This project has received funding from the European Union’s Seventh Programme for research, technological development and demonstration under grant agreement No [308417]”.

New Directions in Seismic Hazard Assessment through Focused Earth Observation in the Marmara Supersite

Grant Agreement Number: 308417
co-funded by the European Commission within the Seventh Framework Programme
THEME [ENV.2012.6.4-2]
[Long-term monitoring experiment in geologically active regions of Europe prone to natural hazards: the Supersite concept]

D4.1

Surface Microearthquake Array and Borehole Seismometers Implementation

Project Start Date	1 November 2012
Project Duration	36 months
Project Coordinator /Organization	Nurcan Meral Özel / KOERI
Work Package Number	WP-4
Deliverable Name/ Number	D4.1
Due Date Of Deliverable	May-2014
Actual Submission Date	November-2014
Organization/Author (s)	Istanbul University; Oguz OZEL Guralp Systems; Cansun GURALP

Dissemination Level		
PU	Public	▨
PP	Restricted to other programme participants (including the Commission)	
RE	Restricted to a group specified by the consortium (including the Commission)	
CO	Confidential, only for members of the consortium (including the Commission)	

TABLE OF CONTENTS

1.INTRODUCTION

1.1 State of the Art

The Ganos Fault (GF) forms a ~50 km long linear fault system and represents the link between the northern strand of the North Anatolian Fault Zone (NAFZ) in the Sea of Marmara region and the North Aegean Trough (NAT) where slip partitioning results in branching of the fault zone (e.g. Barka and Kadinsky-Cade, 1988; Okay et al., 1999). The 9 August 1912 (M_s=7.4) Ganos (Gaziköy) earthquake produced widespread damage and considerable loss of life in western Marmara region. The 1912 rupture appears to have crossed the Ganos restraining bend into the Sea of Marmara floor for 60 km with a right-lateral slip of 5 m, ending in the Central basin step-over. From the Gulf of Saros to the Marmara Sea the total 1912 rupture length is probably about 140 km (Armijo et al., 2002; 2005). A reliable surface-wave magnitude M_s = 7.4 ± 0.3 was calculated by Ambraseys and Finkel (1987). Hence the 1912 Ganos and the M_w = 7.4 1999 Izmit earthquakes are of similar size. When looked into the seismicity of the purposed region, seismic activity in the western part of Marmara Sea region predominantly occurs offshore along the main branch of the NAFZ as identified from the earthquake catalogue by the Boğaziçi University Kandilli Observatory and Earthquake Research Institute (KOERI) that covers the time period 1900-present (Figure 5). The KOERI catalogue for the GF region is complete down to a magnitude of 2.7. Interestingly, the GF is almost aseismic down to this magnitude threshold and a diffuse distribution of hypocenters is observed offshore. In particular, seismicity clusters northwest of Marmara Island and in the Tekirdağ basin. The three largest earthquakes in the GF region during the last century occurred in 1912 within only a few weeks. Two events occurred along the GF with surface-wave magnitudes (M_s) of 7.4 (9 August 1912) [see red star in Figure 5] and M_s = 6.2 (10 August 1912), respectively. The event of M_s = 6.2 was located offshore below the Marmara Sea (see yellow star in Figure 5). These events were followed by another major earthquake of M_s = 6.8 (13 September 1912) (blue star in Figure 5) that was located at the onshore part of the GF (Ambraseys, 2001).

1.2. Description of the Work

Bringing face to face the seismograms of microearthquakes recorded by borehole and near-surface instruments portrays quite different contents. The shorter recording duration and nearly flat frequency spectrum up to the Nyquist frequencies of borehole records are faced with longer recording duration and rapid decay of spectral amplitudes at higher frequencies of a surface seismogram. The main causative of the observed differences are near-surface geology effects that masks most of the source related information the seismograms include, and that give rise to scattering, generating longer duration seismograms.

In view of these circumstances, studies on microearthquakes employing surface seismograms may bring on misleading results. Particularly, the works on earthquake physics and nucleation process of earthquakes requires elaborate analysis of tiny events. It is obvious from the studies on the nucleation process of the 1999 Izmit earthquake that tens of minutes before the major rupture initiate noteworthy microarthquake activity happened (Bouchon et al.,) . The starting point of the 1999 rupture was a site of swarm activity noticed a few decades prior the main shock. Nowadays, analogous case is probable in western Marmara sea region, prone to a major event in near future where the seismic activity is prevailing along the impending rupture zone. Deploying a borehole seismometer e.g. in

Marmara Island and/or eastern end of the Ganos fault zone may yield invaluable data to closely inspect and monitor the last stages of the preparation stage of major rupture.

