Final Report
USGS Cooperative Agreement for Geodetic Monitoring Operations

Reporting Period:	To November 30, 2008
Cooperative Agreement Number:	07HQAG0030
Geodetic Monitoring Project Name:	Maintenance, Archive and Analysis of Pre-PBO GTSM Network in California.
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Major Goal(s) & Activities of the Geodetic Project:

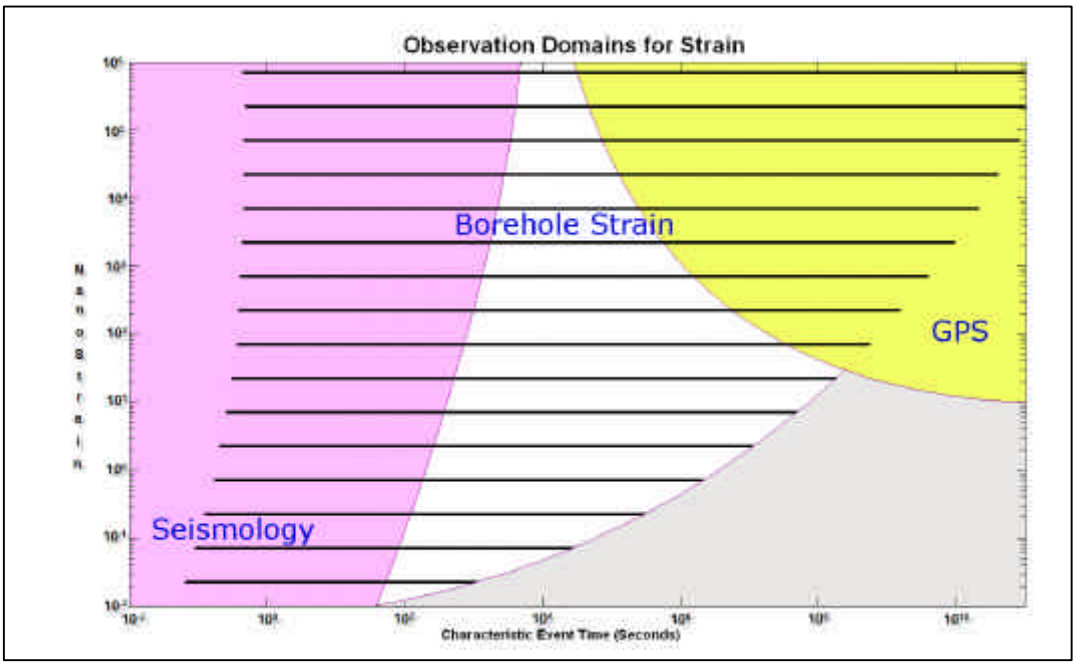
- *Operation and Maintenance* of five instruments in California to continue the 24 year-long baseline of data in regions soon to be populated by PBO arrays.
- *Provision of on line data for use in strain* accumulation and relief studies, and aseismic fault interaction studies.
- *Detailed editing and archive maintenance* of a permanent archive of instrument data at Berkeley, Menlo Park, and in on line user-friendly form.
- *Near-real time response* for data analysis for sections of the San Andreas and Hayward faults monitored by USGS.

Format of this Report:
This report will outline current status of the five sites still operating under this grant, present some new outcomes which have occurred in the past nine months and make recommendations on disposition of residual funds associated with this project.

Accomplishments & Changes Implemented in this Reporting Period:
All five remaining stations have been kept operating for this reporting period with minimal downtime. The data base has been updated to September 30, 2008, and the project has provided the following data sets.

Site	Archive Begins	Archive Ends	Status	Uphole Upgrade Recommended ?
SJT	31/12/1983	30/09/2008	Good	Yes (needs Vsat or ADSL, mains power and extended permit which may be problematic)
DLT	31/12/1987	30/09/2008	Offset by PBO but operational	Possible (needs Vsat)
FLT	31/12/1987	30/09/2008	Degraded	NO
CHT	31/12/1992	30/09/2008	Good	Yes (needs ADSL)
CLT	31/12/1996	30/09/2008	Good	Yes (needs Vsat)

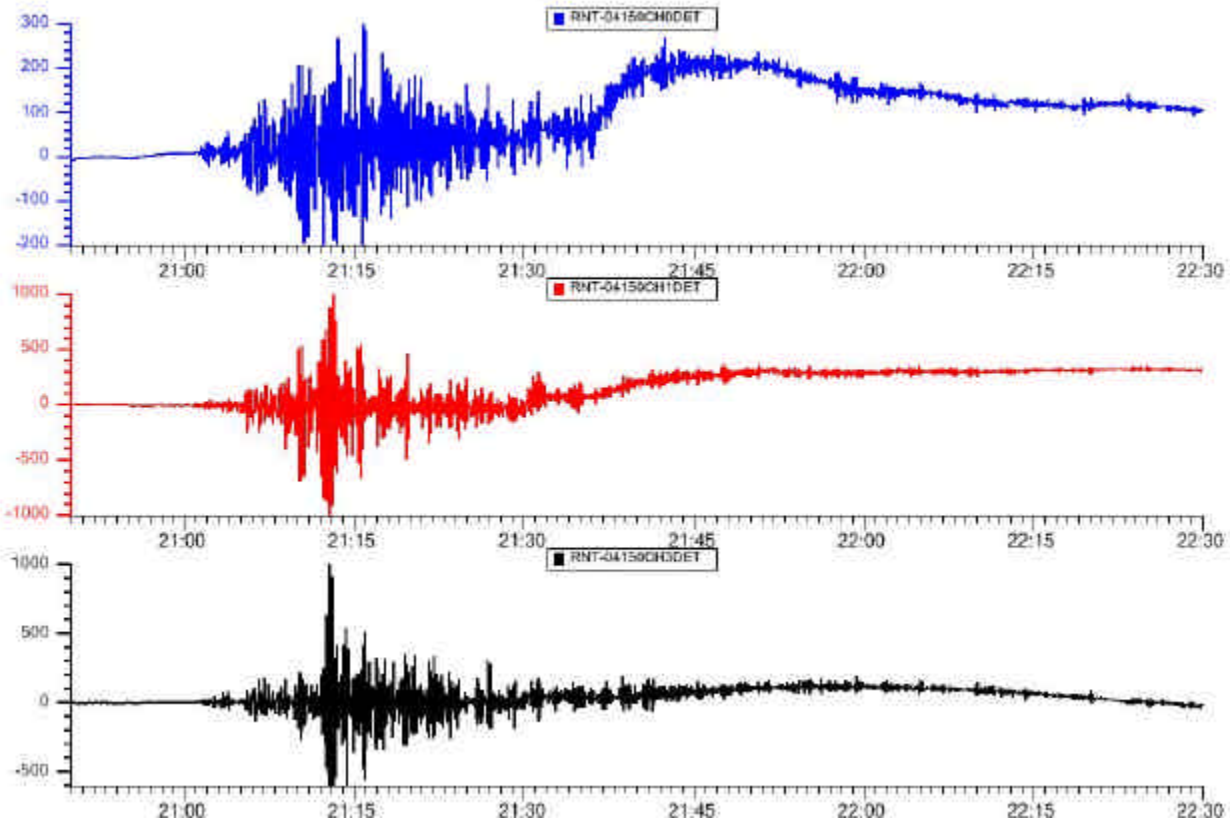
The project has richly achieved its original and evolved objectives of demonstrating and implementing a new technology into the NEHRP program. NEHRP borehole tensor data have provided significant new results. These results were the basis of the PBO borehole strain project and provided instrumentation on which that project is based. The PBO instruments implement the full band width of the instrumentation and when properly installed (http://www.gtsmtechnologies.com/pdf/GeneralPerformance.pdf) provide a bridge between GPS data and seismic data with considerable overlap with both these technologies. The figure below illustrates this broad range of useful measurement regime.



