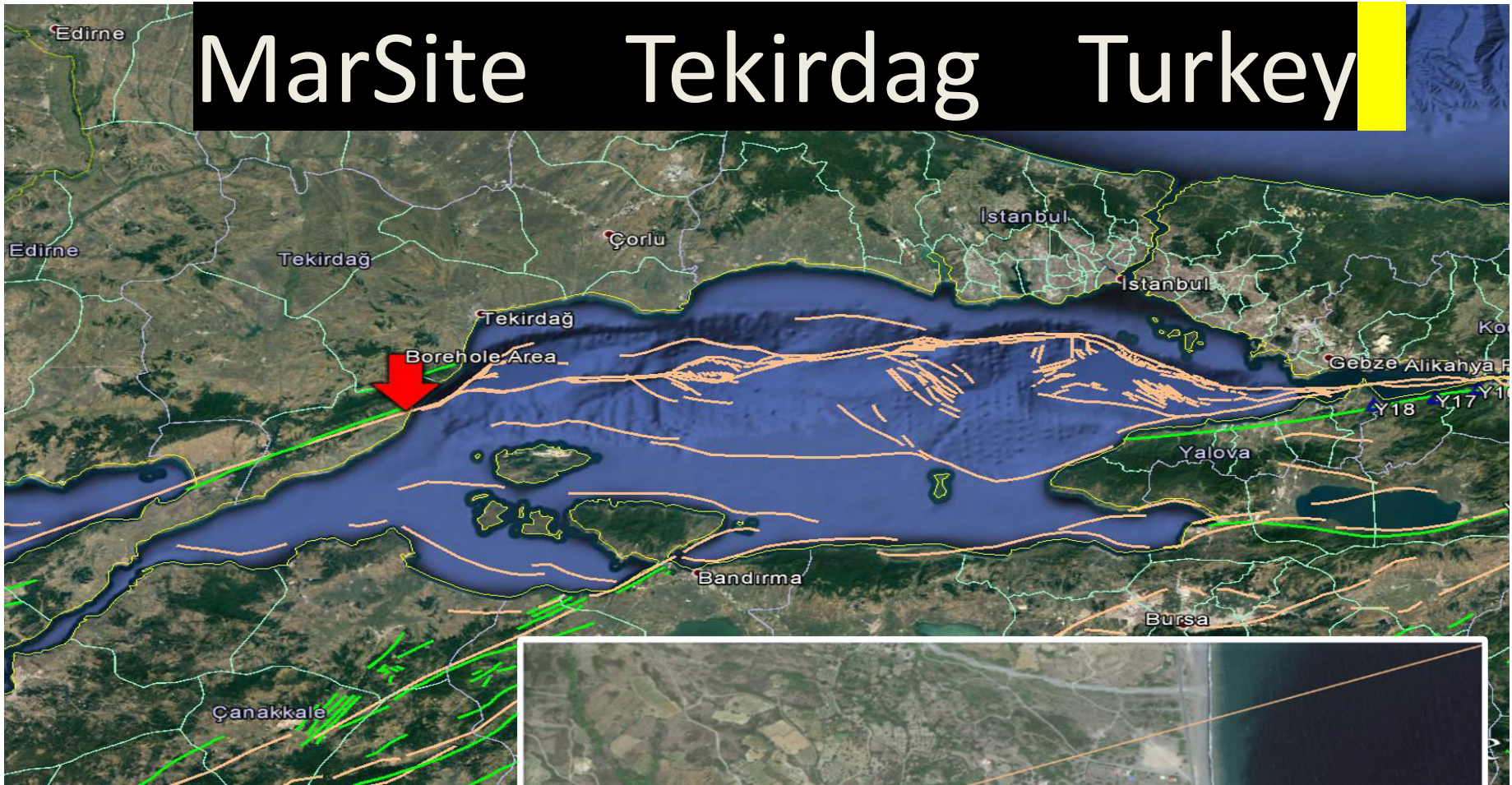
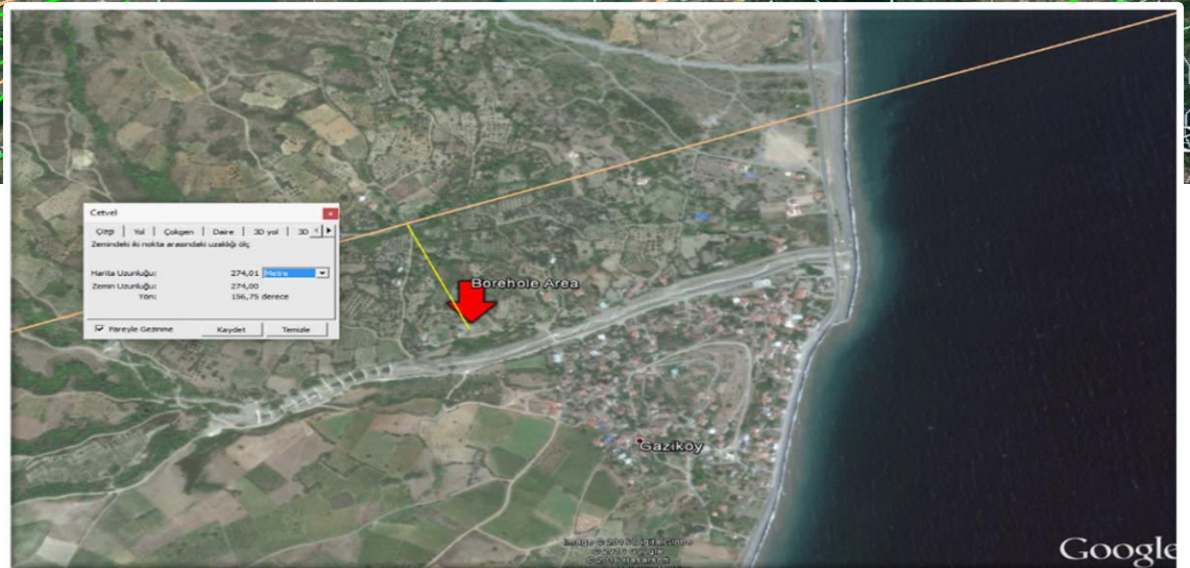


MarSite Tekirdag Turkey



Tekirdag Gazi-Koy
Borehole location is
274 meters away from
the North Anatolian
Fault Zone (NAFZ) line
and 580 meters from
the sea.

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Performance of Multi-Parameter Borehole Instrumentation System (Marsite)

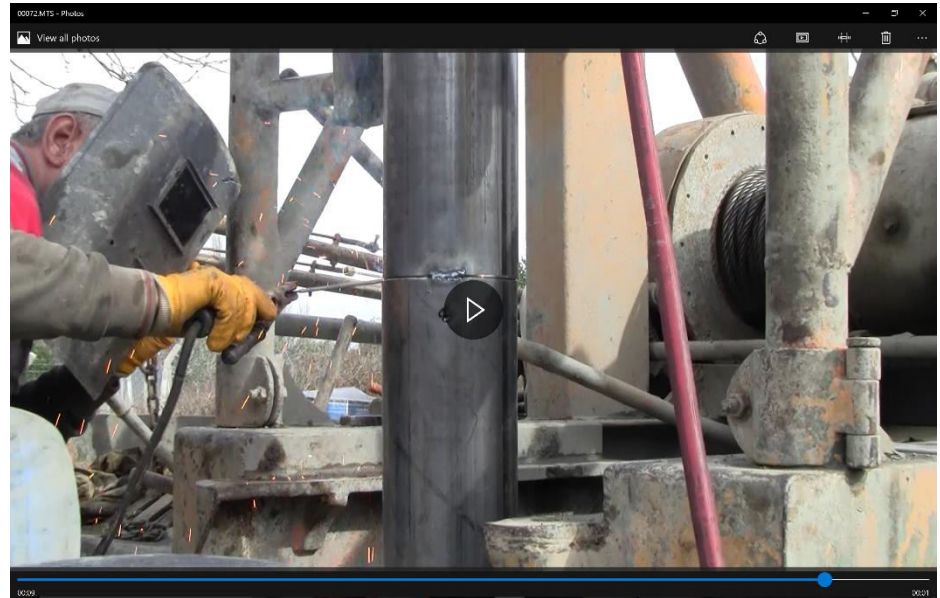
- ✓ Two boreholes 4 meters apart each 150 meter deep has been drilled, cased and grouted. One of the cased borehole is fully water tight.
- ✓ Very high sensitivity two axis borehole tilt-meter design completed, manufactured and installed with a modified three jaw Guralp hole-lock.
- ✓ 200 dB Dynamic range strong motion and weak motion 6 axis very broad band (VBB) CMG-3TB sensor with Strong motion CMG-5TB accelerometer modifications completed, manufactured and installed with a modified Single jaw Guralp Hole-lock.
- ✓ The modified CMG-3TB VBB broad band sensor has velocity response from 360 second period to 150 Hz.
- ✓ The dilatometer design has been finalised and installed. The dilatometer is attached to the bottom of one of the borehole casings and is installed at 146-meter depth and grouted.
- ✓ Temperature variations within the dilatometer housing is measured.
- ✓ Two Surface borehole huts built over each borehole well head as protection and to house one complete surface seismic station.
- ✓ The surface broad band sensor is CMG-3T 120 sec to 5 Hz velocity response.
- ✓ The multidisciplinary borehole and the surface sensors are all digitised with (CMG-DM24) 24 Bit acquisition systems. The acquisition system has sufficient memory to store data for more than 3 days in case of communication line failure.
- ✓ Real time data transmission from all the installed sensors to Multiple Observatories is accomplished.
- ✓ 48 hours Uninterruptable Power Supply (UPS) to supply the multidisciplinary borehole systems is installed.



