USGS Grant G10AC00076
USGS ARRA Strainmeter Installs
Final Project Report

1. USGS Grant Number: G10AC00076

2. Project Title: USGS Replacement Borehole Strainmeters in California

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4. Project Dates: February 15, 2010 to December 30, 2011

Abstract
This report summarizes the work completed by UNAVCO as part of the U.S. Geological Survey (USGS) Grant #G10AC00076. This USGS grant was awarded (under the American Recovery and Reinvestment Act of 2009) to UNAVCO based on a UNAVCO proposal submitted in response to the USGS Program Announcement 10HQPA0008 (Proposals for Upgrades to the USGS Crustal Deformation Monitoring Systems under the American Recovery and Reinvestment Act) – Proposal No. GE-ARRA-0003. Under this grant, UNAVCO completed the construction of two replacement permanent borehole strainmeter stations located in California, a subset of the list of potential stations prioritized by the review panel.

Project Overview
The scope of this project was the installation of two Sacks-Evertson 3-component strainmeters to replace aging sites in the USGS borehole strainmeter network. The existing sites chosen for replacement were GH in Parkfield CA, and XXsj in San Juan Bautista CA. Drilling took place in May and June of 2011, and construction of both sites was completed by early July 2011. The new stations are named B947 Valdez (in San Juan Bautista) and B948 Gold Hill 3 (in Parkfield). B947 is located approximately 500 m from the original XXsj station. B948 is located approximately 400 m from 2 PBO Gladwin strainmeters (B072 and B078) installed 2006 and 2007.

Figure 1. B947 location in relation to the PBO San Juan Bautista GTSM array.

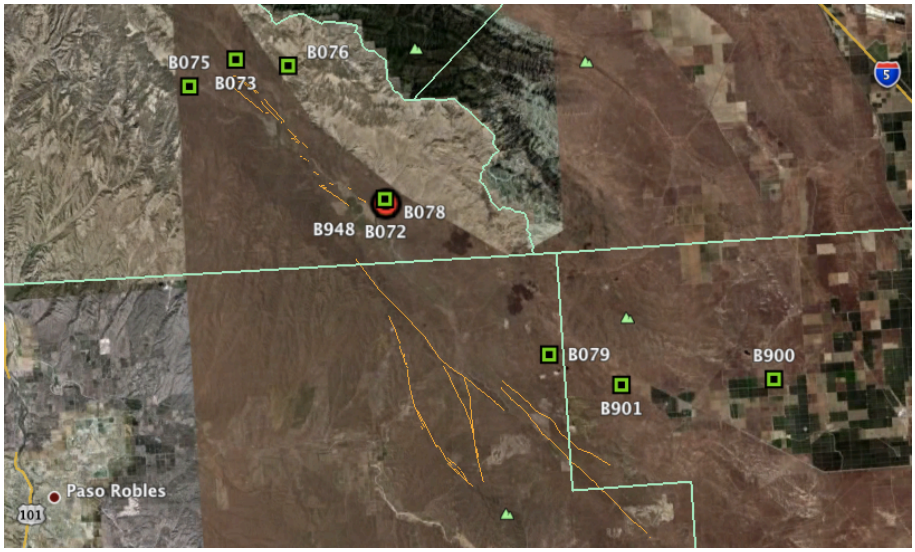


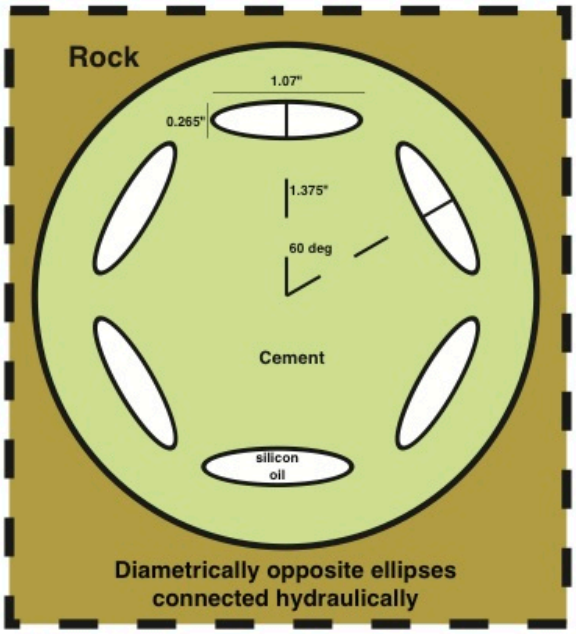
Figure 2. B948 location in relation to the PBO Parkfield GTSM array.

