr compressional in Areal at DLT, from 585 nε/yr negative to 480 nε/yr positive in gamma1, and from 160 nε/yr negative to 1 με/yr extensional in gamma2. (see table below)

DLT	May to Sept 2006 nε /yr	Feb March 2007 nε /yr
areal	240 extensional	960 compressional
Gam1	585 negative	480 positive
Gam2	160 positive	1020 positive

The value of this particular site for 'linking' 20 years of NEHRP strain record into the new PBO Parkfield array now seems totally compromised.

- **Frohlich**

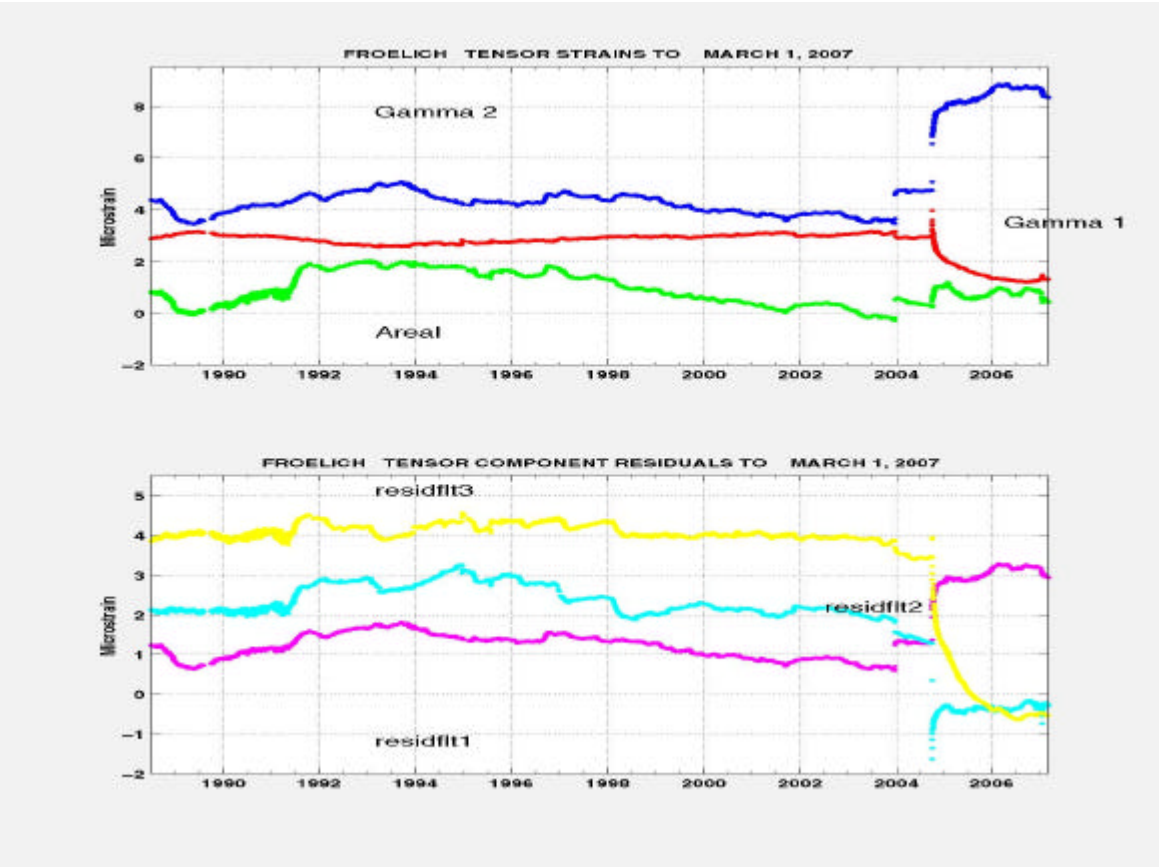

Figure 2*: Long term tidally calibrated residual strain data from Frohlich site at Parkfield to March 1, 2007. As previously, the lower panel contains residual component data after removal of borehole recovery exponentials. Strain residuals are calculated from these component residuals.*

The Frohlich data to March 31,2007 are shown on ***Figure 2*** above. Again, all major steps are associated with the Parkfield M6 event of September 28, 2004. The

gauge residuals at both DonnaLee and Frohlich show that, excluding identified tectonic events, the average variation from the mean in gauge strain rates has been less than +/- 0.3 microstrain per year for the whole of the 20 year record, (1986-2006).

During the period since the 2005 site visit, further deterioration in the downhole cable to the sensor for Channel 2 at FLT has occurred. See ***Figure 3*** below.