The logarithmic X axis identifies the time scale of deformations ranging from the seismic regime (100 Hz and higher) to very long period tectonic deformations hundreds of years. The Y scale (also logarithmic) covers event deformation amplitudes from 0.1 nanostrain to amplitudes of 100 microstrain (approaching rock failure). The range of dominance of GPS is shaded yellow in the top right (i.e. moderate amplitudes and longish periods). The seismic domain is shaded purple and covers a very wide range of amplitudes provided the source is dominantly short period ie faster than 100 of seconds). The horizontally shaded region which significantly overlaps both the seismic region on the left of the figure and the GPS domain of superiority to the top right of the figure is the targeted measurement domain for the GTSM instruments. Very many unexplained natural deformation phenomena occur in the period range. These include the long wavelength phenomena associated with fault dynamics in the period range of minutes to days and months (so called 'slow events'), static offsets due to fault motion, and progressive failure during seismic failure sequences. The high deformation sensitivity of the GTSM system allow detailed investigation of these phenomena, many of which have been first identified in this NEHRP project.

An example of this dynamic range capability is shown in the figure below for an event in 2004, May 29. The figure shows progressive long period failure on the fault plane during the seismic arrival. Here individual components are plotted. The slow failure was observed from two separated sites.

This capability was developed under the NEHRP project but was unfortunately not implemented in the NEHRP array.



New accomplishments and changes for the period are summarized in the following figures.

- Figure 1 is a map of the original network of GTSM sites.
- Figure 2 shows the continuation through 2008 of a large regional anomaly evident in the data for the last several years. Anomalies in the selected components have occurred over a long period of time and across the array from Chabot in the San Francisco area through San Juan Bautista to Colbrook in the Sierra Madres.
- Figure 3A shows the individual strain meter residual components (nanostrain) for LA earthquake of July 29, 2008 measured from the CLT site.
- Figure 3B shows for the LA July 29 event the strains (in microstrain) observed at CLT.
- Figure 3C shows for the LA July 29 event a comparison between the shears (microstrain) observed at CLT and the tits (microradians) at the site. The event is dominantly on gamma1 and the east-west tilt.
- Figure 4 presents the impact of drilling by UNAVCO PBO near the Donna Lee (Parkfield) site. The data are the residuals (nanostrain) and clearly show that recovery of the DLT site to its former stability is unlikely. A similar disturbance has occurred on the USGS dilatometer (DL01) also nearby. DLT and DL01 had shown closely correlated signals and similar stability for more than 15 years.
- Figure 5 shows recent continuing changes of strain rates at the CLT site in the Sierra Madres. Associated changes are evident in both strain and tilt data.

Figure 1 Map of Geodetic Stations:

Sites in the original array are shown in the map below. Eight were funded by NEHRP (CHT, GAT, SJT, DLT, FLT, EDT, CLT and PFT) with deployments over the period 1983 to 1996. Sites GAT, EDT and PFT are no longer operational.