Devised method to ensure that the cased borehole is dry.

Method used to pressurize the casing with air. Air packer is fitted to the top of each casing before it is welded on to the next section of the borehole casing.

Two sections of the casing is welded. The machined edges of the tubing ensures that section of the tube sits accurately on the top of the previous casing.



The borehole casing has 155 mm inside diameter. The borehole casing ends all have been machined to ensure good welding conditions and that the casing is vertical with in the required tolerance of ± 3 degrees. Slotted dilatometer tubing shown in this photo is used to lower the dilatometer to the bottom of the borehole without damaging the fragile tubing of the dilatometer.

First stage of the dilatometer installation

Slotted dilatometer installation casing





The dilatometer cabling is protected with metal tubing welded to the outside of the casing.

The dilatometer is powered and operated continuously during installation.



*The end of the borehole casing is fitted with a Pilot, to guide the **borehole** casing through possible “washed” out borehole zones.*



Borehole casings are inserted section by section in to the drilled borehole that has diameter of 24 cm. the casing diameter is 165 cm allowing reasonable space in between the casing and the drilled borehole for the “cementing” tubing to be inserted

This is the last stage of the borehole casing.

Three plastic piping is used to grout the casing and the dilatometer.

The dilatometer cabling is protected with metal tubing welded to the casing.



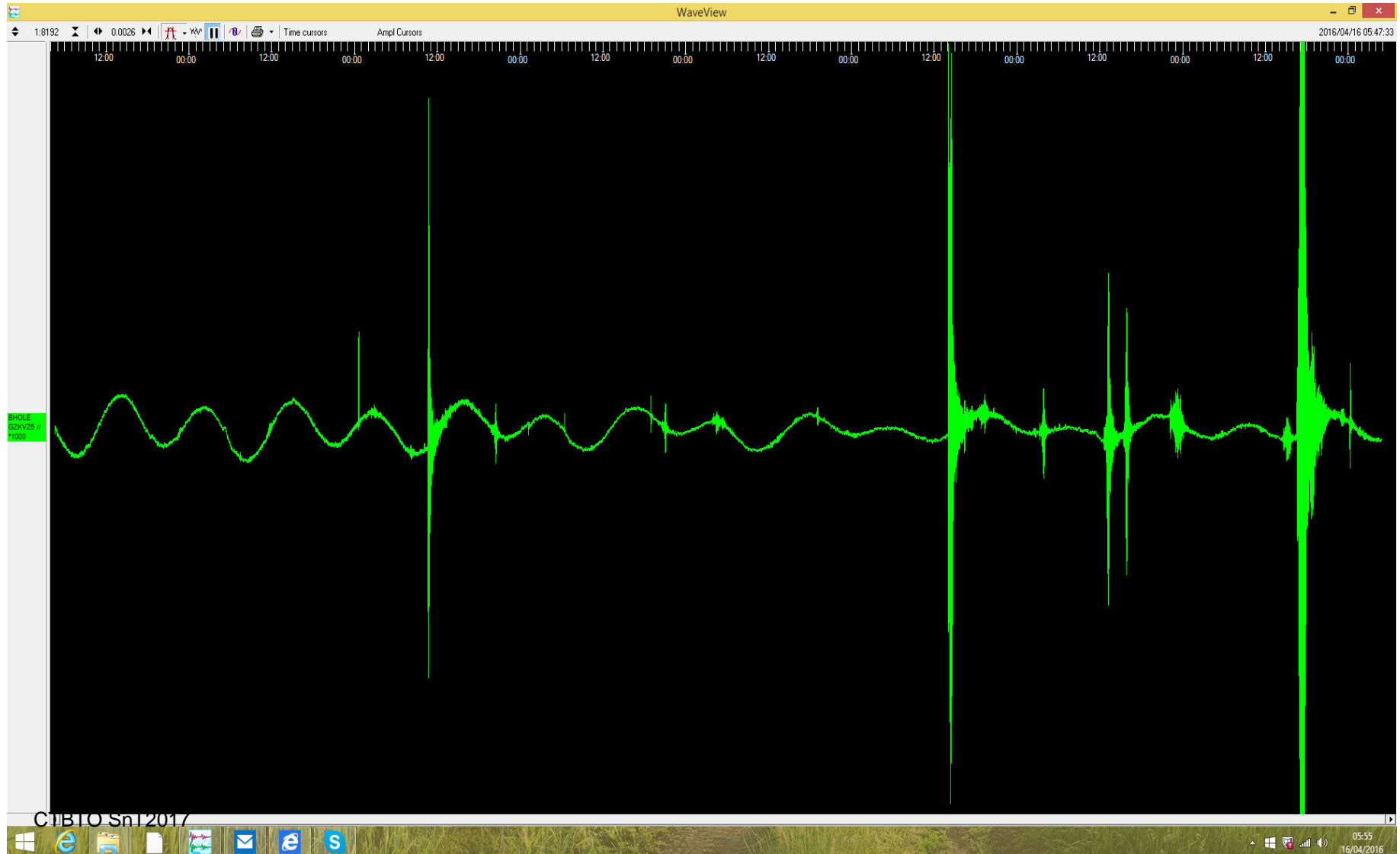
Two Surface borehole huts built over the two borehole well heads.

With in each hut surface digitisers, power supplies and data transmissions systems are installed.

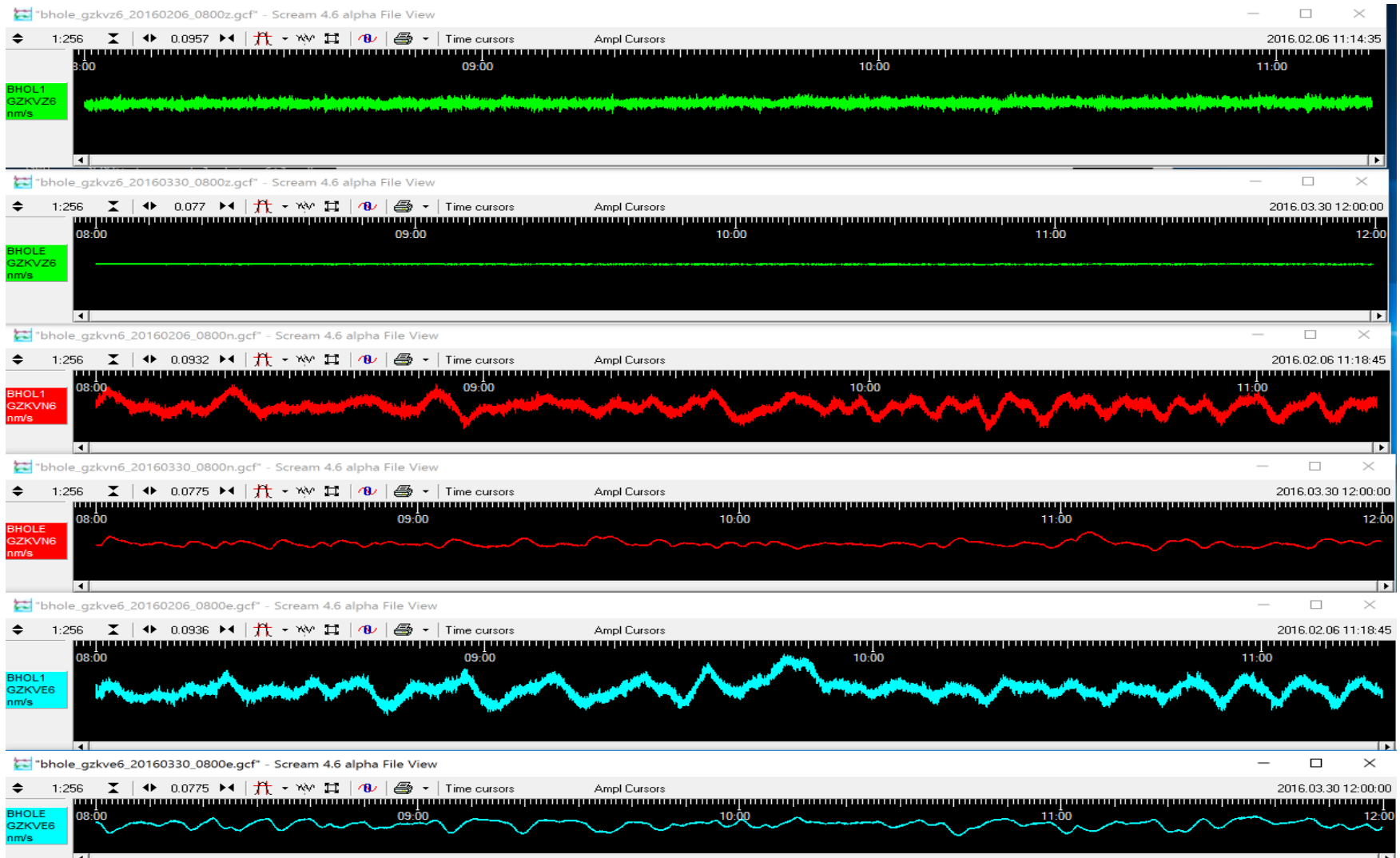
One of the surface hut contains the Surface Broad band sensor which is covered and insulated from temperature and convection variations. Each surface borehole hut cover about less than 2.5 Square meters space.