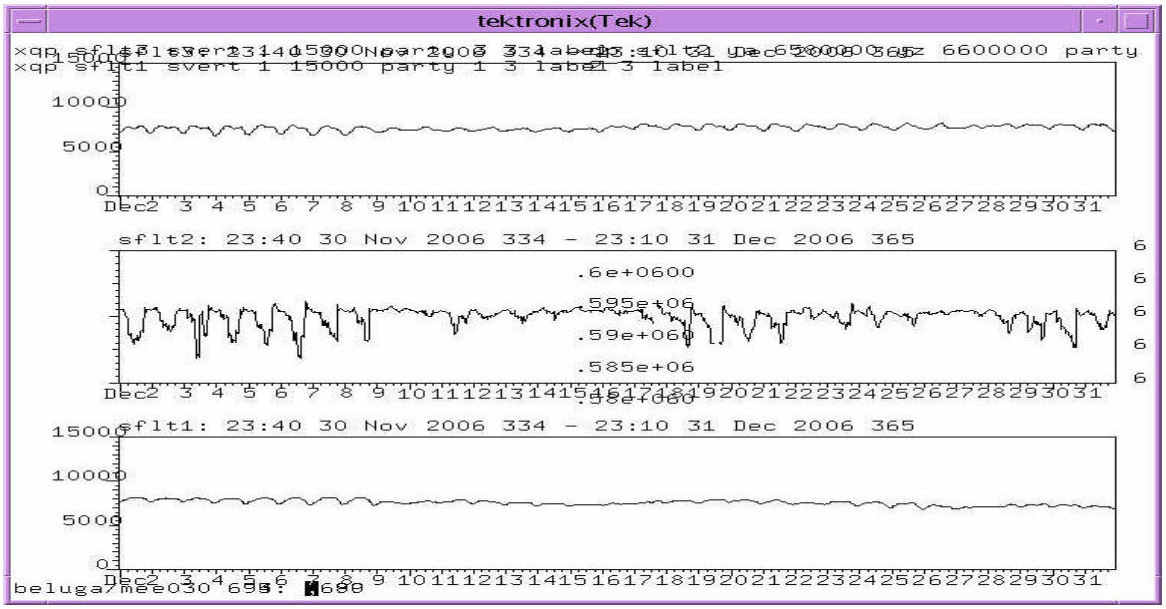

Figure 3*: FLT channels 3,2 and 1at same scales. The spurious signal o Flt2 is now dominant.*

This noise level precludes reliable detailed shear strain studies, though long term observations on CH2 appear to be unaffected.

RECENT PARKFIELD CREEP EVENT

On January 24, 2007 there was a creep event at Parkfield on creepmeters xva1, xpk and xmd. The DLT strainmenter was off line for this event with battery failure, and the event was only recorded in tensor strain by FLT .

The time history of the event is shown in ***Figure 4***(below).

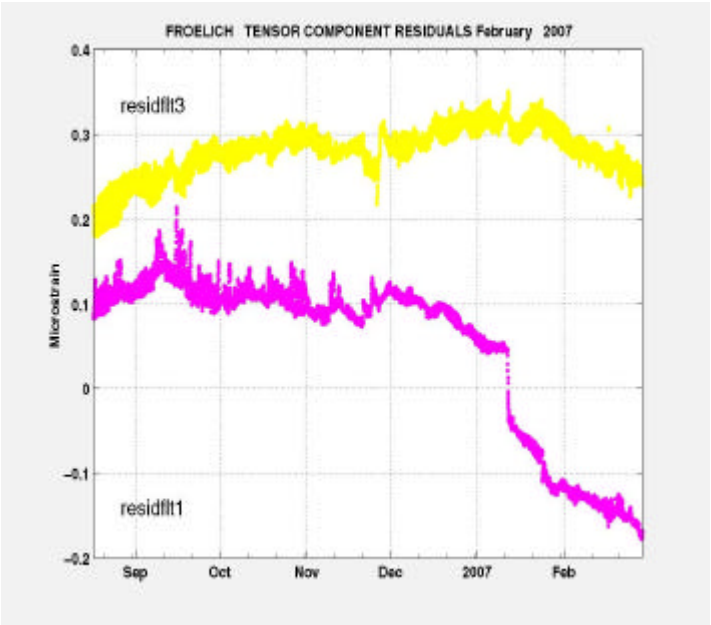

Figure 4*. Data at FLT on two gauges during the January creep event. The associated strain event occurred over a period of about three hours with an extended period of readjustment following it. Noise levels are high and signal to noise on flt2 makes this site unusable for small event strain analysis*

We have made a comparison of this event with the C level alert of October 1997 in ***Figure 5*** below.