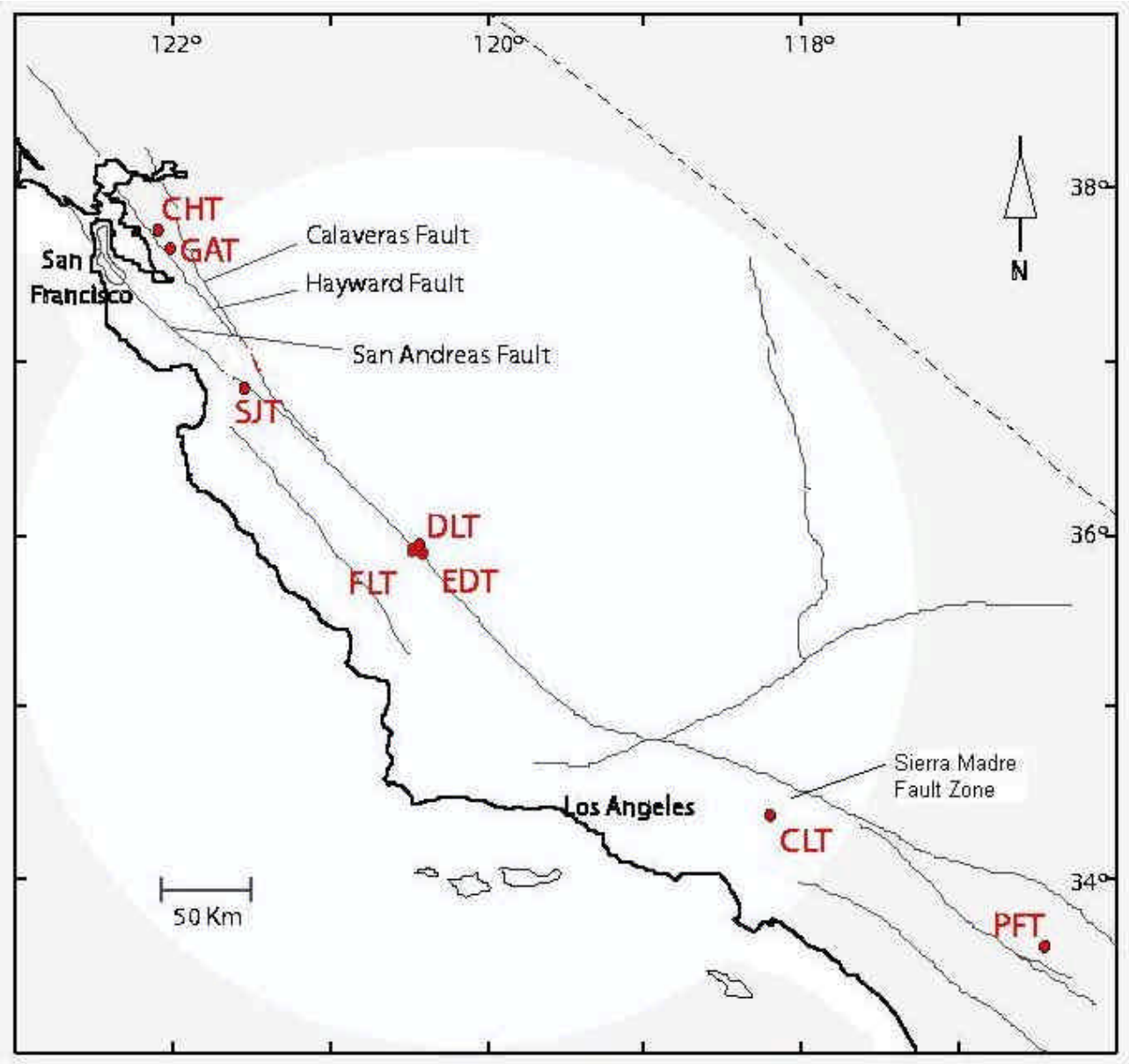
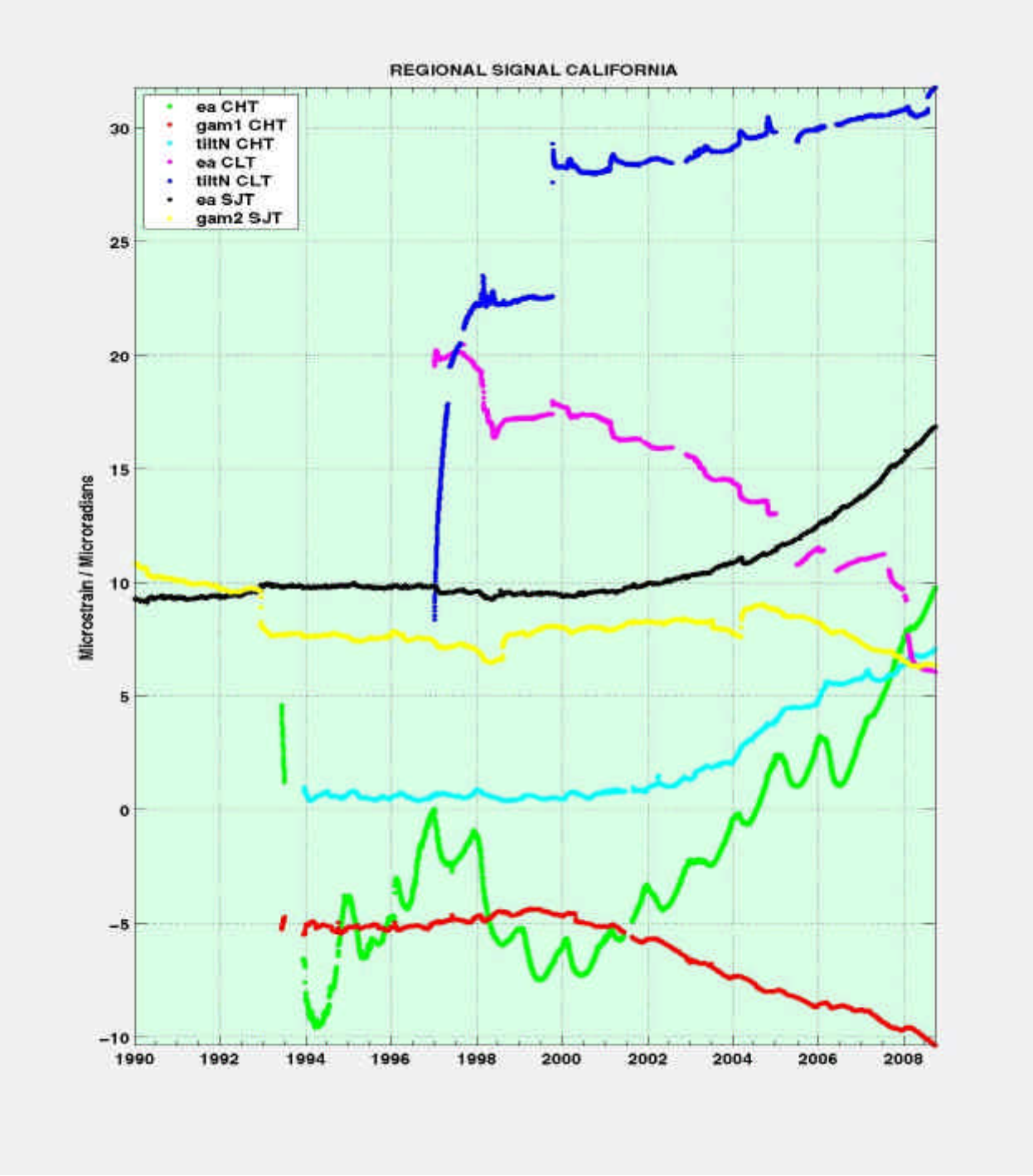


Figure 2A. Large scale ongoing anomaly. The CLT site was installed in 1996 only. A persistent and long term strain rate anomaly is evident at the CHT site and at the CLT site beginning in 2000, and at the SJT site beginning in late 2003.