Instrumentation

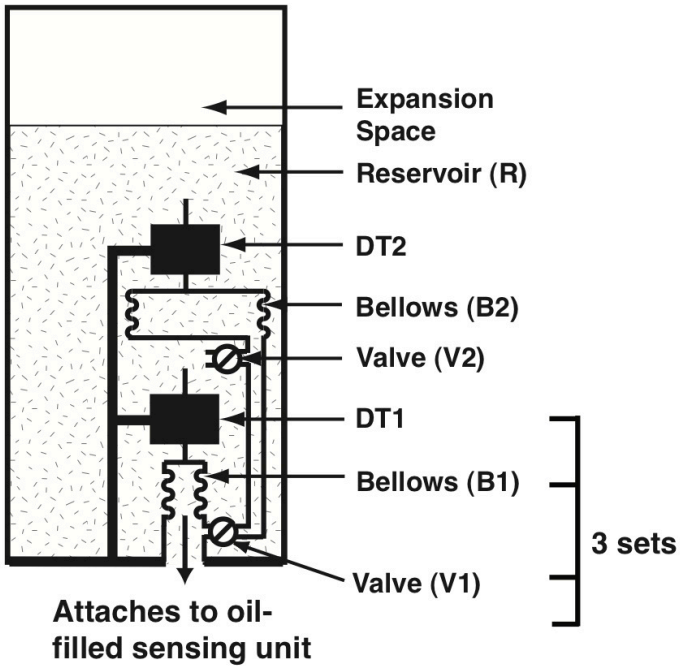
The two Sacks-Evertson three component strainmeters were hand-built by the Carnegie Institute of Washington during 2010 specifically for use in this project. These instruments employ hydraulic sensing similar to that of the original single component (dilatometer) SE design except that there are 6 separate liquid-filled elliptical tubes all of which extend the full 3m of the sensing length. These tubes are arranged symmetrically at 60 degree spacing and diametrically opposite pairs are connected hydraulically before being attached to the bellows whose top level position is monitored to indicate changes in volume of the sensing units. Each of the 3 strain sensing bellows are connected, by valves, to a single secondary bellows (of much larger diameter and volume) so that, when any component signal level exceeds a preset threshold, the sum of the strain changes (i.e. dilatation) is preserved during valve openings. A second valve allows for re-equilibration of the second bellows with the liquid filled reservoir. During normal operation, when both valves are closed, the second bellows responds only to downhole temperature changes; the parameters are such that this allows monitoring of those temperature changes with a resolution of about 10 microdegree C. Nominal strain resolution is about 10 pico-strain.

The strainmeters are connected to a DTM designed electronic unit for instrument control and data logging. Strain data are digitized with 24 bit ADCs at 50 sps. A 20 bit convertor is used to monitor, at 1 sps, atmospheric pressure, battery supply and electronic temperature. The 50 sps data streams are low pass filtered to provide data streams at 1 sps, 1 spm and 1 sph. The 20 bit data are also filtered and resampled at 1 spm and 1 sph. The data logging is performed on a single board computer running Linux and has an Ethernet connection to allow Internet access.