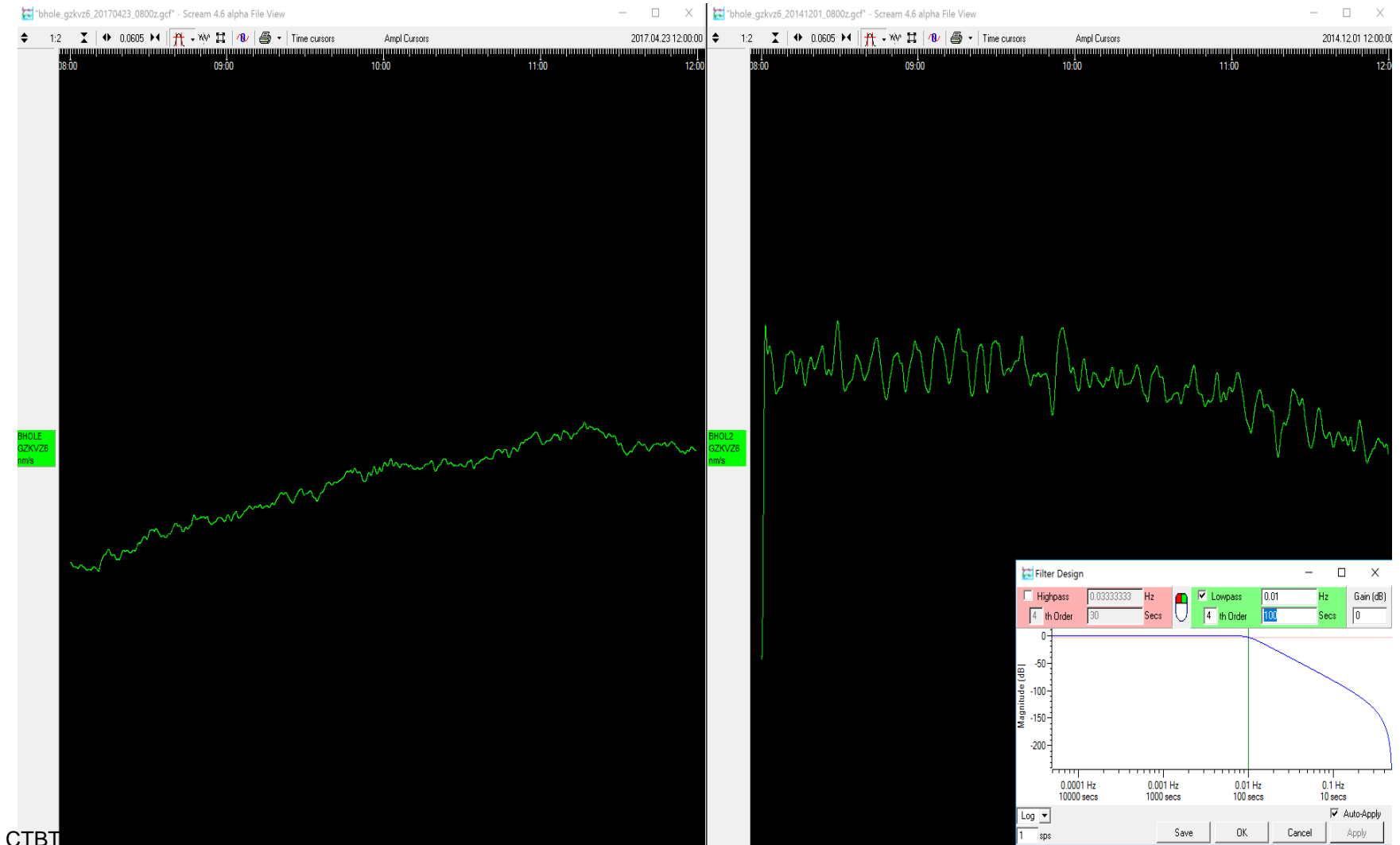
Earth tides showing continuous 8 days recording with many tele-seismic events including **Kumamoto-shi** Japan M 7 event 2016-04-15 16:25:06 (UTC). The amplitude dynamic range detection of the station exceeds 200 dB, when CMG-5TB sensor is also considered. The recording frequency range of the borehole station extends from dc to 150 Hz.



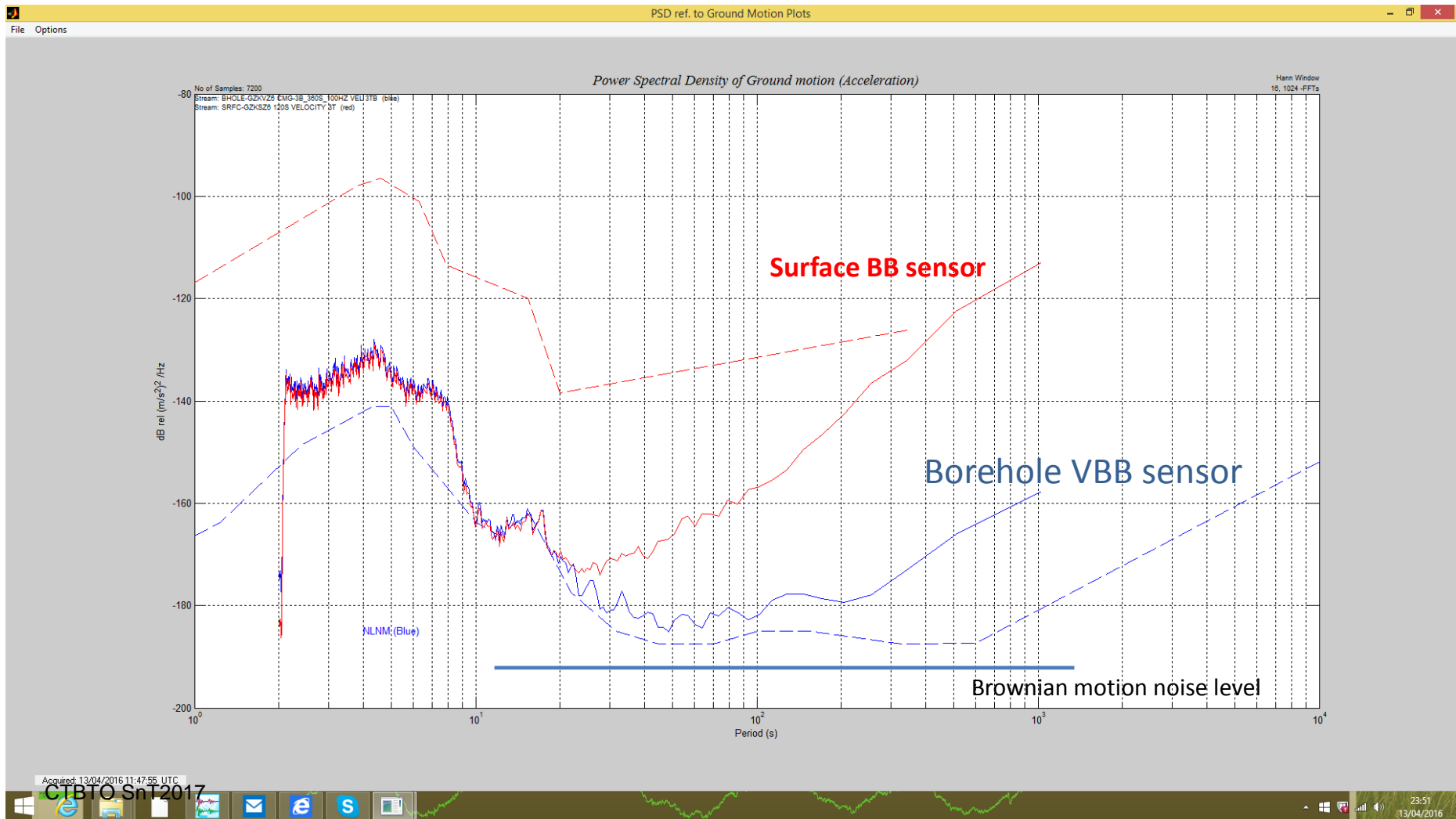
The three component (Z, N/S, E/W) VBB sensor comparison of the fluid filled and dry borehole data is given in the following plot, again showing reduced long period data fluctuations in the very long periods from the dry borehole environment. Top traces are the water filled borehole environment



Comparison of water filled borehole and dry borehole data can be seen more dramatically in the 4 hour time window as shown below. 1 s/s data is low passed at 100 seconds to show the differences in the quality of data.



The noise performance of the vertical VBB seismometer is as good as some of the best surface seismic stations setup in the most remote part of the lad base. The noise performance of the vertical component sensor is virtually as low as the Low noise model and stays like this for all weather and environmental conditions, while the surface sensor noise performance changes reducing the detectable signal levels. Two hours of data is used for this Power spectral density plot.