The raw data from which these are derived are shown in figure 2B and Figure 2C on the following page. Though the effects may appear unlikely to be coupled, they are based on significantly long data sets.

Figure 2B: Component strains for the CHT site from which the strains in figure 2A are derived. The linear rate change in 2000 is strongly confirmed.

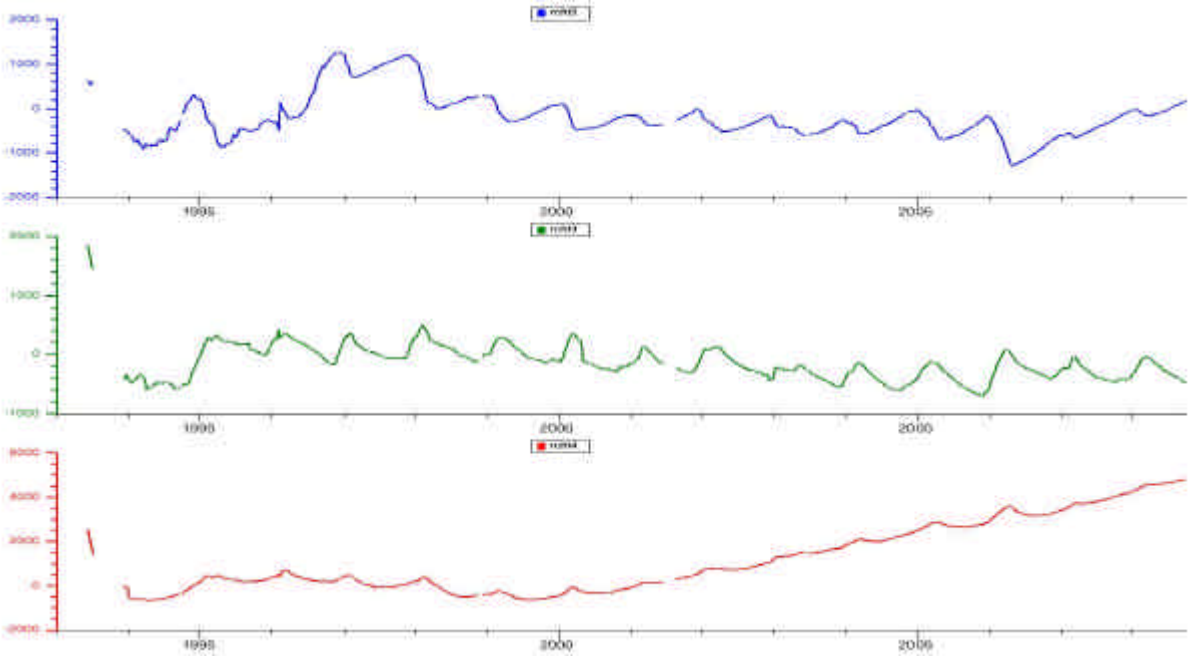


Figure 2C: Components for SJT site. All other step offsets on this plot are for known events, confirming the reality of the linear rate change following the Parkfield event in late 2004.

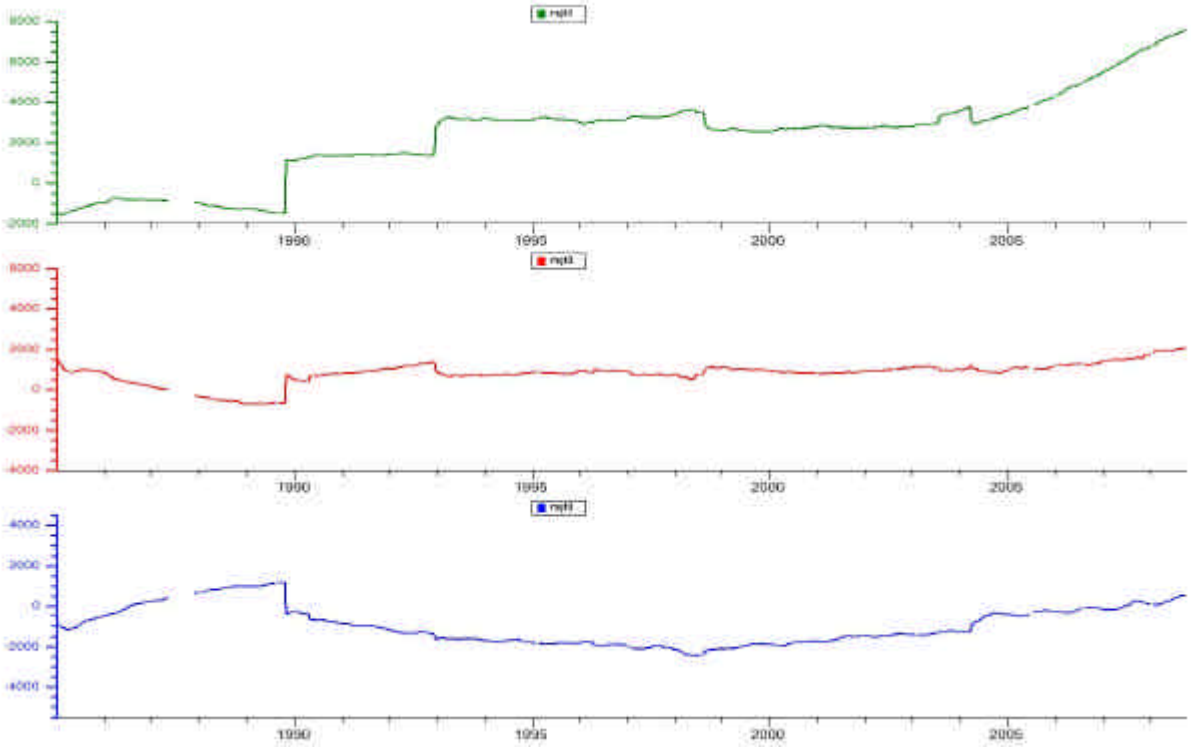


Figure 3A: Response at the Coldbrook site at the time of the LA July 29, 2008 event. Individual component data are shown. Scales for the channels are different. Units are nanostrain.