Strain ne	Oct 1997	Jan 2007
Areal	-17	-450
Gam1fl	6	-2
Gam2fl	-200	-300

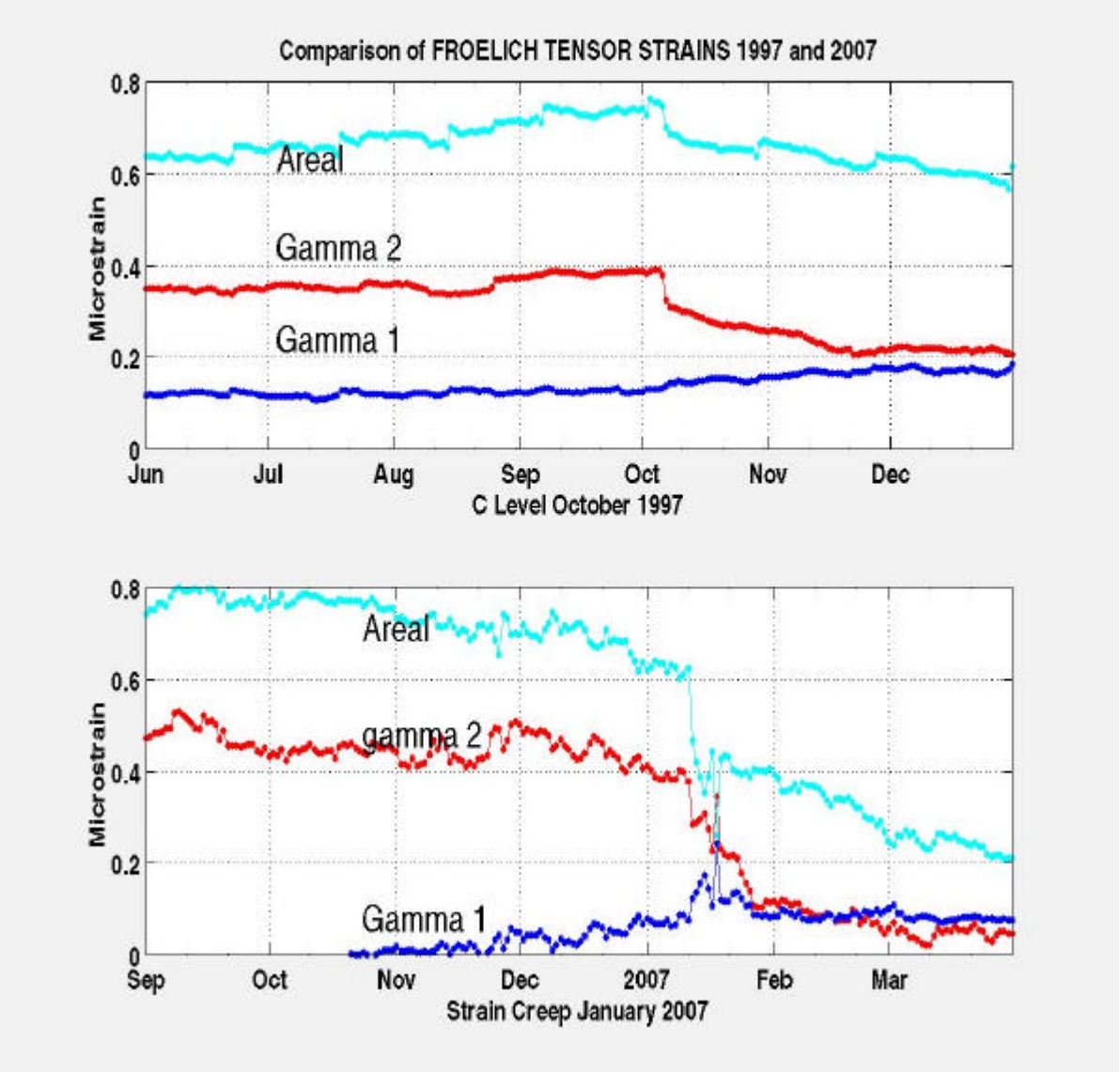

Figure 5*: Records across the January, 2007 event and the 1997 C alert event. The time interval involved is quite similar for both events, and both show a recovery interval of more than a month*