Cross-section sensing sub-system



Transducer sub-system



Diagrams and instrument description courtesy of Alan Linde

Drilling

Tacoma Pump and Drill (TP&D) of Graham WA was chosen through a competitive process to drill the two boreholes. Installation specifications of the Carnegie instrument require a cored 4" borehole, which was accomplished by rotary drilling to casing depth, setting 4" steel casing, and coring until a suitable install zone was found. Initial plans were to collect geophysical well logs in addition to core, but this plan was modified after instability in the B947 borehole forced UNAVCO engineers to abandon an acoustic televiewer downhole. Core alone was used to determine install zones. Drilling and coring at B947 in SJB took from May 6 until June 16 2011. This exceeded the anticipated drilling schedule due to significant time lost attempting to recover the lost acoustic televiewer, as well as several unanticipated cement jobs necessary to stabilize the borehole. Drilling operations at B948 on Gold Hill occurred between June 1 and June 23 2011. Despite the additional costs of the delays at B947, Tacoma Pump and Drill generously completed the B948 borehole at a discounted rate in order to ensure the possibility of a second installation within the project's budget.

Installations

B947

The strainmeter was installed at a depth of 558' on June 26 2011. It was installed using standard IPA Penn Grout. The strainmeter stopped sinking 6 ft from the well bottom, but was determined to be completely encased in grout and declared a successful installation. The borehole was backfilled with cement into the casing, and the datalogger was installed in an underground vault inside a standard PBO strainmeter enclosure. The site is running on A/C power with a 4 x 100 Ah battery backup. Data is currently transmitted via a commercial cell modem.

B948

The strainmeter was installed at a depth of 505' on June 30 2011. After a failed installation attempt using standard Penn Grout, the UNAVCO mix (containing a higher amount of plasticizer) was used successfully in a second attempt. The well was backfilled into the casing, and the datalogger again installed in a vault. A/C power was not an option at this site, so a power system consisting of 6 x 80 W solar panels and 4 x 100 Ah batteries was used. Data communications consist of an Intuicom EB-6+ radio connection with B078, where there was an existing Plate Boundary Observatory Hughes VSAT installed.

Station	B947	B948
Name	Valdez	Gold Hill 3
16CharID	valdez947bcn2011	goldhl948bcn2011
Lat.	36.83277° N	35.83467° N
Long.	121.5484° W	120.3437° W
Lithology	Siltstone	Granitic
SM install depth	558'	505'
SM install date	6/26/11	6/30/11
Grout	Original Penn Grout	UNAVCO mix Penn Grout
Casing depth	452'	460'
Power system	A/C	6 Solar panels
Communications	Verizon CDMA	EB-6+ to VSAT

Table 1. Summary of strainmeter installations at B947 and B948

Combined drilling and installation of these two stations took an estimated 170 field days from UNAVCO engineers, plus an additional 60 field days from Carnegie staff and about 90 man-days by TP&D. These figures do not include the time for construction and testing of the strainmeters, or any of the permitting and other prep work done by UNAVCO.

Performance

Both B947 and B948 went into compression almost immediately after installation. Since installation the strainmeters have continued to accumulate compressional strain. The valves have been resetting as expected to accommodate the high rates of compressional strain in the months following drilling and installation. The time interval between resets is now increasing as the stress field around the borehole re-equilibrates.

An Earth tide signal was evident in the B947 data in the days after its installation. Inspection of the time-series indicates the three B947 volume sensors are recording M2 tides with similar phases. Tides are not evident in the B948 data yet but, based on UNAVCO's experience in installing strainmeters in the Parkfield area, this is not unexpected. Five of the eight PBO strainmeters installed in Parkfield took at least a year to reach compression and record a strong tidal signal.

Both strainmeters recorded the teleseism generated by the October 21 2011, M7.4 Kermadic Islands earthquake. A strain signal was recorded by all volume sensors; a first indication the instruments are performing as expected at seismic frequencies. Some data plots are included in Appendix III.

The dataloggers were installed in underground vaults in order to reduce the diurnal temperature changes, which introduce noise into the system. The vault design appears to be working well; the recorded diurnal changes at both stations are about 0.5 deg C.