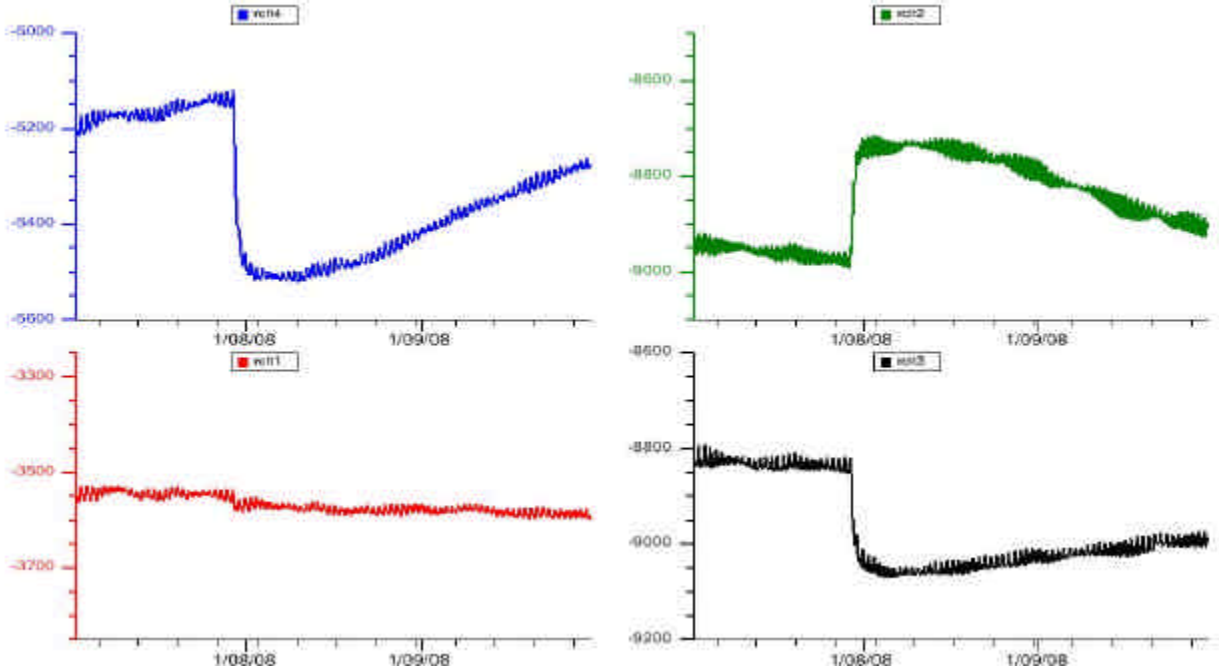


Figure 3B: The strains associated with the same event. Units are microstrain. There was minimal areal strain at this site, and the gamma1 shear strain dominated.

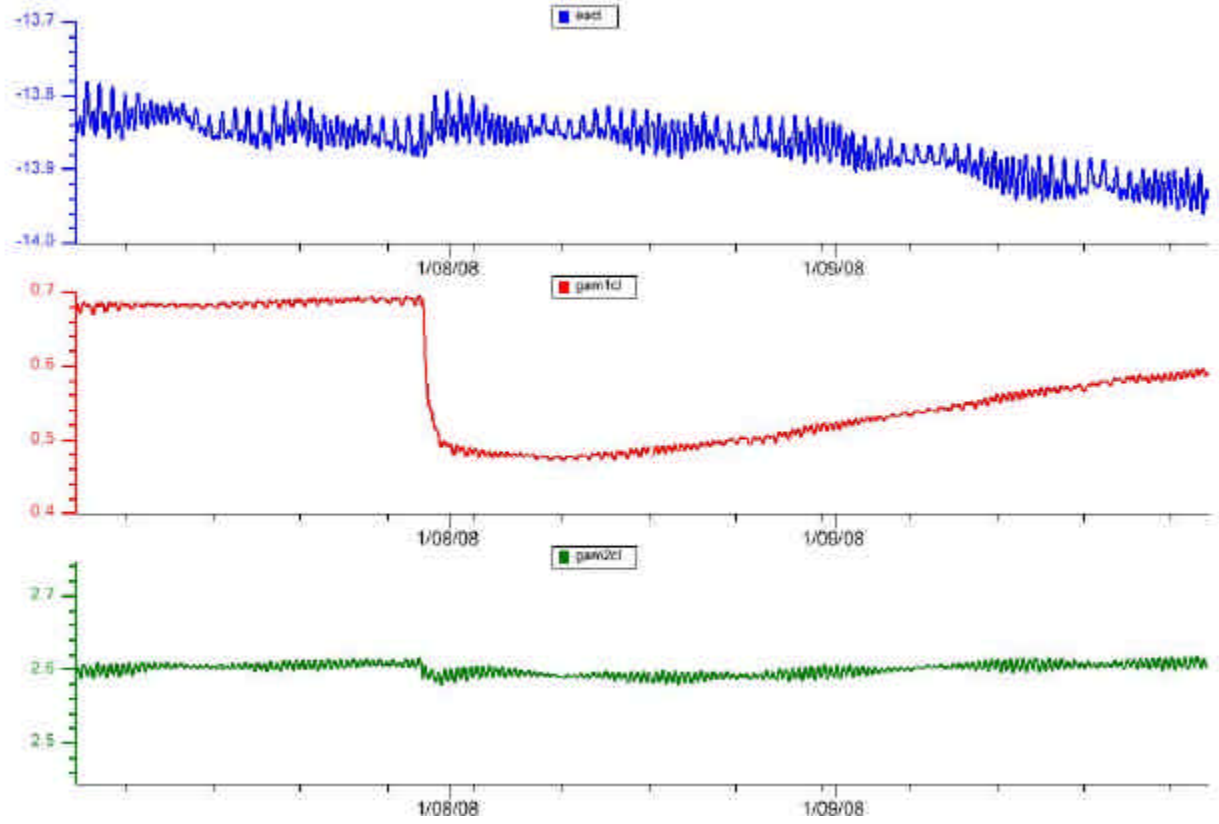


Figure 3C: A comparison of measured shear strains and tilt at the CLT site for the July 29, 2008 LA earthquake. Strains are in microstrain, tilts in microradians. Extended post event recovery signatures are evident in both tilt and strain records.