The 1997 C level event as reported in 1997 is seen in ***Figure 6*****.**

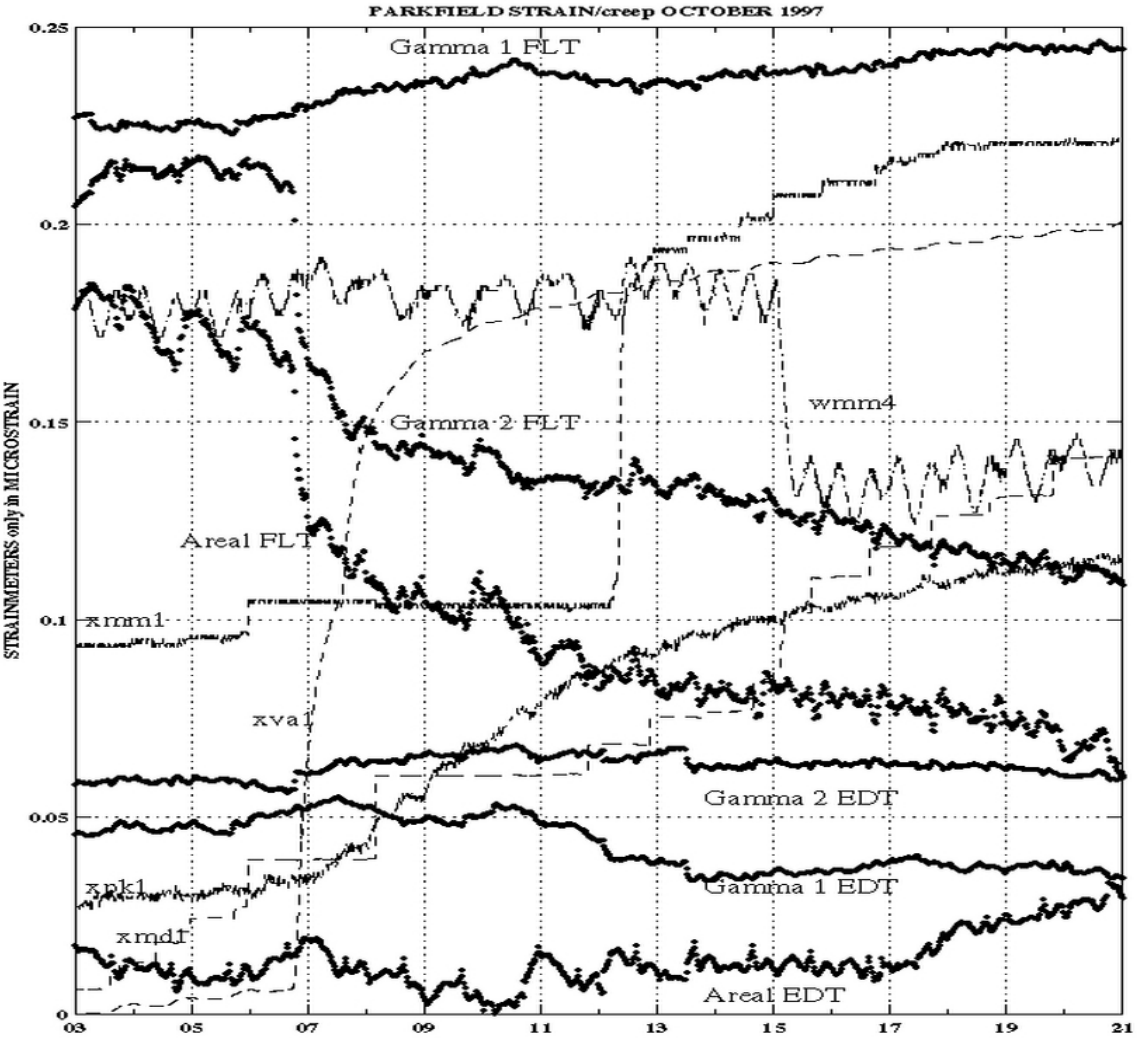

Figure 6: *the 1997 C Level alert event of Oct 6 as reported in 1997. Record shows six strainmeter traces and four creep meter records. The timing of the effects are significant.*

The studies on the Parkfield M6 event of September 2004 have been reported previously. No further work has been possible in the time allowable by this contract.

- **San Juan Bautista and Chabot**

Several maintenance visits have been required to the San Juan site over the past year. These have been associated with battery replacements and drift of the satellite data retrieval systems. The assistance of USGS staff (Langbein, Snyder, and Myren) is acknowledged and greatly appreciated for these visits. The data quality is still excellent.

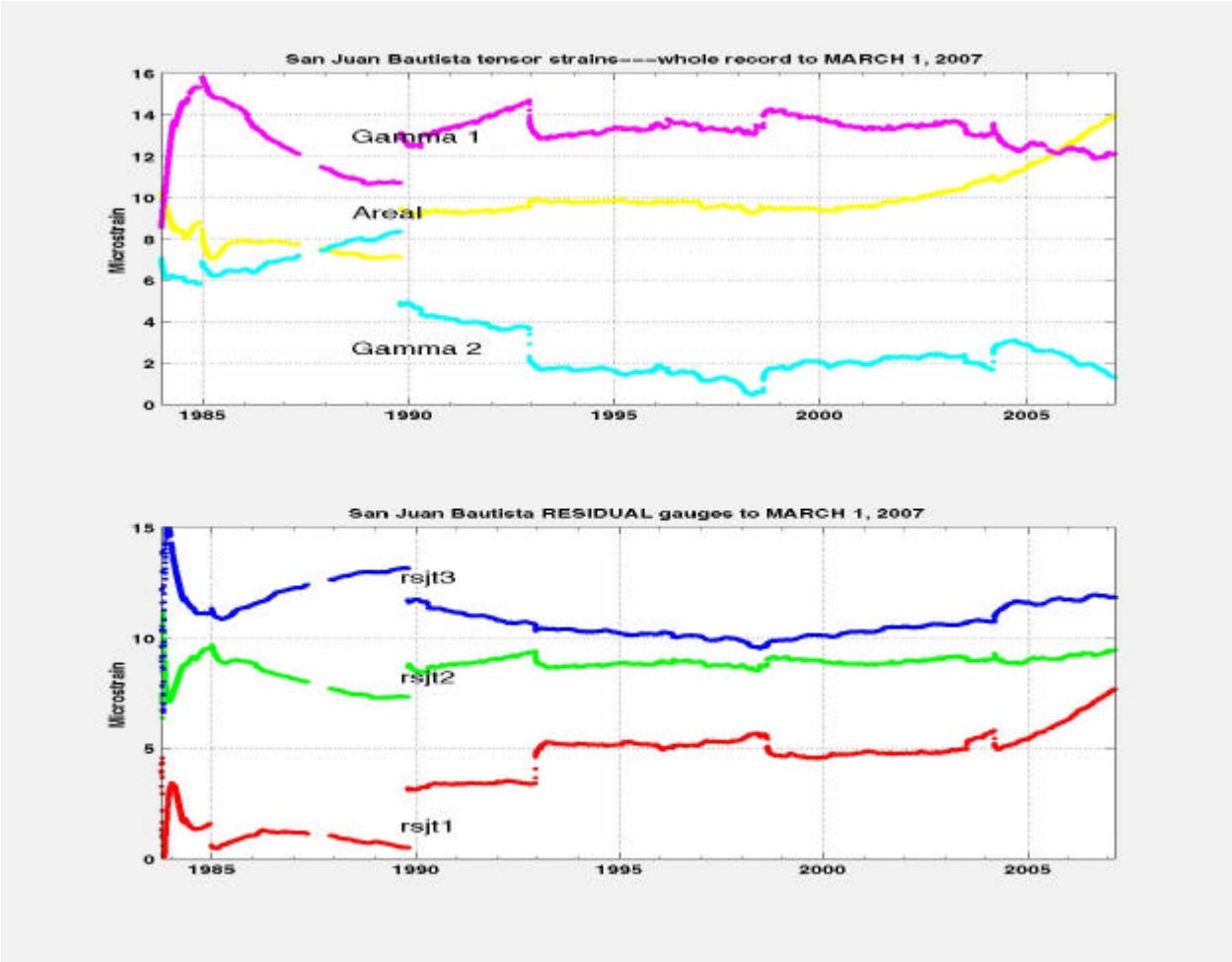

Figure 7*: Long term tidally calibrated residual strain data from San Juan Bautista site to March 1, 2007*