1.3. Objectives of Task-1

- Installation of surface array micro-eartquake stations to monitor the microearthquake activity in the western part of the Main Marmara Fault,
- Choosing borehole location and Determination of S-wave velocity structure by geophysical measurements (Seismic refraction, Seismic reflection, MASW, MAM, SPAC) at the borehole site and at a close site
- Design and manufacture very broadband velocity sensor with an integrated strong motion sensor to capture the very large and very small local and tele-seismic events.
- Incorporate within the same borehole designed and manufactured very sensitive tilt meter with a resolution of 5 nano-radians.
- Design and build a dilatometer (strain gauge)
- Combining borehole and surface network data for earthquake location improvement

2. ACHIEVEMENTS

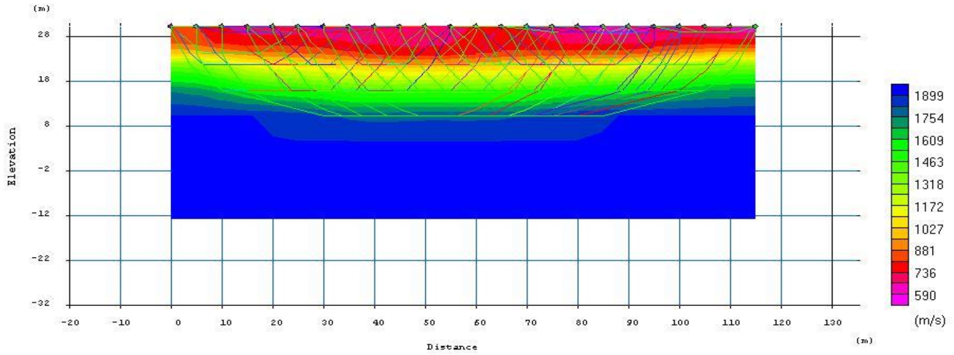
2.1 First 6-Month Activity

- Choosing borehole location,
- Determination of S-wave velocity structure by geophysical measurements (Seismic refraction, Seismic reflection, MASW, MAM, SPAC) at the borehole site and at a close site,
- Analysis of the data acquired by the geophysical measurements,
- Site selection of surface array stations,

One of the aim of this task is to monitor rupture nucleation and propagation using the borehole **and surface array data. This necessitates the borehole be right on the fault zone. Partners IU and** Guralp Systems together fixed borehole location. It is located in the Gazikoy village where the North Anatolian Fault Zone passes through. The google maps below show the location of the borehole.

Figure1: The location of the borehole.

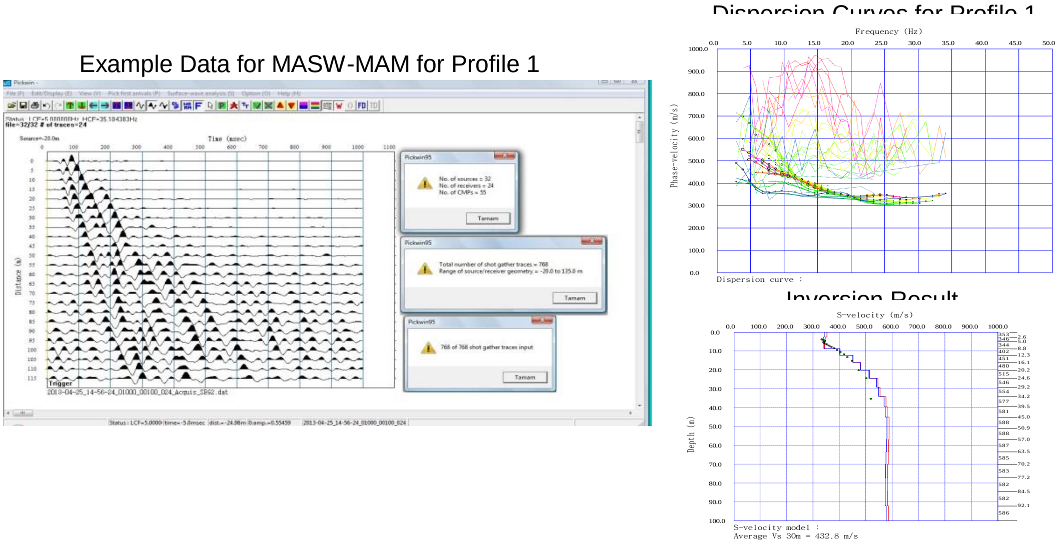
Since the depth of the bedrock will give the borehole depth and thus the design parameters of the borehole system to manufacture, geophysical measurements were performed to determine the S-wave velocity structure and the depth of the seismological bedrock. Unfortunately seismic refraction and reflection data didn't allow to go down deeper than 20-30m. The seismic refraction results and MASW results are respectively given below.



P –Wave Velocity Model for Tomography for Profile 1
(Borehole Location)

Figure 1: P-wave velocity model for Profile-1 tomography at the borehole location.

Example Data for MASW-MAM for Profile 1



Pickwin95

No. of sources = 32
No. of receivers = 24
No. of CMPs = 55

Tamam

Pickwin95

Total number of shot gather traces = 768
Range of source/receiver geometry = -20.0 to 135.0 m

Tamam

Pickwin95

768 of 768 shot gather traces input

Tamam

Figure 2: Example Data for MASW-MAM for Profile-1

The deeper results are obtained by SPAC method (Spatial Auto Correlation Method) at a site 500m away from the borehole location shown by red circle on the google map. Since there was no convenient space to make large array, large array SPAC measurements were performed 500m away. According to the preliminary results, the engineering bedrock lies at a depth range of 60m-200m.