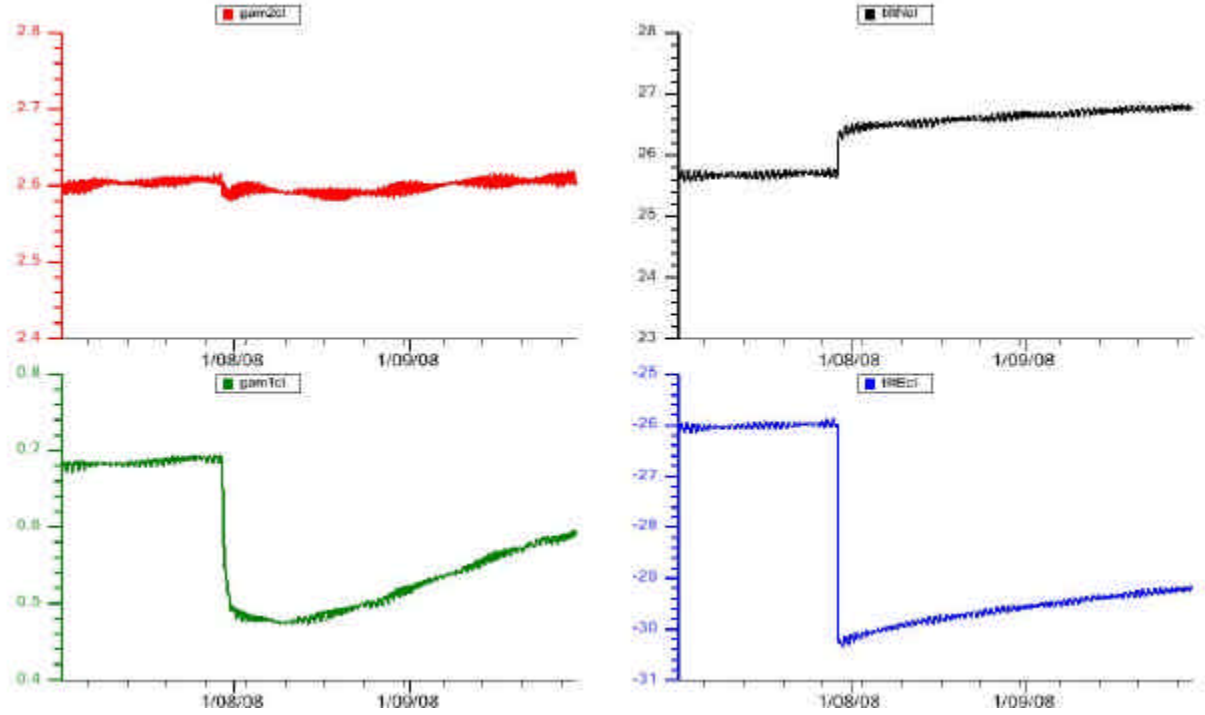


Figure 4: Documentation of the disturbance of the DLT GTSM site with UNAVCO drilling. The raw component data is presented. The drilling disturbance in shown in the long term context (1988 to 2008) including offsets at the time of the 2004 Parkfield event. Return to pre PBO levels is unlikely.