Data archiving

The stations are collecting 3 channels of strain data, as well as environmental and SOH data as described above. All data collected is stored in SAC format by year, month, and day of month on pore.unavco.org, and is available for download at:

ftp://bsm.unavco.org/pub/ARRA/

A complete list of the channels collected can be found in Appendix I.

The core samples collected were given to Andy Snyder with the USGS in Parkfield for storage.

UNAVCO is open to continued archiving and full integration into it's current archive and archive interface.

Participant list

UNAVCO: Michael Jackson, David Mencin, Michael Gottlieb, Wade Johnson, Elizabeth van Boskirk, Chad Pyatt, Warren Gallaher, Tim Dittmann, David Kasmer, Doerte Mann, Kathleen Hodgkinson, Brent Henderson
Carnegie Institute of Washington: Alan Linde, Selwyn Sacks, Michael Acierno, Brian Schleigh, Michael Crawford
USGS: Evelyn Roeloffs, John Langbein, Andy Synder
Tacoma Pump and Drill: Eric Hansen,

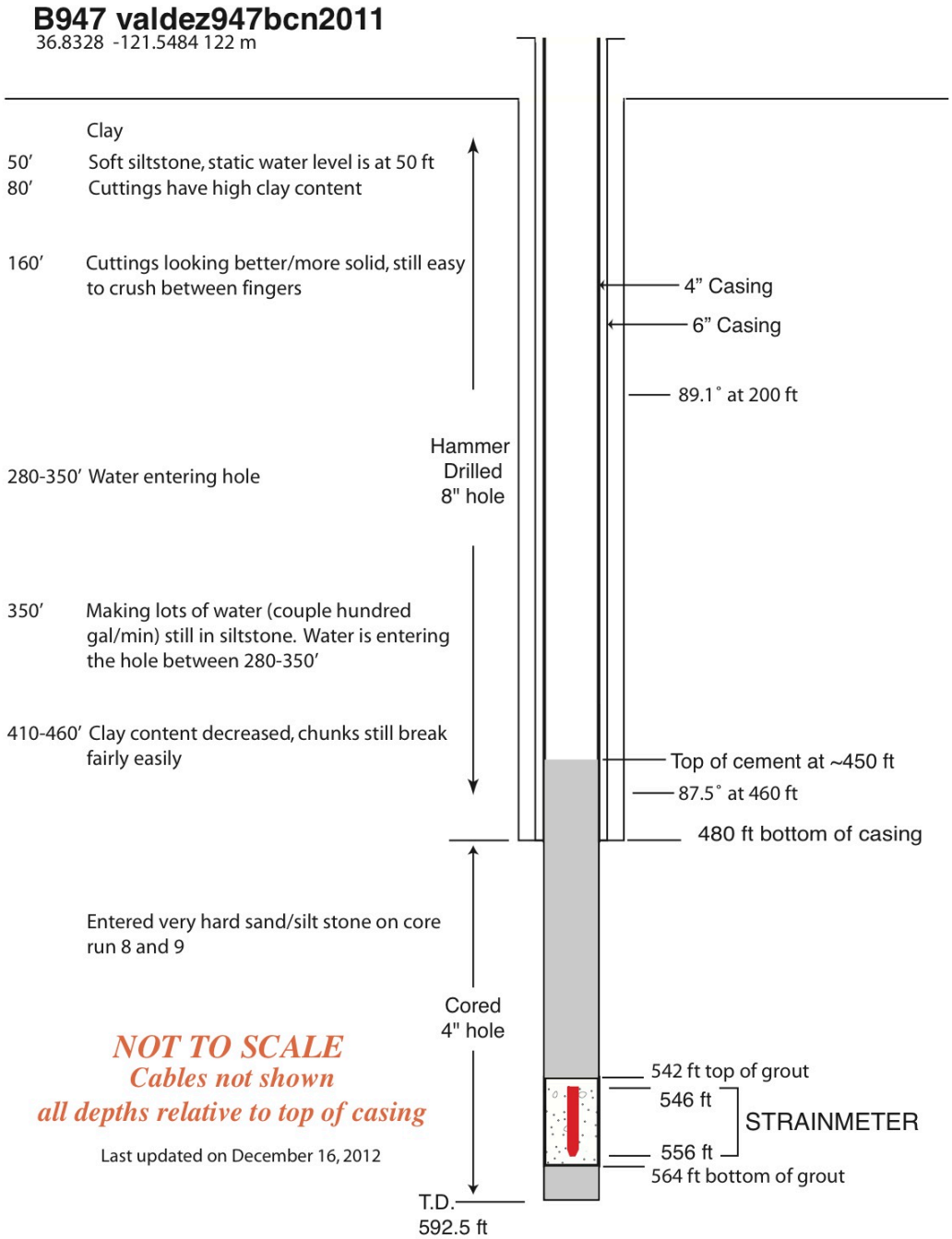
Appendices

Appendix I: Data Channels

Channel Name	Description
bar	barometric pressure
g1a	DT1A x 8
g1b	DT1B x 8
g1c	DT1C x 8
mx4	unused
pwr	battery voltage
s1a	DT1A
s1b	DT1B
s1c	DT1C
s1s	DT1 power supply
s2a	DT2A
tmp	Logger temperature

Table 2. Data Channel Key for Carnegie Strainmeters