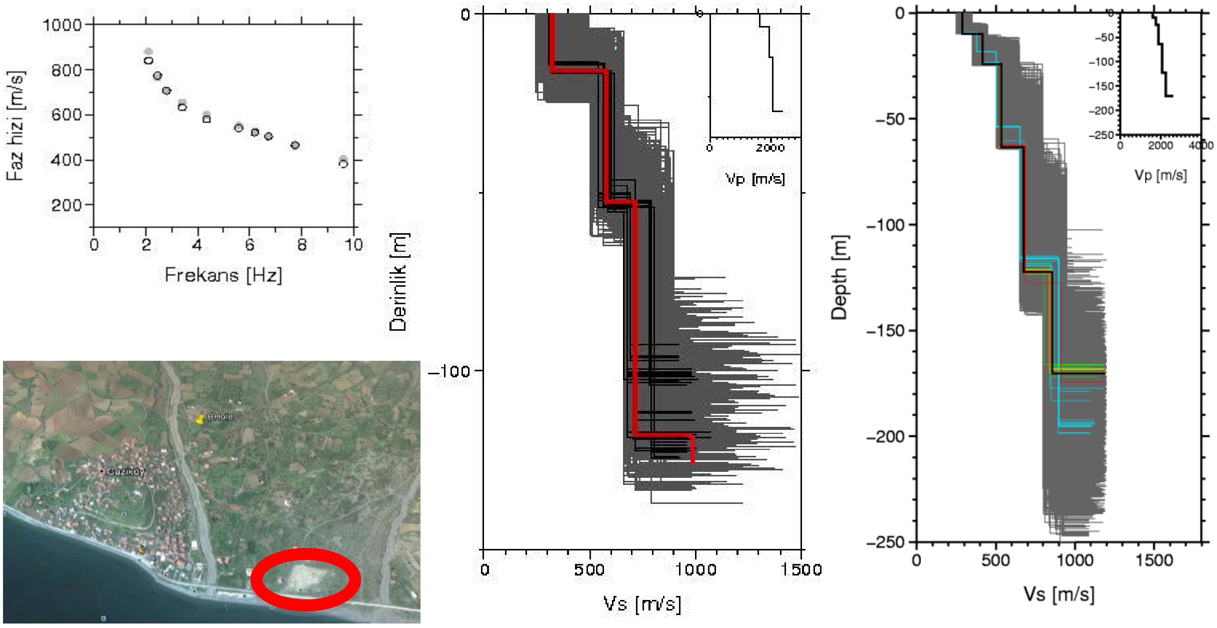


Figure 3: Deeper results obtained by SPAC method (Spatial Auto Correlation Method).

2.2 Second 6-Month Activity

- Restoration and furnishing the data center room,
- Re-performing of geophysical measurements (Seismic refraction, Seismic reflection, MASW, SPAC, single station microtremor measurements) at the borehole site and at a close site,
- Re-Analysis of the data acquired by the geophysical measurements to construct the velocity structure beneath borehole,
- Remaining 2 surface array station locations on the Marmara island are determined.

The Geophysical Department of Istanbul University provided a room to be used as data center for the MARSITE project. This room was restorated and furnished by necessary equipments, and also telephone and internet connections made ready to get the data, which will be sent from the surface array stations and borehole system. Some photos from the data center are given below.

Figure 4. MARSite Data Center at IU.

Figure 5: MARSite Data Center at Istanbul University.

Between May 2013 and October 2013, geophysical measurements (seismic reflection and microtremor measurements) which have been performed in the previous period were repeated. The campaigns for these measurements were performed in May and June, 2014. The location of the seismic reflection profile is shown on the map.

Figure 6: The location of the seismic reflection profile.

The result of seismic reflection measurement is given below.