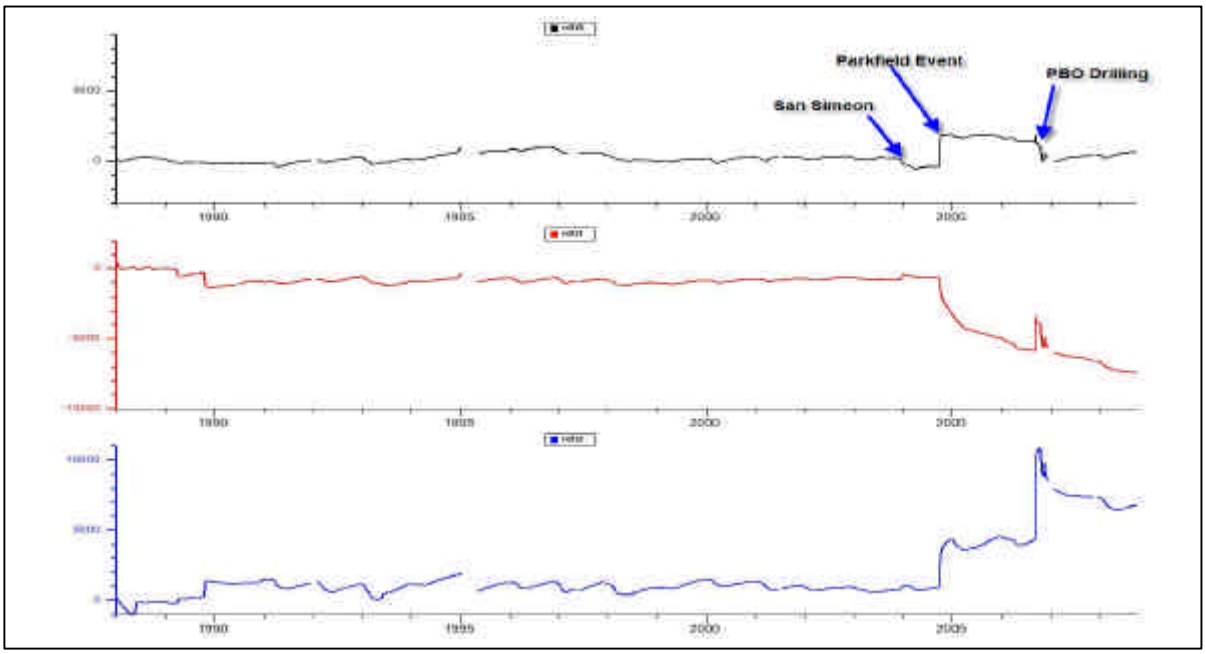
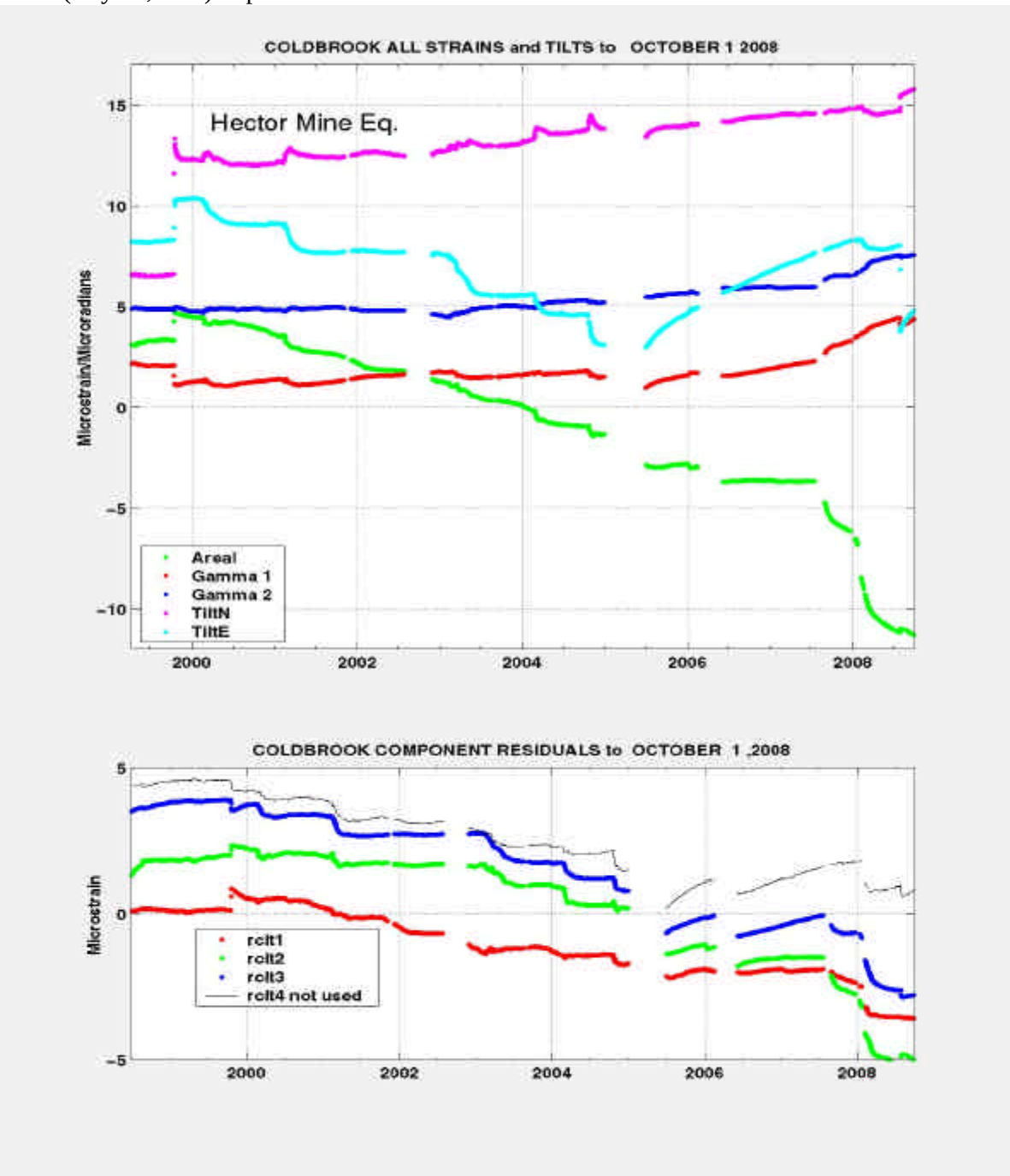


Figure 5: Plot of strain and tilt at CLT. The data shows clear association of change of strain rate with tilt changes. The result is important as it documents the value of co-located tilt data of comparable sensitivity with tensor strain data. A significant anomaly has occurred over 2008. Examination of the 2008 data on this plot shows that some relief of the regional strain anomaly occurred at the LA M=5.4 event (July 29,2008) in particular in the EW tilt.



List of currently operational Geodetic Sites with station information

Site		Azimuth Degrees E of N	Magnetic Deviation	Region	Latitude	Longitude	Depth	Elevation
CHT	cht2 cht3 cht4	121.8 61.8 31.8	15.6 E	East SF Bay (Hayward Fault)	17.7489	122.0958	127m	293m
SJT	sjt1 sjt2 sjt3	327.4 267.4 207.4	15.8 E	East Monterey Bay (Calaveras Fault)	36.8366	121.5441	146m	134m
FLT	flt1 flt2 flt3	39.75 159.75 99.75	15 E	Parkfield (San Andreas Flt)	35.9107	120.4859	237m	545m
DLT	dlt1 dlt2 dlt3	71.4 11.4 131.4	15 E	Parkfield (San Andreas Flt)	35.9401	120.4234	174m	513m
CLT	clt1 clt2 clt3 clt4	46.5 166.5 106.5 76.5	13.9 E	San Gabriel Mtns (Sierra Madre Flt)	34.288	117.841	95m	1024m

All data are transmitted via GOES #2 satellite to Reston, Virginia, to USGS , Menlo Park, Ca.