Appendix II: Borehole Drawings



B948 goldhl948bcn2011

35.8347 -120.3437 423 m

Clay

60 - 80′ Sand with feldspar & mafics, angular, poorly sorted

80-100′ Greenish gray clay

100-112′ Greenish grey clay with feldspar fragments

112′ Hit hard diorite

112-130′ Dark diorite

130-160′ Lighter diorite(less hornblende/olivine/ biotite, more feldspar/quartz)

160′ Harder drilling

170-190′ Granodiorite, significantly less mafics/more silicates

200-240′ Diorite

240′ Harder drilling

240-300′ Diorite

300-330′ Diorite, more compact, finer grained crystals, harder drilling

330′ Borehole started making water

340′ Diorite, more coarse grained

350′ Ganodiorite, more silicates, less mafics, light green crystals of quartz/hornblende/mica

360-370′ Diorite, hard drilling

380-430′ Diorite with very hard fine grained dark metamorphic/xenolith fragments

410′ Borehole making more water

420′ Harder drilling

440′ Diorite without metamorphics

460′ Diorite/granodiorite, borehole estimate to be making more then 60 gal/min. Inflow increased with depth

Hammer Drilled 6" hole

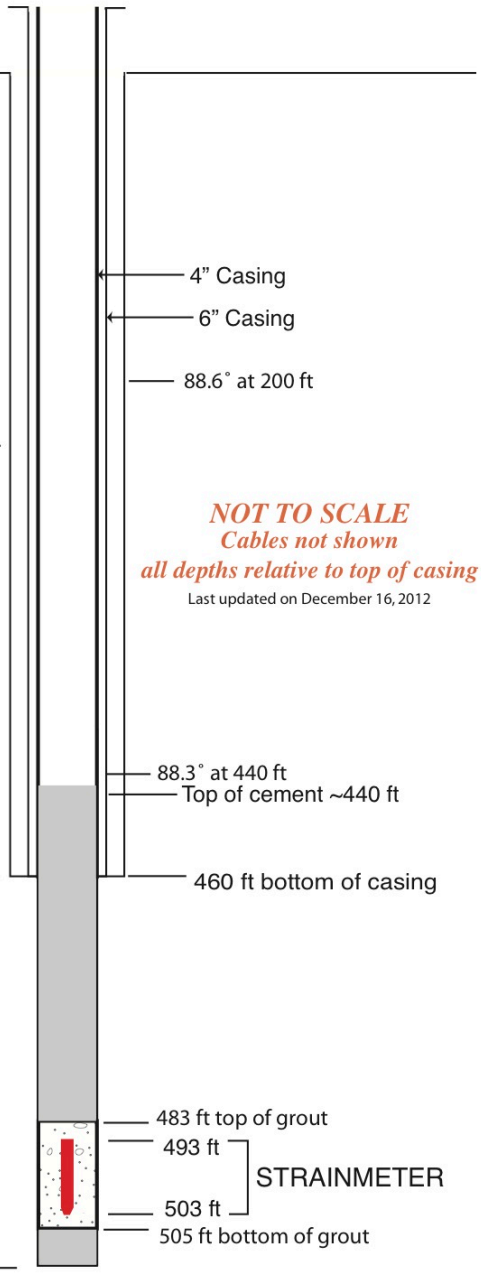
Upper core runs went through zones of significant fracture/fault gouge, with slickensides evident on some fracture surfaces. The diorite/granodiorite is slightly altered

