Strainmeter metrics

- Borehole in compression
- Recording Earth tides
- Atmospheric pressure effect correct sign
- Absence of steps
- Recording teleseisms and microseisms
- Minimal cultural signals
- Recording strain transients
Borehole Trends

• It is expected that the dominant strain recorded by the strainmeter is that of borehole relaxation.

• 3 gauges in compression after 1 year is a good sign

• B004 displays the expected “classic” borehole compressional signal

Borehole Trends

• Poro-elastic modelling by Amy Day-Lewis of Stanford shows that the orientation of the strainmeter within the regional stress field can influence the amount of strain on one gauge.

• Conclusion: Only three gauges need be in compression
Borehole Trends: B004

The first PBO BSM Serial # US00

Counts

Extension +ve

Rule of thumb:
areal strain = 2(CH0 + CH2 + CH3)/3

Borehole Trends: B004

The first PBO BSM Serial # US00

Counts
Borehole Trends: Mt St Helens

Borehole Trends: Mt St Helens

Borehole Trends: Mt St Helens

Borehole Trends: Mt St Helens
Borehole Trends: Extension?

Extension is a problem!
Instrument designed to be in compression

B075, Parkfield

Borehole Trends: Steps

Steps recorded on B039 7 months after installation

B039, Northern California
Large steps on individual gauges
Difficult to isolate tectonic transient
Borehole Trends: Grout

• The grout proved critical.

• Some sites exhibit “hole trauma” within a few days of install if the coupling of the strainmeter to the surrounding rock was not good.

• PBO engineers worked with grout manufacturers to get the correct mix.

Borehole Trends: Grout

B943, B014 installed with the PBO - Penn Grout mix

Free of steps, tides visible within 2 weeks
Borehole Trends: Grout

B040 installed using Masterflow grout. Many steps in data set, tide not visible at 14 days.

Compression: There is hope!

Several PBO strainmeters took ~8 months to turn towards 3-gauge compression.
Compression: There is hope!

B088, Anza, was one of the first BSMs to display trauma 18 months later, hole in compression, nice tidal signal.

Borehole Trends: Hydrostatic Coupling

B006, Shores, Washington

Possibly hydrologically coupled
- Little or no shear strain
- Drifting phase in tidal signal
- Little strain accumulated over 2.5 years
Borehole Trends: Seasonal signals
B009, PGC

John Langbein detects change in trend May 29
Herb Dragert reports farmer irrigating fields
Non Tectonic Noise: Rain

• Several of the PBO BSMs show strain signals correlated with rainfall
• When looking at transients check the rainfall measurements, all PBO sites have rain gauges
Non Tectonic Noise: B003 Rainfall

B003, FloeQuarry, Washington

PGC reports tremor

CH0
CH2
CH1
CH3

Rainfall (mm/hr)

But no GPS displacements

Heavy rainfall
Site on side of hill
Non Tectonic Noise: Pathfinder, Anza

B082 and B089, Co-located, Pathfinder site

Microstrain

B089

B082

Microstrain
Non Tectonic Noise: B036 Restarts

B036 Southern Oregon

Strainmeters: Tides

Strainmeters designed to record signals in the tidal band. Some rules of thumb:

• A clear tidal signal should be visible even in the time domain
• You should see at least M2 and O1 peaks in the spectrum
• The tidal phase should not vary by more than a few degrees over years
• The amplitudes should not vary by more than a few percent
• In tidal analysis the error in the phase should be less than a degree and the amplitude error less than one nanostrain
B018 Tidal signal

Tide can be modelled and removed
B018 Tidal signal

Rule of thumb: Pressure increase = gauge compression

B018 Tidal signal: Atm Correction

Rule of thumb: Pressure increase = gauge compression
Strainmeters: Barometric Pressure

Barometric pressure response

B017
B027
B073
B208

PNW  MSH  S.O.  SJB&PK  ANZA  YS

Barometric pressure response

B028: Small tidal amplitude

CH0
CH1
CH2
CH3
Tides: Amplitude and phase

- CH3 M2 amplitude is < 2 nanostrain, error in phase is ten times that of the other 3 channels

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<td>Phase °</td>
<td>Amp (ns)</td>
</tr>
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<td>CH0</td>
<td>-2.9 ± 0.1</td>
<td>27.31 ± 0.04</td>
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<tr>
<td>CH1</td>
<td>138.0 ± 0.1</td>
<td>34.59 ± 0.07</td>
</tr>
<tr>
<td>CH2</td>
<td>57.6 ± 0.1</td>
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<tr>
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<td>37.1 ± 0.1</td>
<td>32.02 ± 0.08</td>
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Tides: Amplitude and phase

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B028 Tidal Spectra

Change in CH0 M2 phase

2-month windows
Change wrt 3-4 month after install

Change in CH0 M2 Amplitude

Vancouver Island
1-sps Strainmeter Data

9-12 second calibration signal, 30 minutes past the hour
Null point before and after signal

B022, May 31, 2008, 1-sps data

B022 Spectrogram, May 31, 2008

6.6 Mid Indian Ridge
Calibration spikes
Microseism
Ratio Transformer Problem

B035, Grants Pass, Southern Oregon

CH0 and CH3 were stuck on gain 3. When the ratio transformer controller board was swapped, data quality improved.

Non Tectonic Noise: B001 Pumping

B001, Golbeck, Washington

Hours of pumping
Noise on the 1sps channels

B012, Vancouver Island, BC

Counts

CH0
CH1
CH2
CH3

B012, Vancouver Island, BC

Areal strain recorded by PBO Borehole Strainmeters

M 6.0 - Nevada, 2008 February 21 14:16:05 UTC

Nominal Nanostrain

14:15 14:20 14:25 14:30

February 21 2008 UTC

Cowich, Vancouver Island
Delphi, Seattle
Madison, Yellowstone
Lake Junction, Yellowstone
Lester, Central Oregon
Grant's Pass, Southern Oregon
York, Northern California
Gabilan Ranch, San Juan Bautista
Varian, Parkfield
Pinyon Flats, Anza
20-sps Data Set: Timing

- PBO monitors timing on a daily basis, loggers drift a few seconds at all BSMs

- If GPS time is lost logger can fall behind UTC by a few seconds each day (B201)
20-sps Data Set: Timing

- 20-sps data collected in 60 second files
  Logger calculates sample rate as n/60
  \[ n = \text{number of data points} \]
  \[ \Rightarrow \text{variation in sample rate} \]
- PBO only converts data with sample interval of 0.05s to mSEED
- For 4 BSMs this \(\sim1\%\) of data are not converted to mSEED

20-sps Data Set: Solar Noise

- It was found that noise was introduced when the solar panels started to charge up in early morning.
- The noise is visible in the 20-sps data set.
- PBO engineers found that rerouting cables helped.
20-sps Data: Solar Noise

B916, Mojave, March 20, 2008

20-sps Data: Solar Noise

B916, Mojave, March 25, 2008
A Strain Transient: Cascadia ETS

B004 2007 Cascadia ETS


Microstrain

Ee-Enn Strain

B004 2005 Cascadia ETS


Microstrain

Ee-Enn Strain

Tidal Signal
A Strain Transient: Cascadia ETS

Olympic Network: Shear strain