The up-hole electronics technology deployed at seven of the eight sites is based on late 1970's equipment, and is currently severely limited in data throughput rates by the embedded control electronics used and by the limited bandwidth of the GOES platform (208 characters per 3 hours). Consequently data is transmitted in compressed form, with most significant digits measured each 3 hours, and least significant digits measured at a 30 minute or 18 minute sampling rate. Processing of this data is a non-trivial task which is not suited to automation, requiring intensive manual intervention to produce archive quality data with 8 digit precision

Data Management Practices:

The raw and archive quality strain data have been available in the Menlo Park computer system of the USGS since 1992, and disseminated to the community at USGS discretion. For USGS internal users, the archived data is available in standard USGS bottles in thecove:/home/mick/BASEDATA, and the near real-time data collected and processed automatically is in thecove:/home/mick/QUICKCHECK. This mutually agreed-to specification is accepted by USGS.

Additionally, and under our direct control, a web page describing the GTSM instrument operation, NEHRP data download facility and including plots of the long term strains recorded at each site, was established in 1995. It now has links to the USGS pages and the UNAVCO web pages and is located

at http://www.gtsmtechnologies.com/NEHRP/strain_download/NEHRP/nehrp.html **This facility will not be updated for NEHRP data beyond Sep 30 2008,** when responsibility for these data will be transferred to USGS staff.

Data has been routinely transferred by Stan Silverman of USGS to the Berkeley data archive NCEDC in Northern California. This Berkeley archive is part of the UNAVCO data retrieval process, and has been available to them since 2001. Note the raw Berkeley archive was required by the archivist to be in 8 digit format. Because of bit resolution in that format it is of lower precision than the original instrument data or the GTSM archive.

Continuity of Operations and Response Planning:
Continuity of operations has been achieved by regular review of the data flow by GTSM and particular USGS scientists. Notification of any abnormal behavior at any site identified at Menlo Park was sent to GTSM for hardware fault identification and definition of a recovery procedure. Effective recovery of stations after equipment shutdowns has been greatly facilitated by assistance received from John Langbein, Doug Myren and Andy Snyder.

The PI visited DLT in September, and in December. SJT was visited by both GTSM staff in December, 2008 for routine maintenance. **No PI visits have occurred since Jan31, 2008**.

Response to major earthquakes is usually is initiated either by GTSM or Menlo Park staff. Menlo Park personnel using thecove:/home/mick/QUICKCHECK have near real time access to the data via automated processing. If there is any ambiguity, direct requests for up to date processed data (eg M5.4 Diamond Bar, in July, 2008) have been immediately acted upon by GTSM staff.

All processing and maintenance of the residual network is to be taken over as a direct responsibility by USGS at Menlo Park from October, 2008. Menlo staff will use their own processing procedures for handling all data. The on line download product based on the GTSM Technologies archive and via our web site will be terminated as of September 30, 2008. The closed archive will be left on line for the next year only.

Problems or Concerns Encountered
Ageing of all the ***Data Collection Platform*** (DCP) equipment at the sites and the lack of spare boards for the systems has been highlighted in our previous reports. These systems (both designed in the late seventies) are populated with components not generally available.

Future Strategic Plans:
A review of the viability of the sites was detailed at length in the Progress Report submitted in January, 2008. Further discussions of this evaluation and on the proposal for the array to be taken over by USGS in 2008 have been held with Thatcher, Langbein, Johnston, once UNAVCO determined that it was not in a position to taken the sites into their program. Assistance has been provided to USGS via transfer of data handling programs to the Menlo machines, and transfer of residual incidental legacy electronics will occur in the near future. This assistance will be probably be insufficient to maintain the current network for more than a few years without our participation. A summary of recommendations has been provided earlier in this document. The FLT site is now compromised by cable failure, the DLT site is compromised by the nearby PBO installation. SJT is difficult to upgrade and would require probably unacceptable environmental impact for addition of

additional solar panels and a Vsat communication system.CLT shows no signs of degradation of performance. CLT controller (an early COMPAC laptop) is however compromised. It runs an assembly based code set which cannot be maintained at this time. Despite its high value in Southern California, it could only be kept alive by complete replacement of the uphole system.

A summary of previously presented (January, 2008 report) review of long term options for the sites is given below. Where uphole replacement is recommended, please note that this could only be done by GTSM Technologies staff.

DLT:

A new PBO site has been installed about 90 m from the original DLT site. During drilling of this site, an aquifer was evidently penetrated and effective water control was not established by the drillers or the deployment group. Replacement of the complete up-hole electronics at DLT with PBO style electronics is therefore of diminishing worth except to continue the long data base. It is technically possible, but now that the stability of the site has been compromised in favor of the PBO site, it is not recommended.

SJT:
Replacement of the up-hole at SJT is technically more difficult than at DLT. The site would also require additional permitting to install the size of solar farm (or TEG infrastructure) required for the PBO communications system to upgrade to a PBO like reporting site. In the context of current land usage and the experience of UNAVCO crews attempting in 2006/7 to permit this area for adjacent PBO sites, it is probable that additional permits from landowners are not likely to be available. The site could be kept operational using spares generated by closure of the DLT system. These two systems are not identical, but share much common circuitry.

FLT:
There was lightning damage on channel 2 documented in 2003 which has caused electrical leakage in the down-hole cable to produce progressively increasing noise in the data. Cable noise is increasing and the expense of replacing the up-hole system is not justifiable. In addition, USGS operates a good dilatometer at the FLT site.

CHT:
The up-hole strain system could be retrofitted with a PBO type measurement system for the remaining strain channels. The CHT site is mains operated, but does not currently have adequate bandwidth for PBO uphole systems but could be upgraded with CDMA data streams to adequate bandwidth. It would be preferable to install ADSL into the bunker.

CLT
CLT has 4 functioning strain channels, and 2 functioning tilt channels. The tilt data are reliable and require minimal editing. To replace the up-hole strain channels would require 1 current GTSM PBO up-hole system to be modified but it could be done. To retrieve the tilt data would require a second GTSM up-hole system and significant field time to breakout the various components. Being only 12 years old and well placed in the Sierra Madre system, it is worth maintaining by replacement.