Starting with core #9, the occurrence of fracture/gouge decreased

At core #10 and below, all fractures appear to occur along pre-existing healed fractures or are mechanical.

Cored 4" hole

T.D. 521 ft



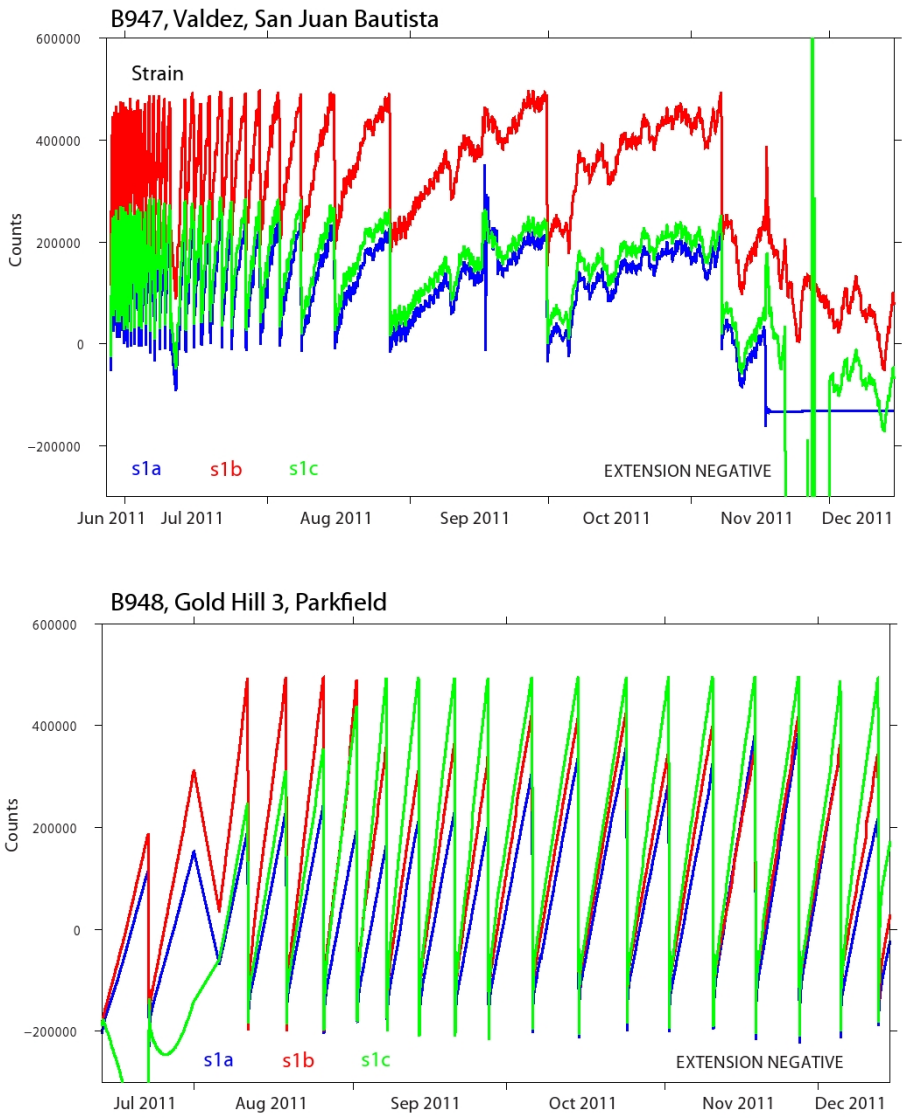
NOT TO SCALE

Cables not shown