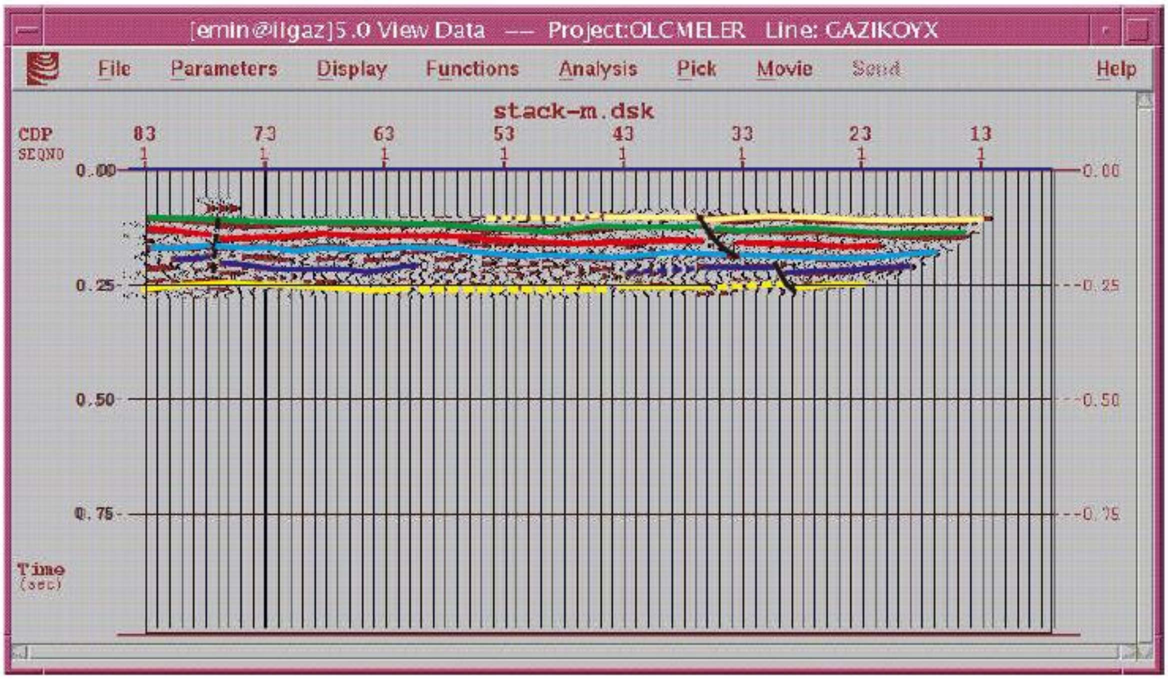


Figure 7: The result of seismic reflection measurement.

After several data processing steps, especially surgical muting, which removed all surface wave effects and also first arrivals, and resulted in zero amplitudes in the deeper parts of the section, it is found that average velocity changes laterally from 1050 m/s to 1150 m/s. Taking the average velocity as 1100 m/s, the discontinuity at 0.25 msec corresponds to 137.5 m depth. This convinced us to determine the borehole depth as about 150m.

On the other hand, MASW measurements are also repeated by high frequency sensors and the SPAC measurements are performed by larger arrays. The SPAC results are given below.

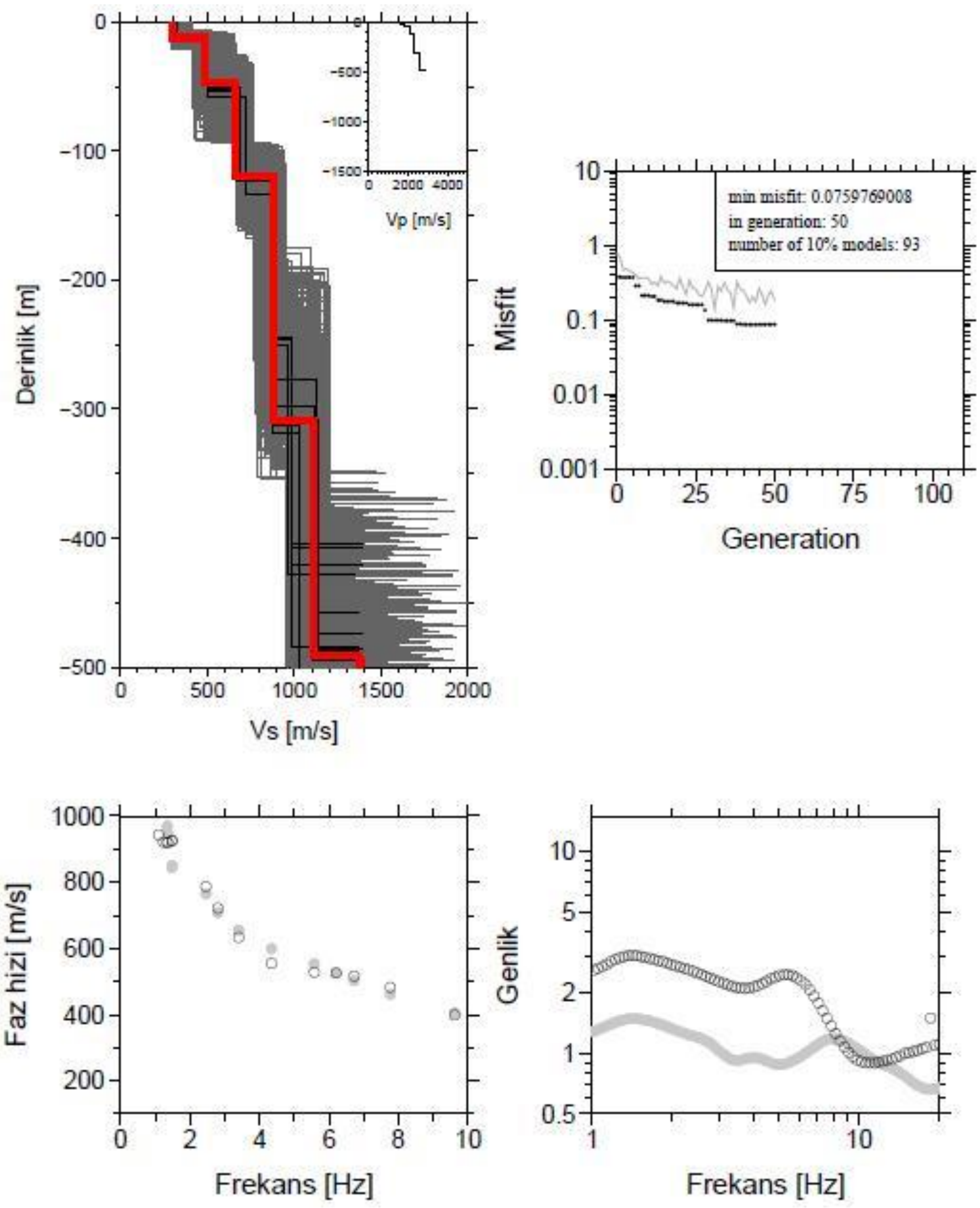


Figure 8: SPAC results. (ŞEKİL TÜRKÇE!!!!!!!!!!!!!!!!!!!)