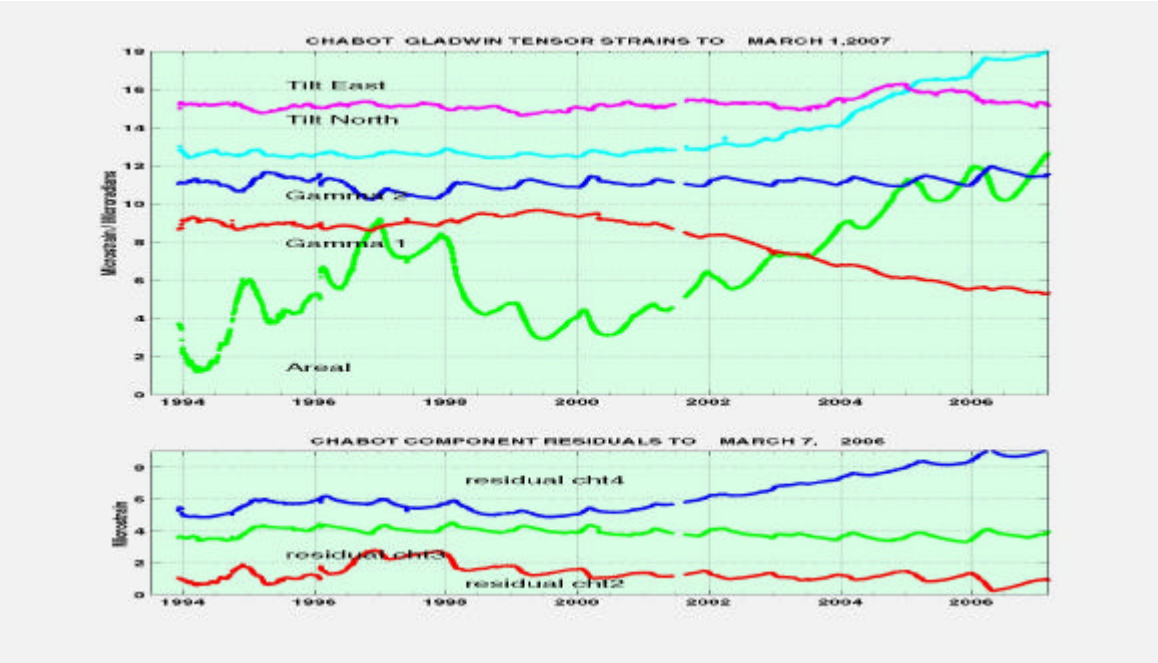

Figure 8.*: Long term a priori calibrated residual strain and tilt data from Chabot site in San Francisco Bay Area to March 1, 2007.*

The Chabot site has operated without problems over the period of this report. The annual cycle in the data has been associated with the level in the San Leandro reservoir in previous reports, and the effect has continued through this season.

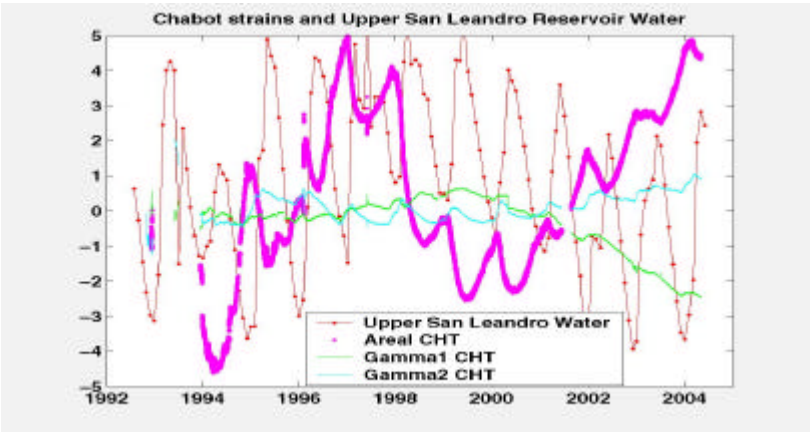

Figure 9. *Long term Chabot Strains and San Leandro water levels . Note that the measured areal strain is dominated by the water level at the annual level, and that the shears are relatively unbiased by this water induced signal. The change in gamma1 strain rate (green trace) beginning in early 2000 is probably not due to the progressive rise in water level because for the years 1994 to 1997 when a similar water level rise occurred there was no corresponding change in gamma1. Note also that the shears are mainly immune from the reservoir effect.*

The previous report discussed a large signal anomaly across an eleven year record comparing responses at SJT and at CHT. There was a change of strain rate on the areal strain at SJT and on the gamma1 shear at CHT beginning in about 2000. These sites are quite far apart and totally independent, yet the time signatures and amplitudes of the anomalous responses in areal strain at SJT and Gamma1 strain at CHT were remarkable. Taken at face value the responses represented an anomaly at a spatial scale not previously identified in this project. The change in strain rate is approximately 0.6 microstrain per year at SJT and nearly 1 microstrain per year in Gamma1 at CHT, approaching the levels which can be detected by GPS studies. At both sites the trend changes are almost undisturbed by the SJT slowquake of March 2004 or the Parkfield event in September, 2004.