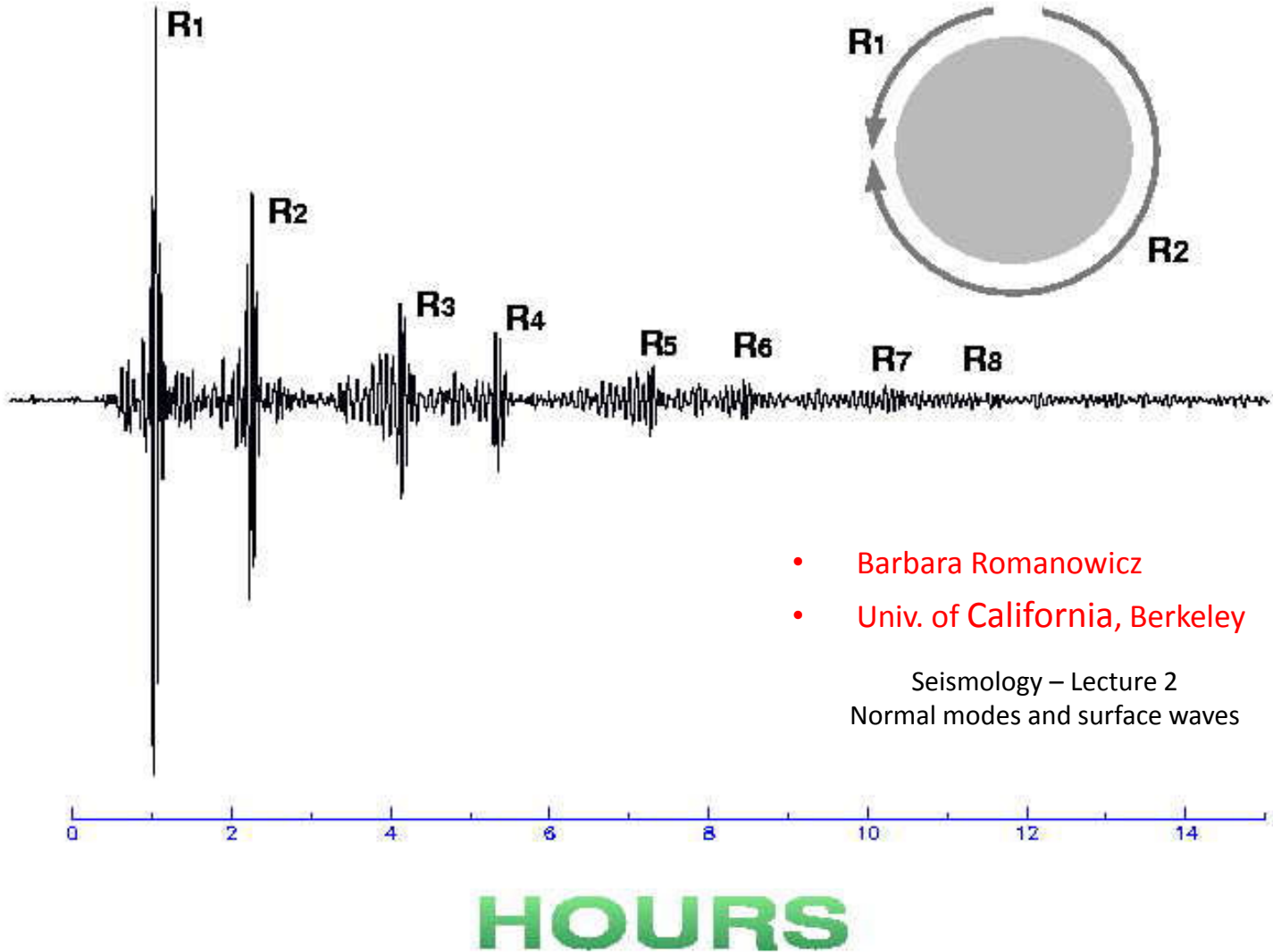
Columbia College, Columbia, CA, USA
BK CMB commences operations on: 1986,298

<http://earthquake.usgs.gov/monitoring/operations/station.php?network=BK&station=CMB#site>



station: CMB
channel: LHZ

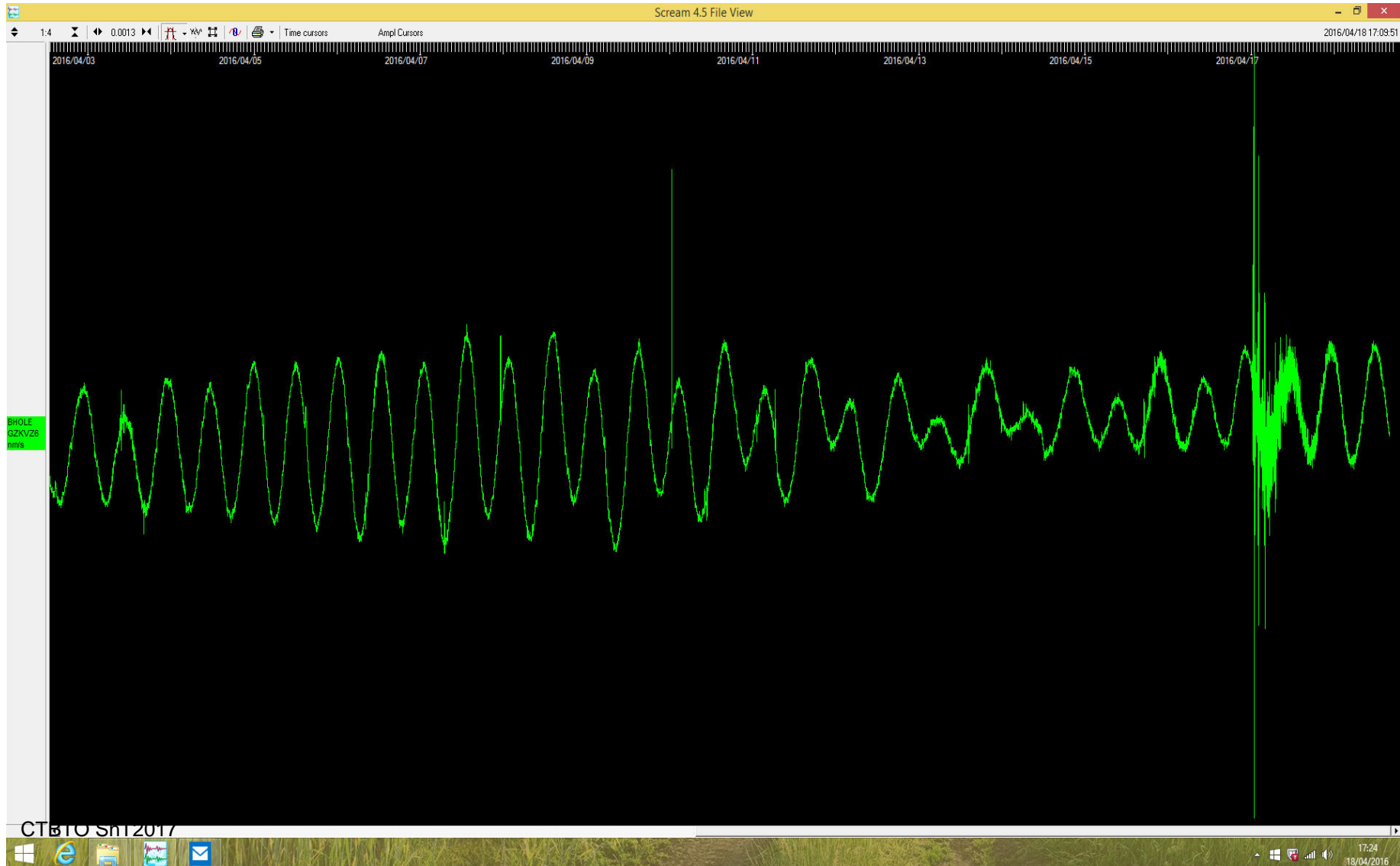
1996/07/11 21:46:39.7 h= 15.0km $\Delta=109.7^\circ$ $\phi= 32.3^\circ$
Burma-China Border Region Mw=6.8



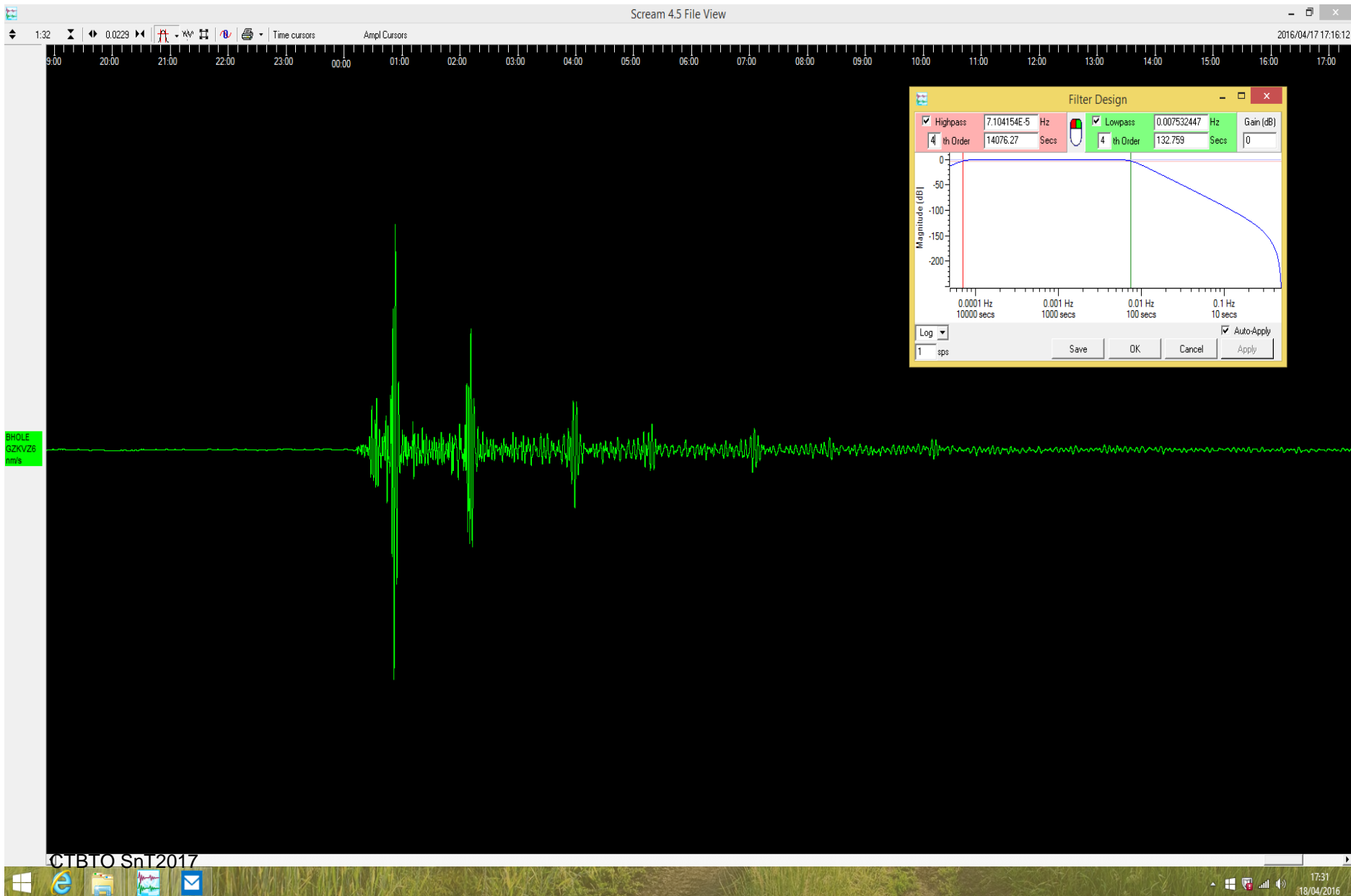
- Barbara Romanowicz
- Univ. of California, Berkeley