The lower frequency range (lower than 2 Hz) of the dispersion curve is obtained by 100m array size-measurements and combined with those from smaller arrays. The SPAC measurements also point out a velocity discontinuity between 100m and 150m (about 130m), that is compatible with the seismic reflection result.

As for the MASW results,

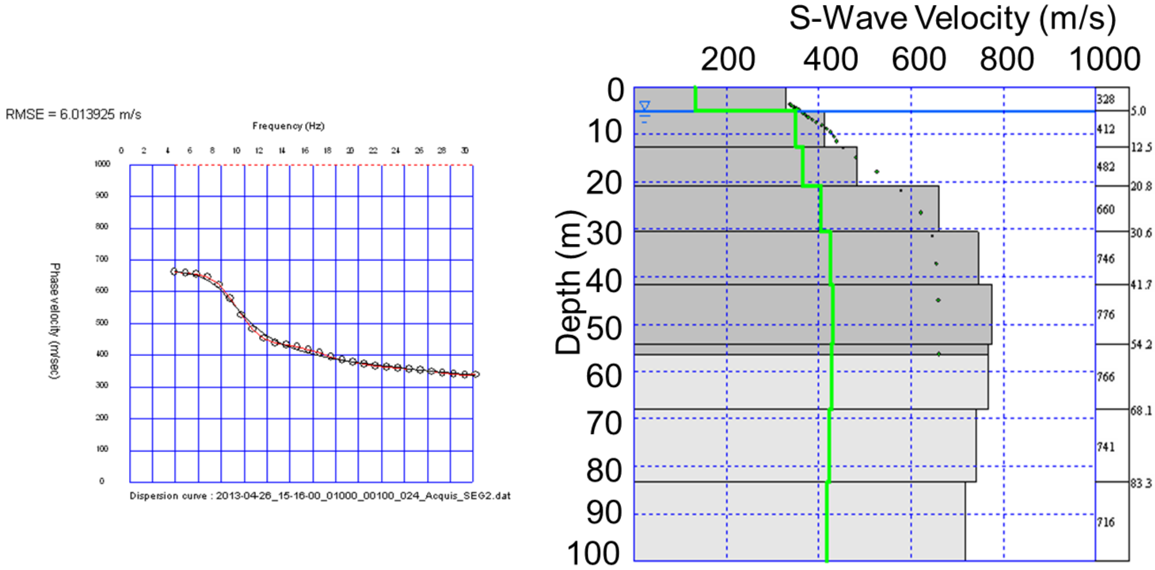


Figure 9: MASW results

2.3. Third 6-Month Activity

- Preparation of the locations of the surface array stations,
- Installation of surface array stations,
- Preparation of borehole location,
- Sharing wave form data and monitoring the micro earthquake activity in the western part of Marmara,
- Design and manufacture very broadband velocity sensor with an integrated strong motion sensor to capture the very large and very small local and tele-seismic events.
- Incorporate with in the same borehole designed and manufactured very sensitive tilt meter with a resolution of 5 nano-radians.
- Design and build the dilatometer

2.3.1. Surface Array Stations

In the third 6-month period, the locations of the surface array stations (see the map below) are prepared for instrumentation (i.e. cabins, seismometer grouting, solar panels and internet connections). The instrumentation is completed, and all the surface array stations (currently 8 stations) are in operation beginning from 10th April, 2014. The data from these surface array stations are reachable through internet for the project partners.

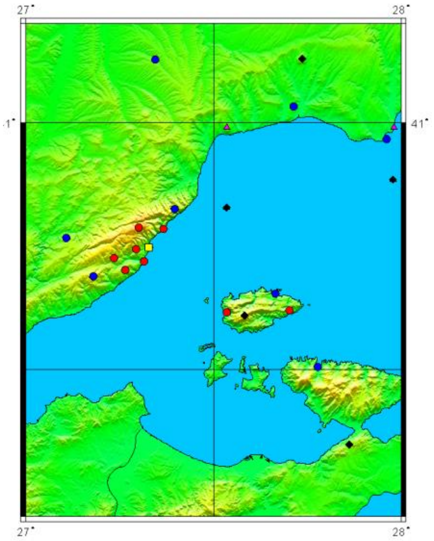


Figure 10: The locations of the surface array stations (red circles) and the location of the borehole (yellow rectangle).

In the map above, red circles show the locations of the surface array stations and yellow rectangle shows the location of the borehole. Blue and black circles (Sea Bottom Systems) show the existing stations run by TUBITAK and KOERI. The photos below show some of the surface array stations.