The trends there noted are continuing, and other scale-similar deviations have been noted in the southern California site over the same time window. ***Figure 10*** below shows long term strain rate changes for SJT, CHT and CLT sites on particular components.

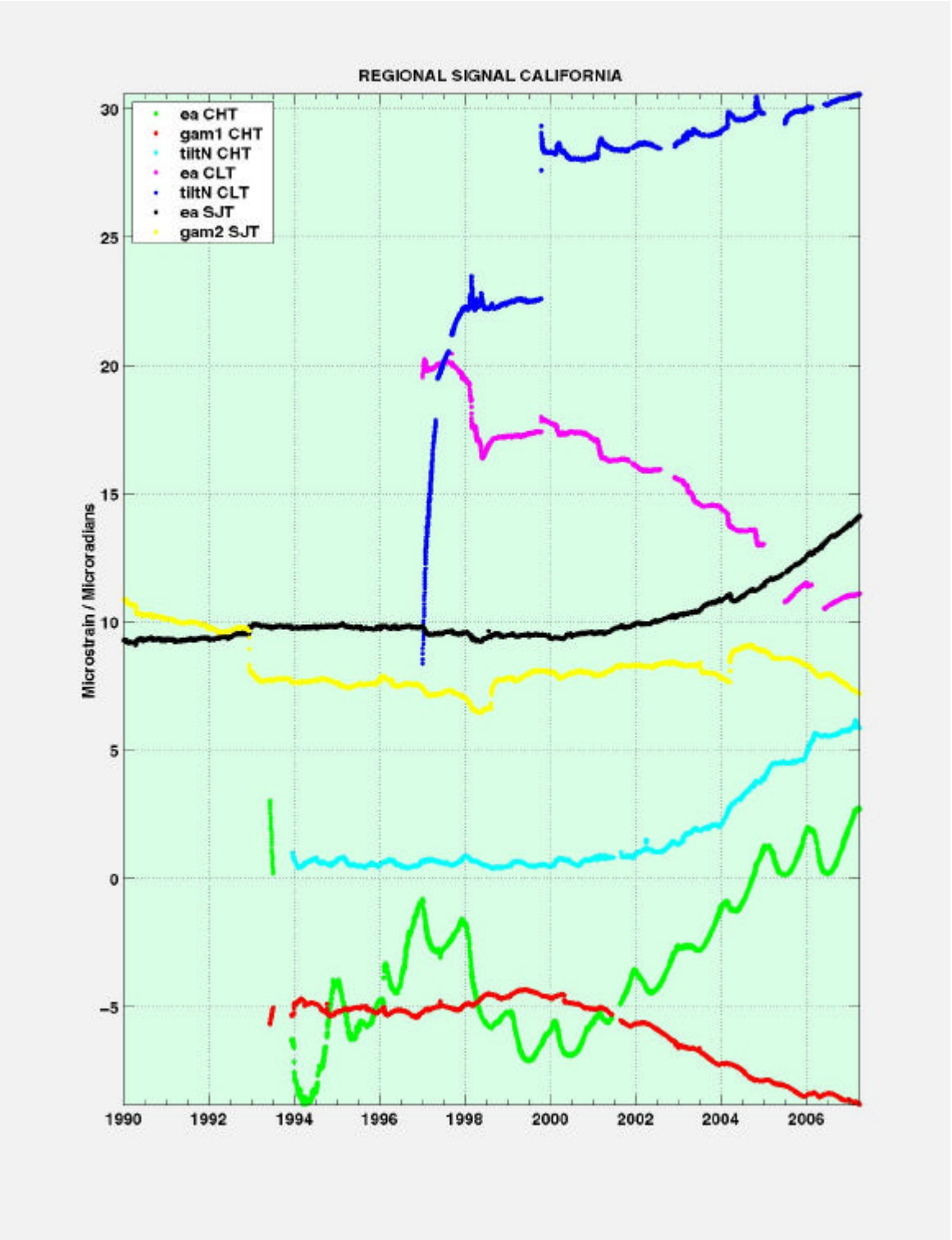

***Figure 10**: Simultaneous long term strain rate changes at SJT, CLT and CHT beginning in early 2000. The offset of the Hector Mine event (late 1999) shows on the southern station CLT (magenta areal strain and dark blue tilt north). Almost a year later these components began a clear change of strain rates. At the northern end of the array, changes of strain rate are indicated at CHT in areal strain (green) and in shear gamma1 beginning about 2000, and in tilt (teal) in about 2002. Changes of rate are clear at SJT by 2002 (Black). All of these anomalies are well above established noise and drift levels at any of these sites.*

Strain and Tilt at Chabot site.

The CHT instrument is fitted with two components of tilt incorporated without Federal funding when the instrument was deployed in 1992. This tiltmeter is an experimental pendulum instrument, with Kevlar polyfilament strip suspension. It is undamped.

The tilt data require a great deal of manual editing to remove the steps caused by monofilament failures triggered either by weather shocks or more commonly seismic shocks. All such steps have been removed. 19 years of tilt data have now been recorded and regularly reported in a time series plots along with with the computed a priori calibrated strain data from channels 2, 3 and 4 from this instrument.