Seismology – Lecture 2
Normal modes and surface waves

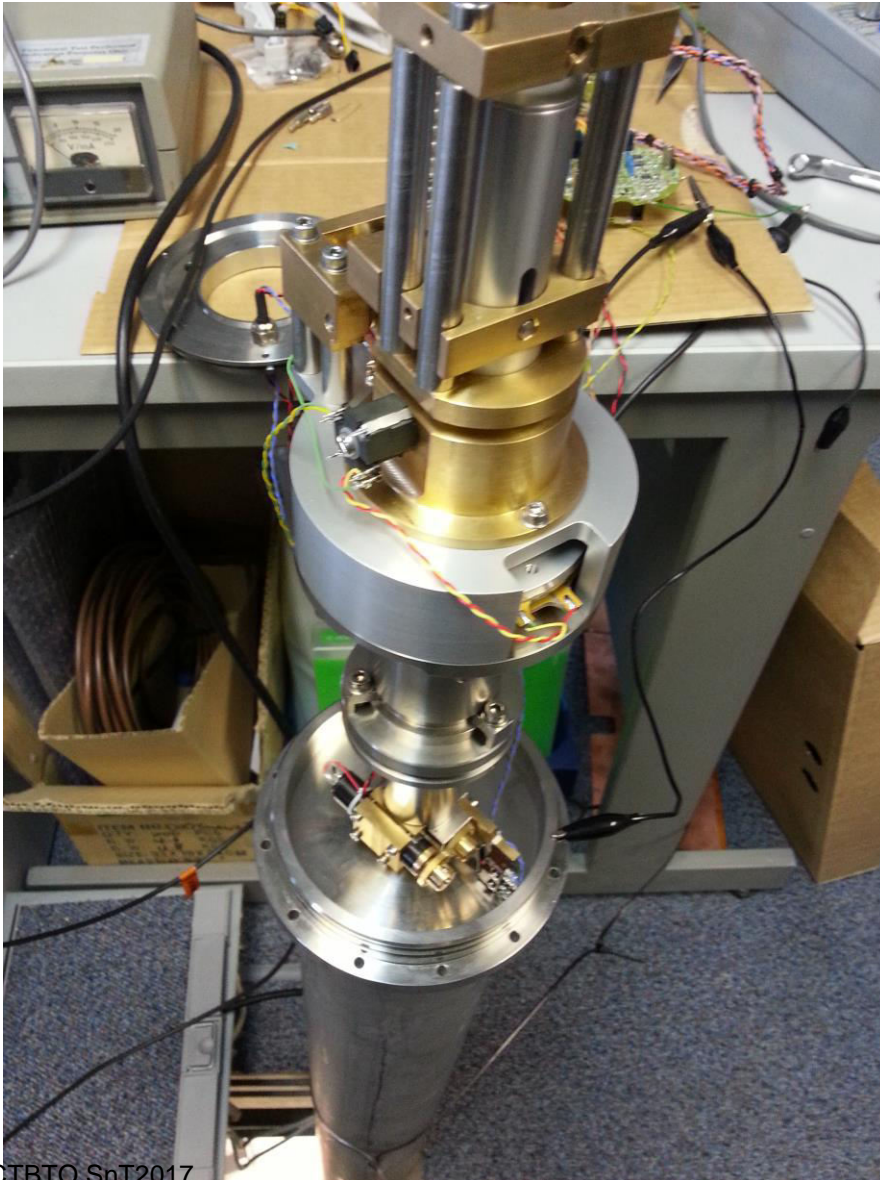
17 days of continuous Earth tides with tele-seismic events from VBB 360 second borehole seismometer velocity output is recorded without disruption. Magnitude-7.8 Ecuador event recorded at Marsite.



Ecuador Magnitude-7.8 quake with 130 second low pass filter showing very high signal to noise ratio when compared to some of the most quite land based seismic stations.



Dilatometer design has frequency response from DC to 30 Hz



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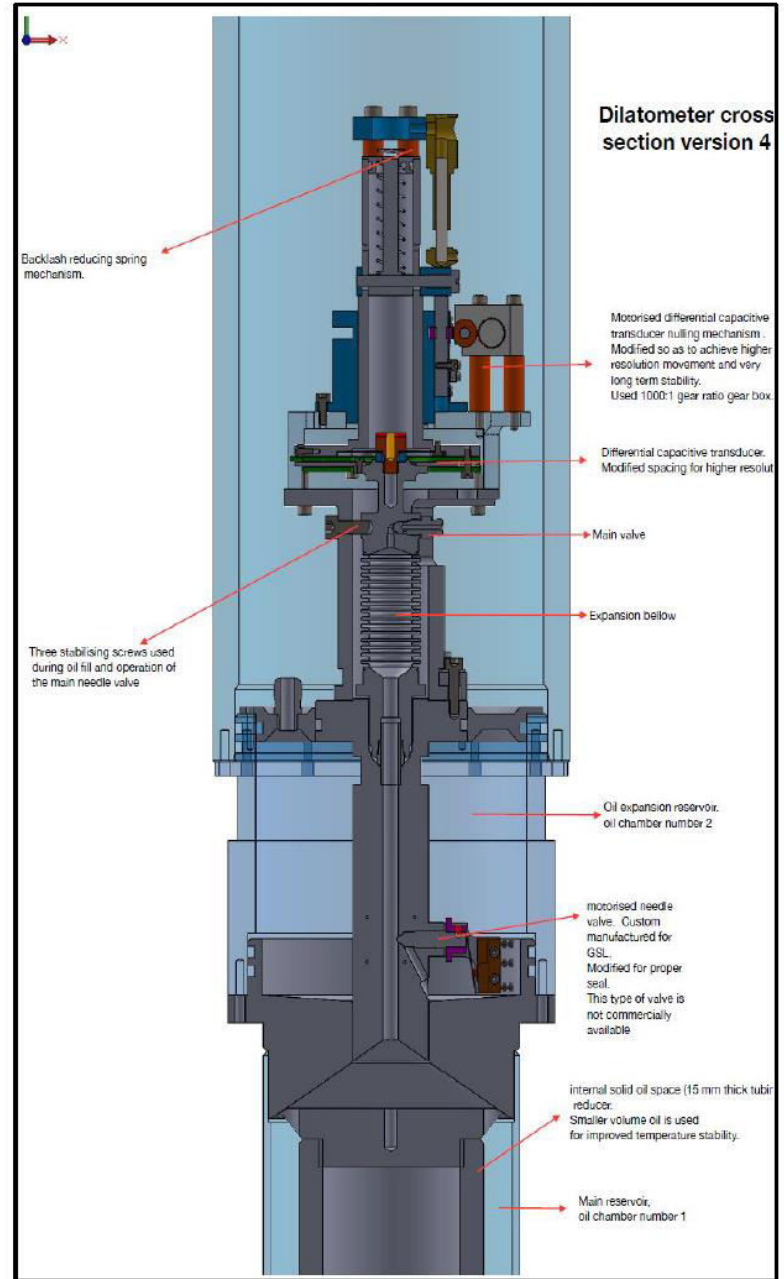


Figure 28 Cross section of the dilatometer tool, different parts of the design are identified.