Figure 11: Photos of some surface array stations.

MAR1 (Gazikoy-Borehole)	40.74810° - 27.327319°
MAR2 (Hoskoy)	40.71724° - 27.31229°
MAR3 (Guzelkoy)	40.743197°- 27.294489°
MAR4 (Murefte-Radar)	40.787977°- 27.300685°
MAR5 (Ucmakdere)	40.795465°- 27.365792°
MAR6 (Kirazli)	40.703548°- 27.263265°
MAT7 (Mursalli)	40.726282°- 27,234344°
MAR8 (Marmara Adasi-I)	40.726782°- 27.234344°
MAR9 (Marmara Adasi-II)	40.619611°- 27.702046°

The instrumentation of each surface array station consists of those shown in the following photos.

Figure 12: Instrumentation in the surface array stations (30 sec seismometer, solar panel, modem and battery etc.)

The data from the surface array stations are transmitted to the Marsite Server at KOERI and Istanbul University Data Center through GPRS, and shared with the other project partners. A screen shot from the monitoring system that shows the data streams is given below.

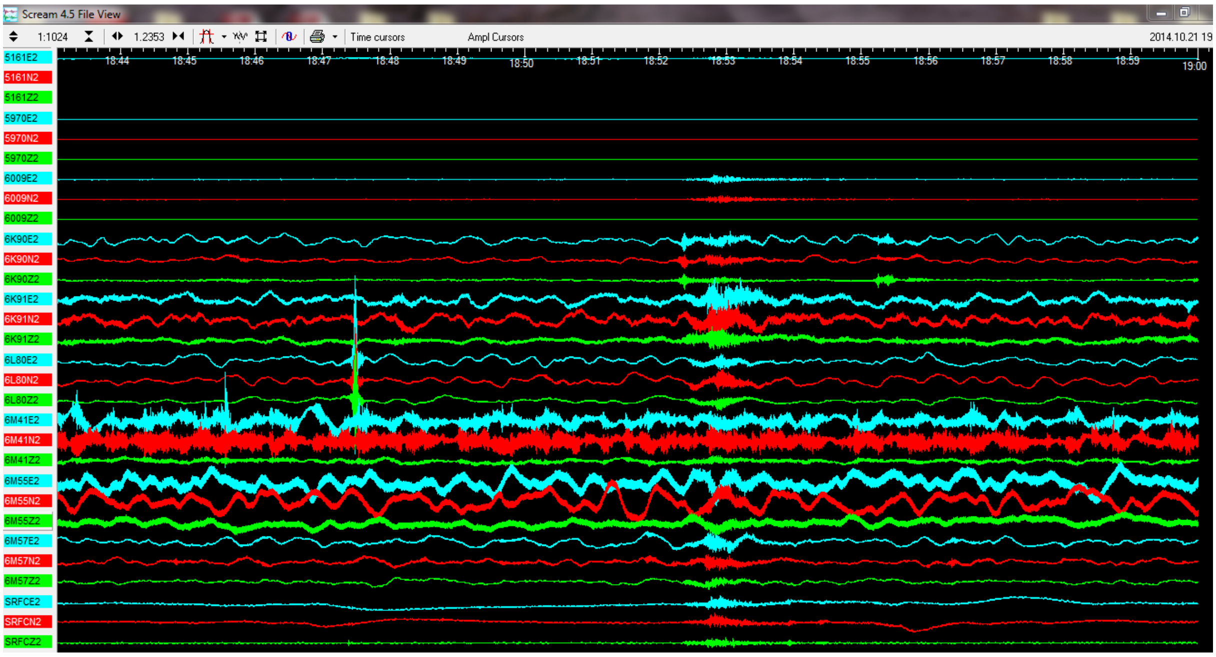


Figure 13: Data streams from the surface array stations (20141020 event with M=1.9) recorded by surface array stations)

2.3.2. Micro-seismic Activity

For the period of the years 2013 and 2014, the micro-earthquake activity in the western part of the Marmara Region has also been continued to monitor by TUBİTAK MRC seismological broadband stations together with surface array stations. 1327 events in 2013 and 2460 events (4.5 ≥ ML ≥ 0.5), totally 3996 events were located. The located events are shown on the maps below.