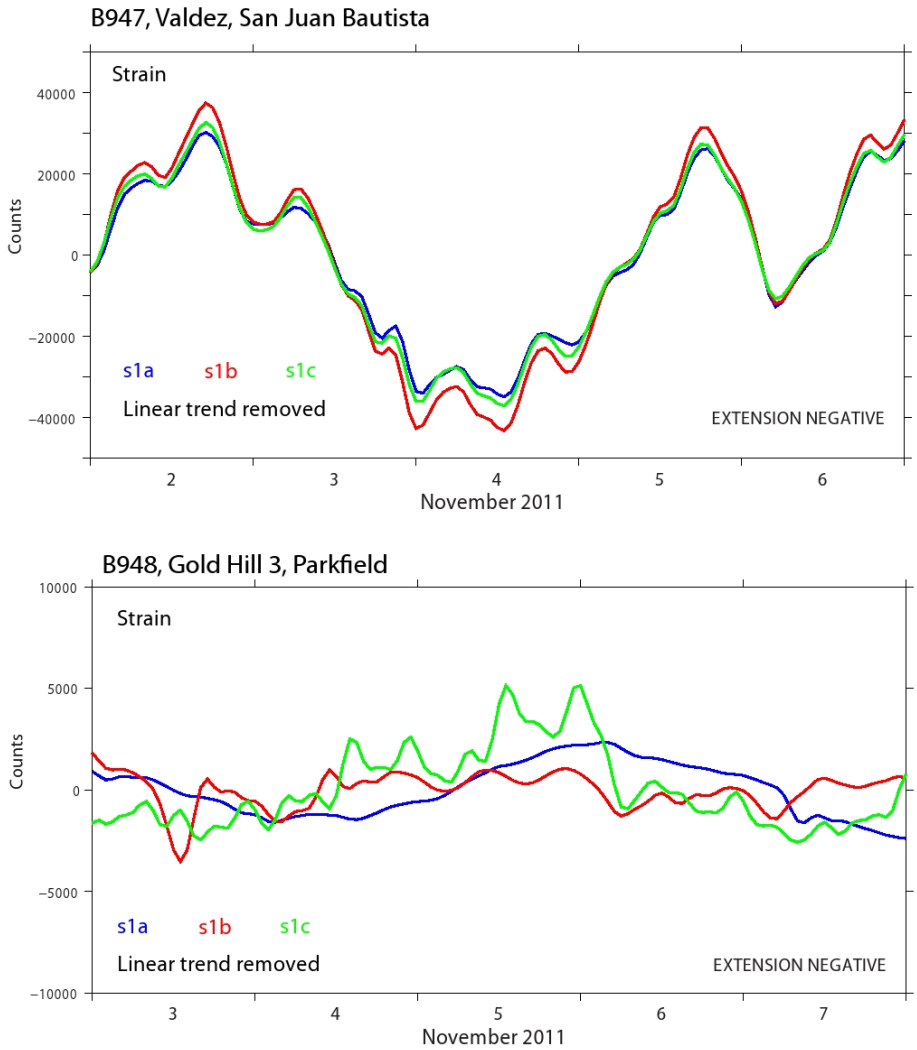
all depths relative to top of casing

Last updated on December 16, 2012

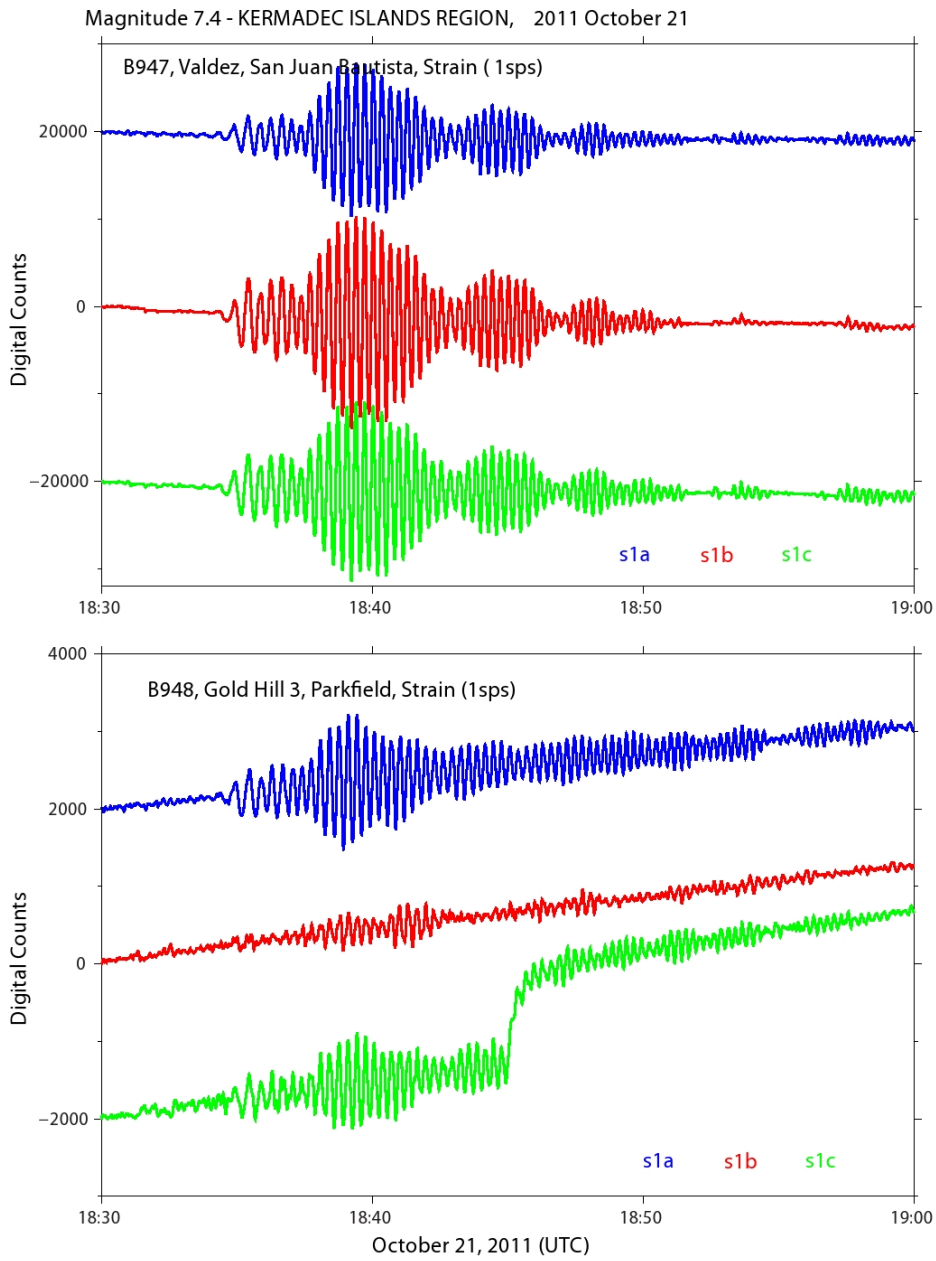
Appendix III: Plots



Plot 1. Raw data collected since installs. Large steps are valve openings.



Plot 2. Processed data showing tides at B947.



Plot 3. Teleseism recorded from Oct 21 2011 M7.4 Kermadic Islands EQ

Appendix IV: Photos

Photo 1. Completed site showing enclosure and solar panel array at B948.

Photo 2. Drilling operations at B947 with Tacoma Pump and Drill.