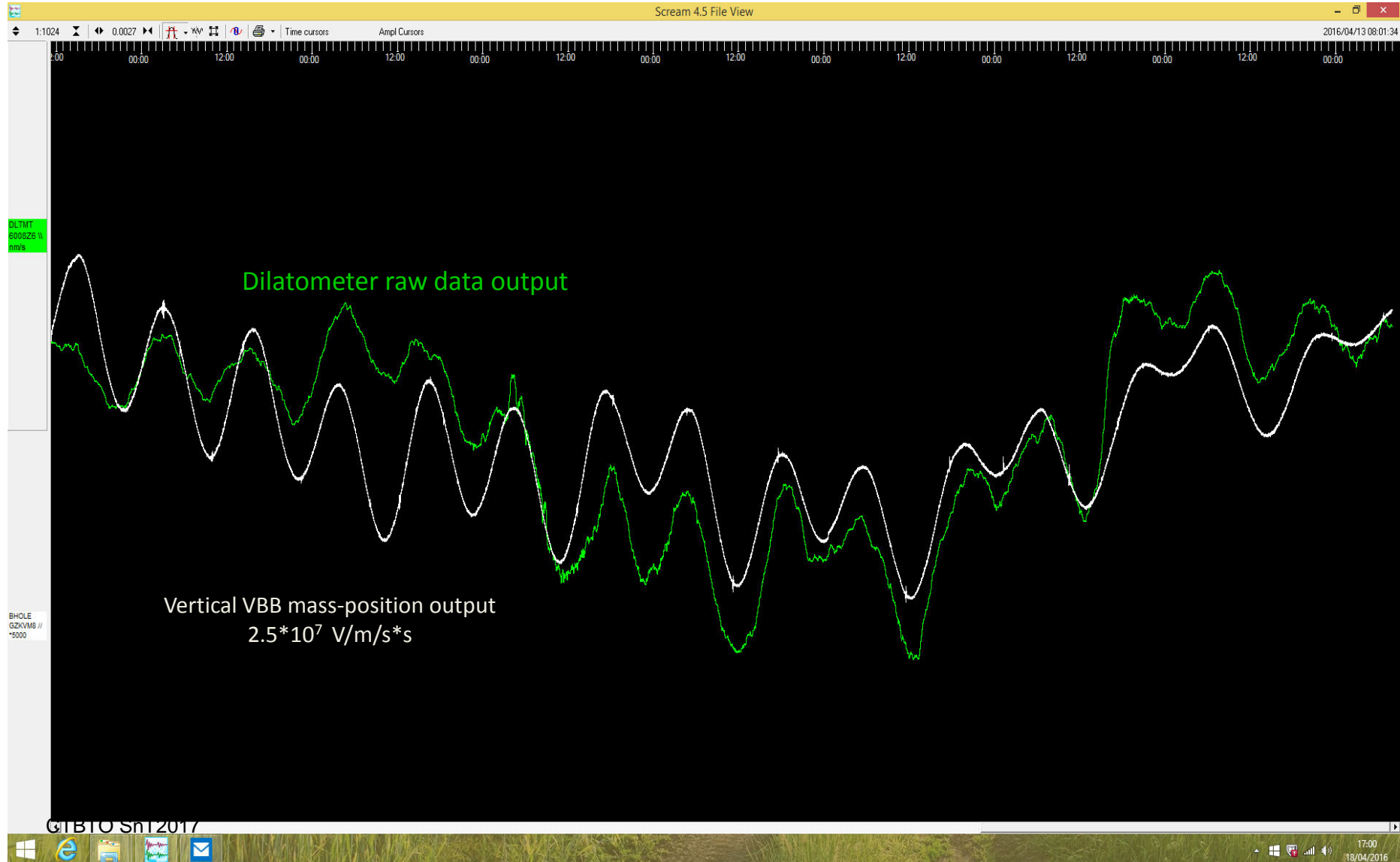
Comparison of dilatometer output with that of the mass-position output of the VBB seismometer which are 5 meters apart. The correlation between the two outputs is reasonably close. Success of this strain meter depends on the attention to detail from design to installation.

The dilatometer oil is filled under vacuum ensuring no bubbles are trapped with in the dilatometer casing.

During the installation the cement used was very low viscosity mixture and the injection of the cement from bottom of the borehole upwards ensured that the cement sets arounds the dilatometer casing.



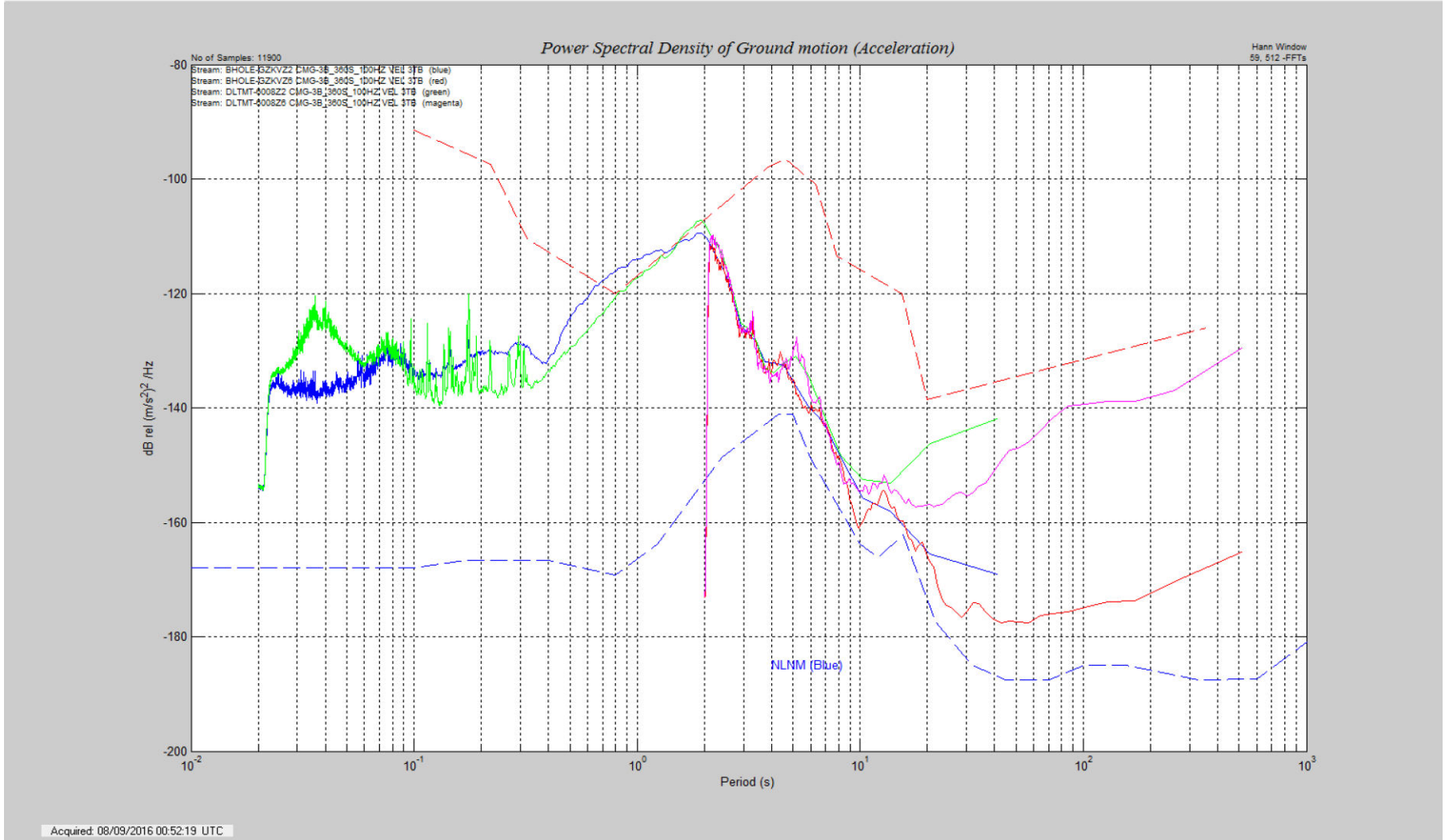
Calibration of dilatometers is not easy as the sensor has to be calibrated once the sensor is installed. Collocated high sensitive VBB sensor is likely to provide an accurate method of calibrating a dilatometer. This has never been tried as no one has successfully co-located a VBB sensor and a dilatometer side by side.



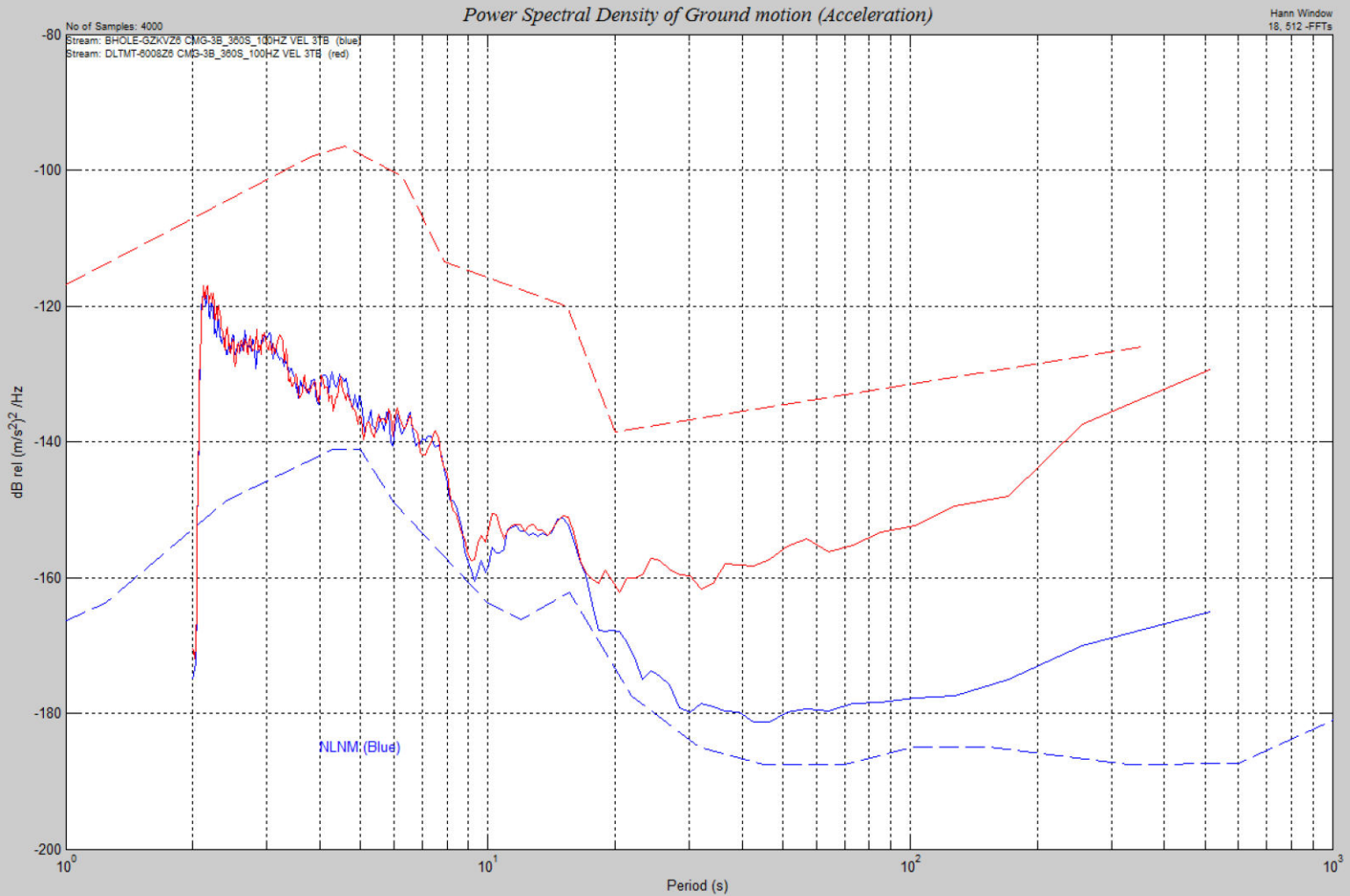
Calibrated VBB seismometer is compared with dilatometer output for 100 s/s and 1s/s. The same transfer function applied for VBB sensor is also used for the dilatometer.