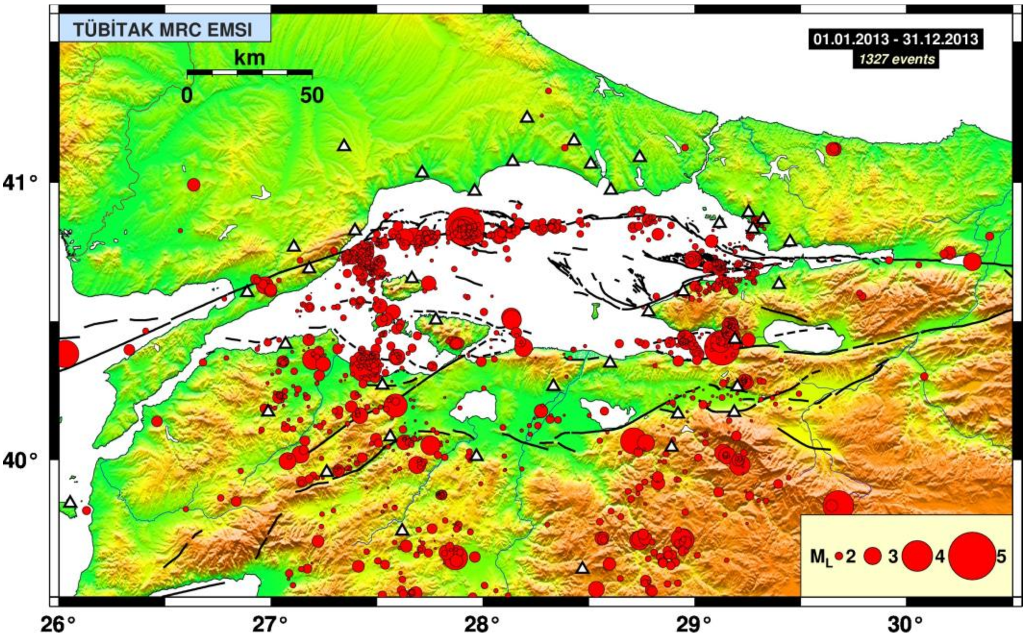


Figure 14: The microseismic activity in the Marmara Sea for 2013.

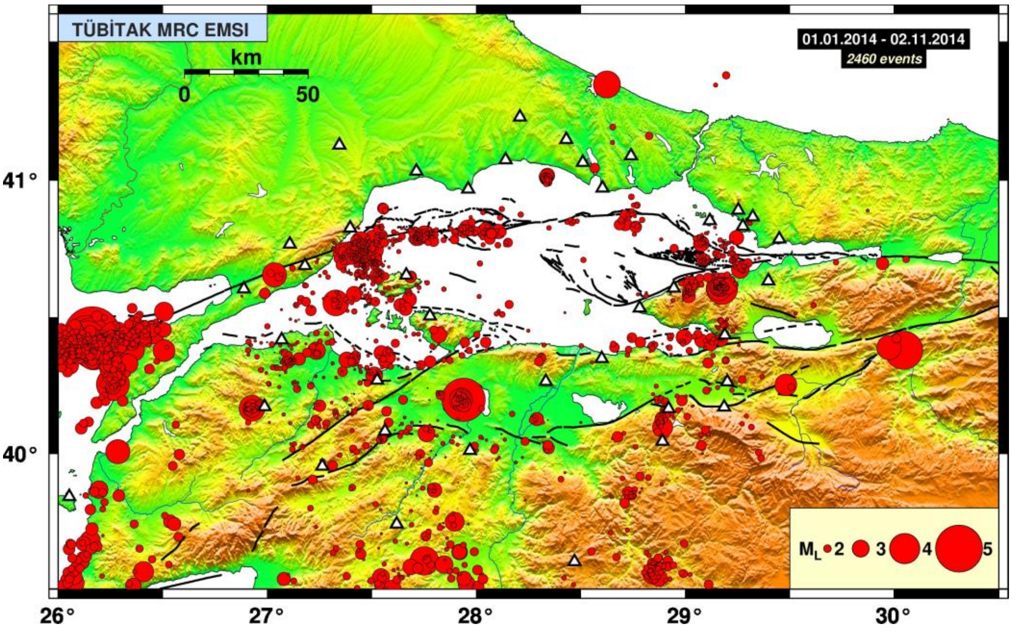


Figure 15: The microseismic activity in the Marmara Sea for 2014.

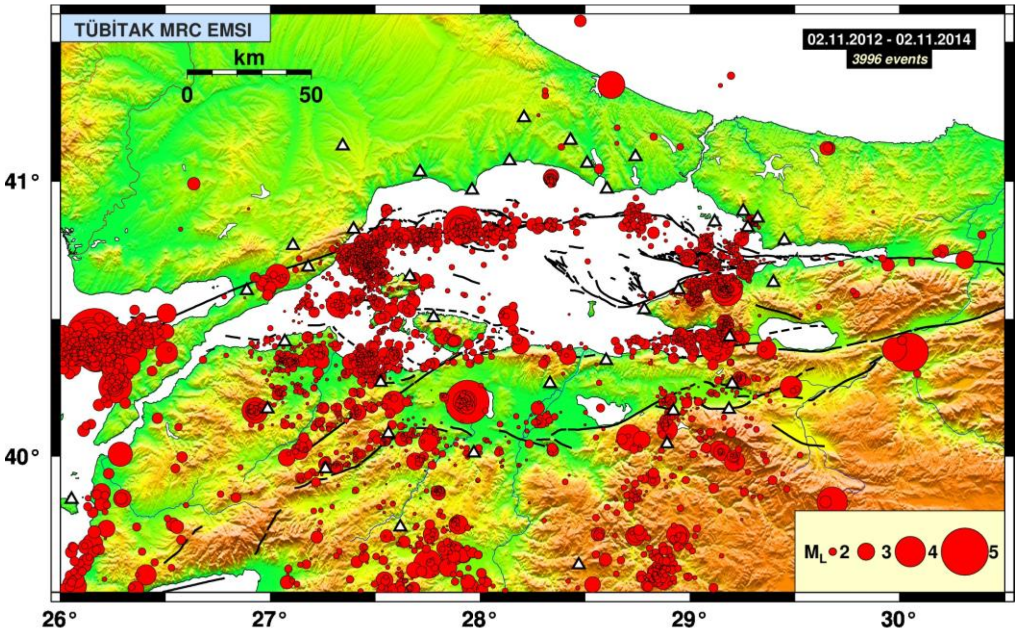


Figure 16: The microseismic activity in the Marmara Sea from the beginning of the Marsite to the present.