The long term trend of the tilt to the north (cyan trace) can be seen in ***Figure 10*** above, correlating with the areal (green) and gamma 1 (red) signals at this site. Also of interest is detail of the strain and tilts in the annual rain season signal as seen below (***Figure 11***).

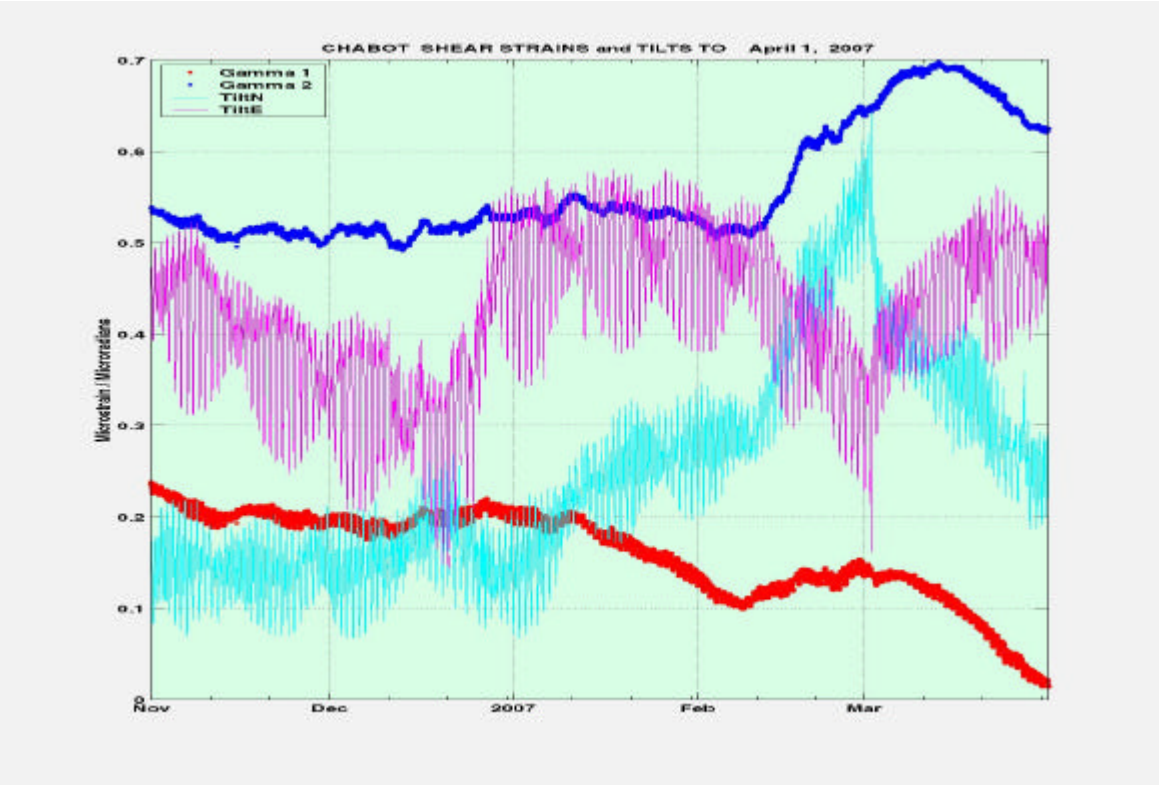

Figure 11: *Shear and tilts during seasonal rain at Lake Chabot site near San Leandro Reservoir in SF Bay. Cyan is TiltN, Magenta is TiltE, Red is Gamma1 and Blue is Gamma2.*

The tilt records (cyan and magenta) showed sensitivity to the beginning of the wet season in late December. The Gamma1 signal was stable till mid January when it changed rate to -1.2 $\mu\varepsilon$/yr with no change on Gamma2. This trend continued until about February 10 when the gamma1 strain rate reversed and a strong rate change occurred on Gamma2. On March 2, a further reversal occurred on Gamma1 which was accompanied by strong rate changes on both tilt channels. The site has a strong topographic component which enhances the tilt sensitivity.

- **Southern California**

Coldbrook

For **CLT**, the major step is the Hector Mine Eq. of 1999. Here gauge residuals show that excluding known tectonic events, and a large local transient offset measured on all strain and tilt channels late in the 1998 rain season, the average variation in gauge strain rates has been less than +/- 0.4 microstrain per year over the 8 year record (1996-2004). The strain calculations here are from components 1, 2 and 3.(cf 1, 3 & 4 previously).