PSD ref. to Ground Motion Plots
File Options

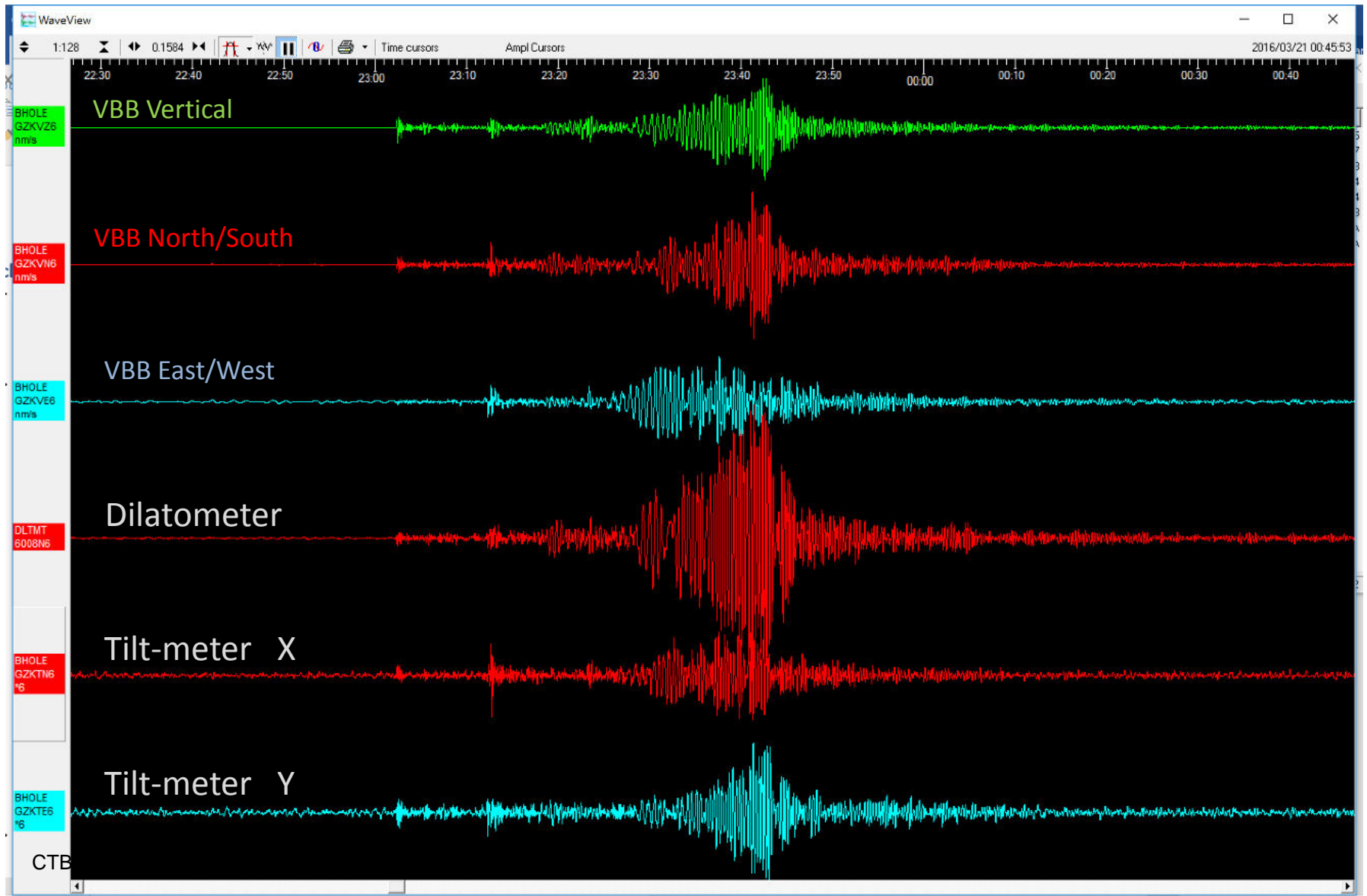
- □ ×



Calibrated VBB seismometer is compared with dilatometer output with 1s/s data during seismically quite period. It is possible to model the dilatometer with reasonable accuracy.

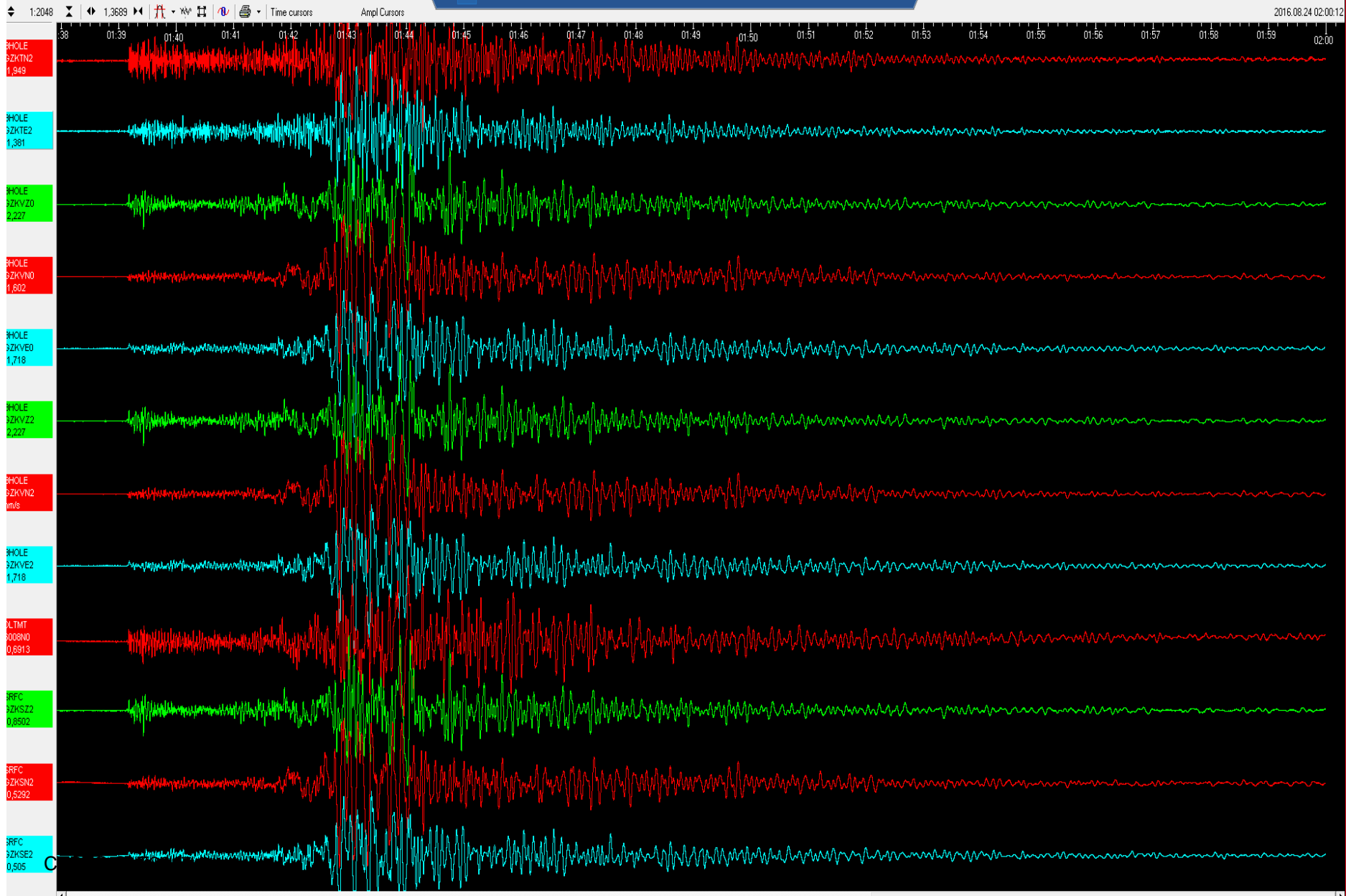


Three component VBB sensor, Dilatometer and tilt-meter X and Y outputs recoding the same tele seismic event. The sensor outputs are sampled at 1 s/s.

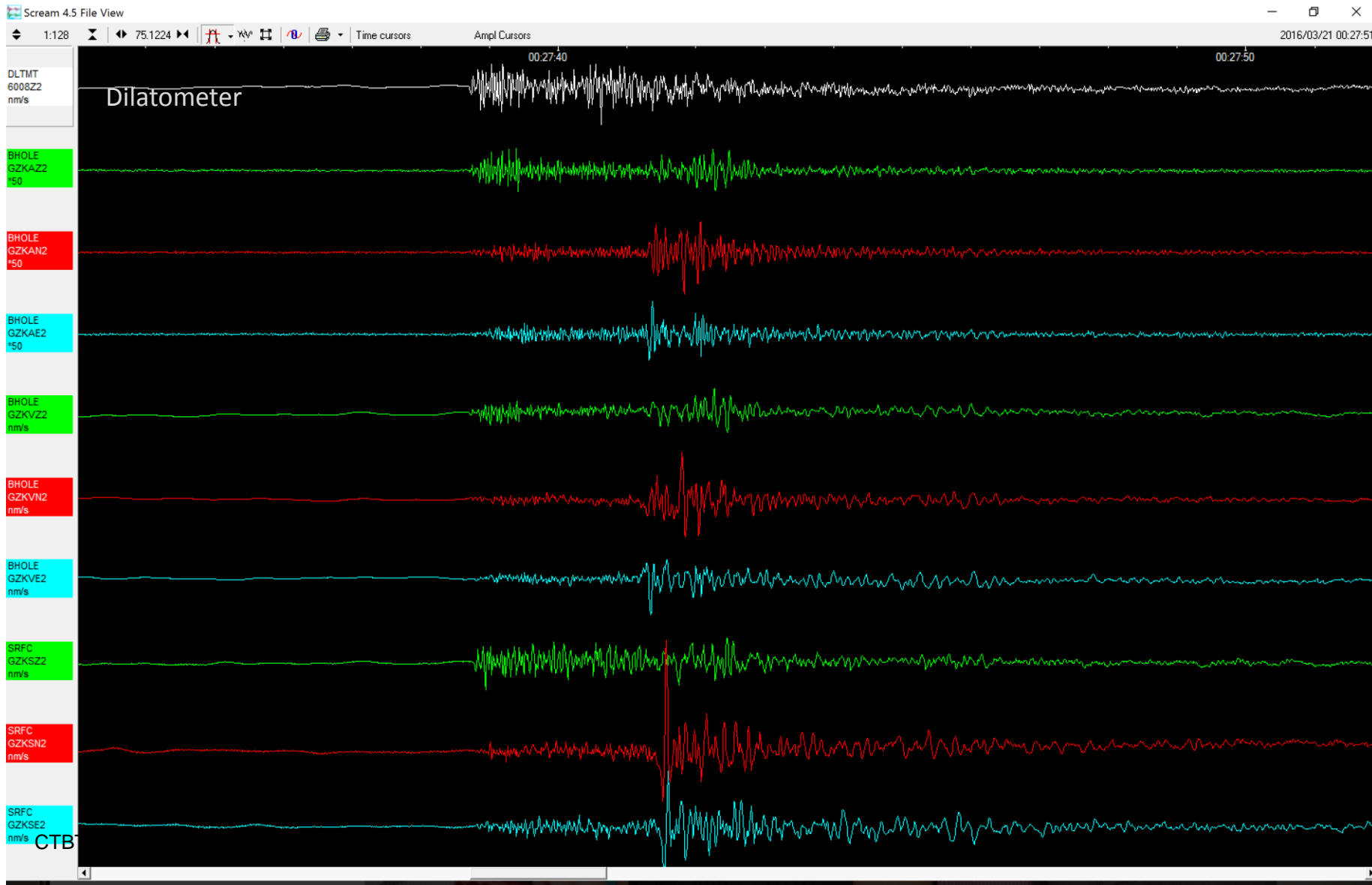


Mw 6.2 Region CENTRAL ITALY

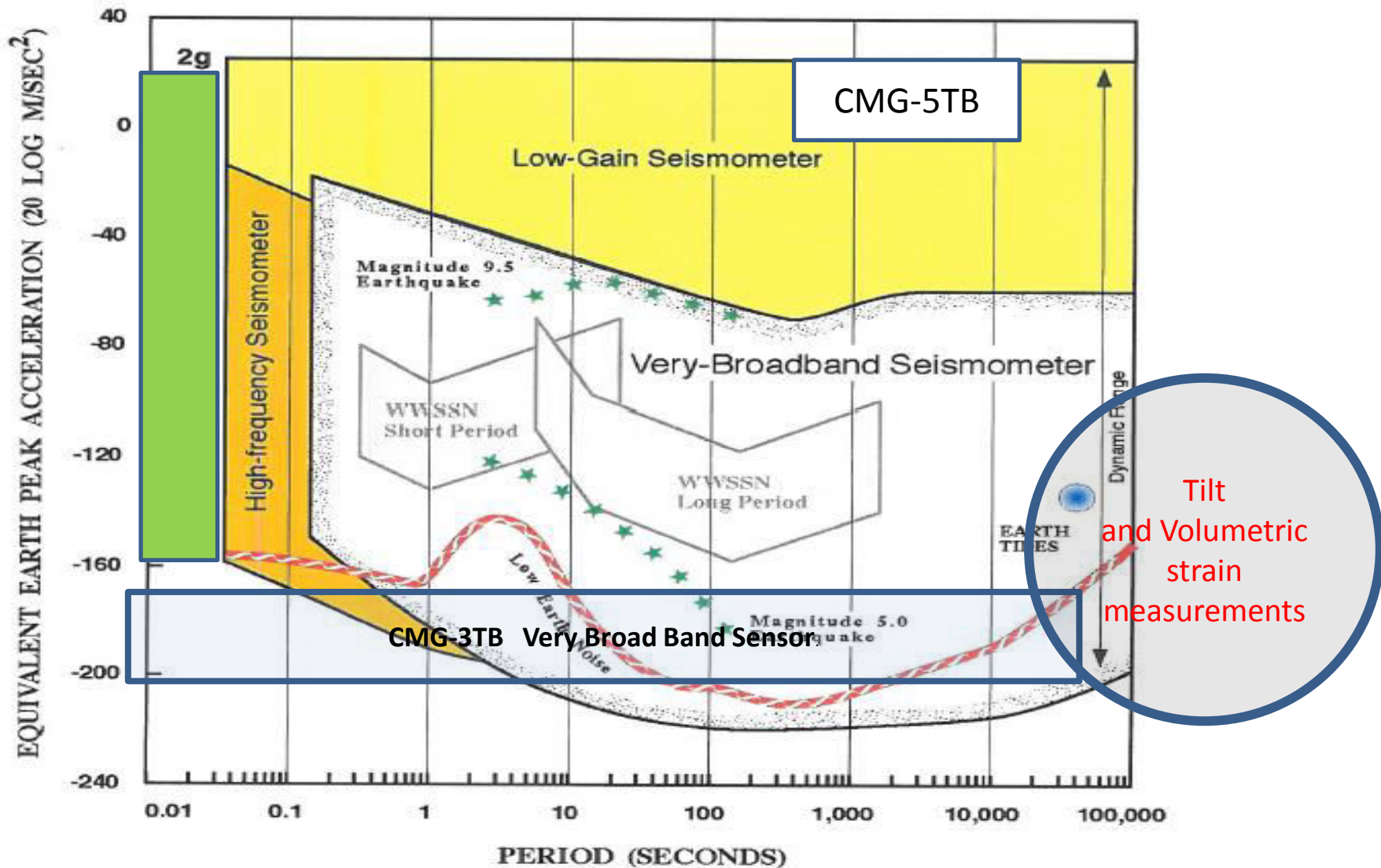
Date time 2016-08-24 01:36:32.3 UTC recorded at Marsite Turkey



Very small local event recorded with all the sensors including the **strong motion** three component borehole sensor. White trace is the dilatometer followed by the strong motion borehole sensor with borehole velocity sensor and the surface three component broad band sensor . The displayed data is filtered from 0.01 Hz to 50 Hz.



In conclusion all the required instrumentation set out to record comprehensively the ground movement near an active fault line recording strong motion, weak motion, strain and tilt in a 150-meter deep borehole have been accomplished with meaningful results.



Multi component borehole instruments: its contribution and “monetary value”

- Study of seismic strain step
- Study of Slow earthquakes, has it been monitored in Turkey?
- Earthquake precursor with strain and tilt measurements.
- Ambient noise tomography, requires many more good quality stations.
- Subsurface deformations changes and behaviour before, during and after an earthquake, especially at a seismically active fault line. Can one get repeatable results?
- Analytical methods of understanding volumetric strain measurements and comparison to instrument measurements in conjunction to a very broad band sensor. (360 second to 150 Hz)
- There is evidence that the volumetric strain is more responsive to the strain plane perpendicular to the borehole rather than parallel. This is observed when VBB sensor mass position outputs are compared with Dilatometer output.
- Comparison of strain measurements to a very broad band seismometer to calibrate strain meter at short periods and tidal frequencies. Calibration of strain meters is normally carried out by calculating the tide signal levels and comparing to strain measurements. In-situ calibration of strain meters at tidal frequencies, this is new?
- Comparison of tilt changes (in the Nano-radian level) with that of strain meter co-located with Broad band seismometer. This is new?
- Use of mass position output of horizontal VBB seismometer as tilt and comparison to a tilt meter. Likely to reduce the number of required sensors and one VBB sensor can provide:
 - Short period
 - Very Long period, tidal frequencies
 - Tilt N/S and E/W outputs
- Long term Comparison of GPS measurements and strain measurement. Strain measurements are 2 to 3 orders of magnitude more sensitive than GPS measurements in the time scale measurements of days to months. Is this true for MARsite?
- Evaluating different borehole instrumentation side by side. Performance comparison of a borehole, station to that of surface stations.
- New way of setting up VBB seismic stations inside a watertight borehole?
 - Is it better that the multidisciplinary stations incorporation strong motion sensors should always be borehole sensors?
 - Must be desirable for early warning systems because of improved signal to noise ratio?