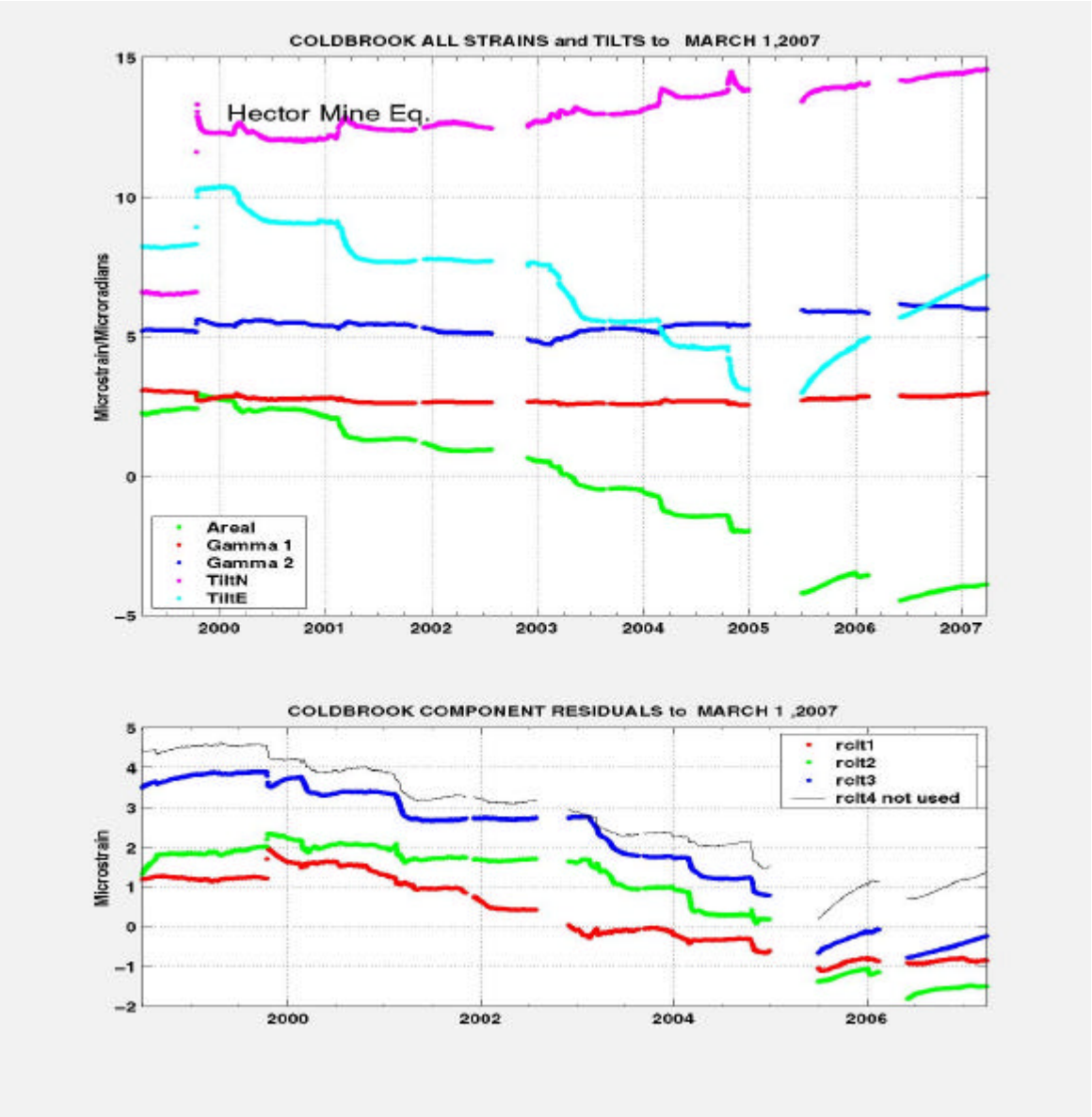

***Figure 12**: Long term data from Coldbrook to March 1 2007 with residual strains calculated from component channels 1, 2 and 3. Recovery to prior trend after the repair at June 2006 is also demonstrated indicating good downhole stability..*

CLT is the only California tensor system with this particular data acquisition system. The site was restarted in a visit by the PI in June 2006, and is now producing continuous data. Long term survival of this site **uphole** electronics is unlikely. The downhole

system is in excellent condition, but the uphole electronics (a one – off use of this design in the California program is subject to repeated hard drive failure in the 1990 Compaq data acquisition system), needs complete replacement. When PBO extends its southern Californian coverage, this site should be investigated for upgrade to PBO electronics, and is compatible. This initiative will have to come from the science community or PBO.

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).

Data is also available from
http://www.gtsmtechnologies.com/NEHRP/strain_download/strain_form.html.

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

Scientists requiring further or more extensive access to the archived data should contact Marie Mee, email *marie@ gtsmtechnologies.com*

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Recent Publications

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Non-Technical Summary

Maintenance, Data Archive and Analysis of existing low frequency GTSM Installations in California

NEHRP Grant 04-HQ-AG-0116
August 1, 2004 to February 28, 2007

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seismology, geodesy, borehole geophysics

This project provides borehole observations of horizontal strain changes over timescales from minutes to years, which are critical to an understanding of fault processes associated with earthquakes along the San Andreas and San Gabriel / Sierre Madre fault systems. It continues a program of maintenance and analysis of deep borehole tensor strain instrumentation initiated at Pinon Flat and San Juan Bautista in late 1983, with deployments at Parkfield in late 1986, at San Francisco East Bay in 1992, and in the San Gabriel mountains region (Coldbrook) in 1996.

The project aims to continue these now five historic data sets into the new PBO program which is now being installed. Continuous high precision and high resolution borehole tensor strain data provide a powerful complement to GPS studies, and seismic characterization of faults. A major feature of this report is the inclusion of data showing *changes of strain rates which are coherent in time at sites separated by large distances and beginning in about the year 2000. It is also correlated with tilt measurements at two regionally separated sites*.

Post seismic recovery processes following the 2004 Parkfield event are continuing in the Parkfield area, but ongoing disturbances to the DLT site due to the new PBO installations, and degradation of the Ch2 downhole at FLT, indicate a lost hope for a smooth transition of historic NEHRP strain datasets to the 21st century.