2.3.3. Determinations of the Physical Properties of the Geologic Formations in the Borehole:

After drilling the hole, firstly caliper log was performed for determining the radius of the hole (Figure 17). From the result of calisper test shows that the drilled bore is consistent with the initially set out specification, of which the diameter should be at least 185mm to wide enough to install borehole system. Then, SP log, gama log and sonic log (Figure 18) were performed to determine the geological formations. All the log results show that the lithology does not change so much down to the depth of about 500 feet.

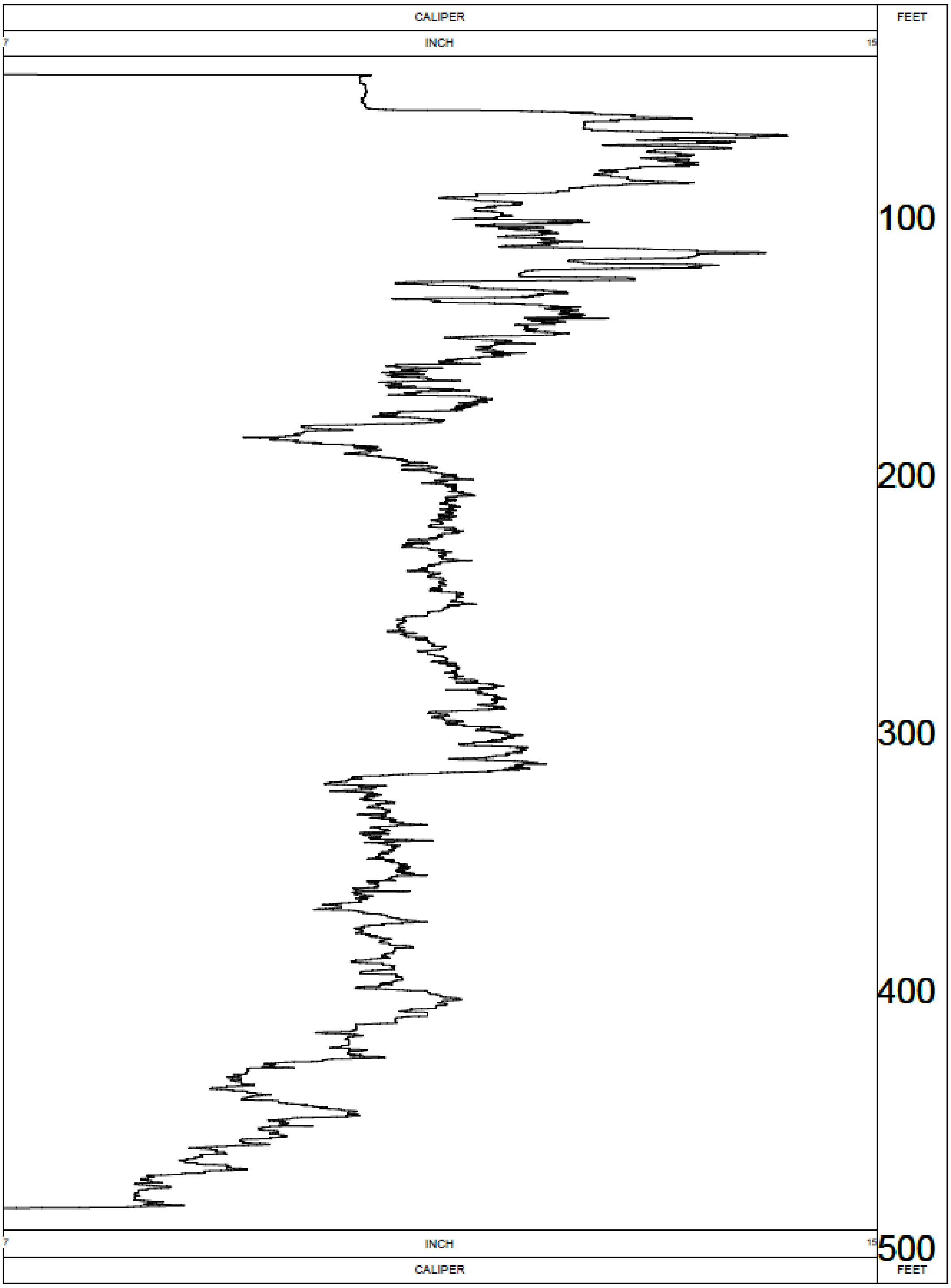


Figure 17. Caliper log result

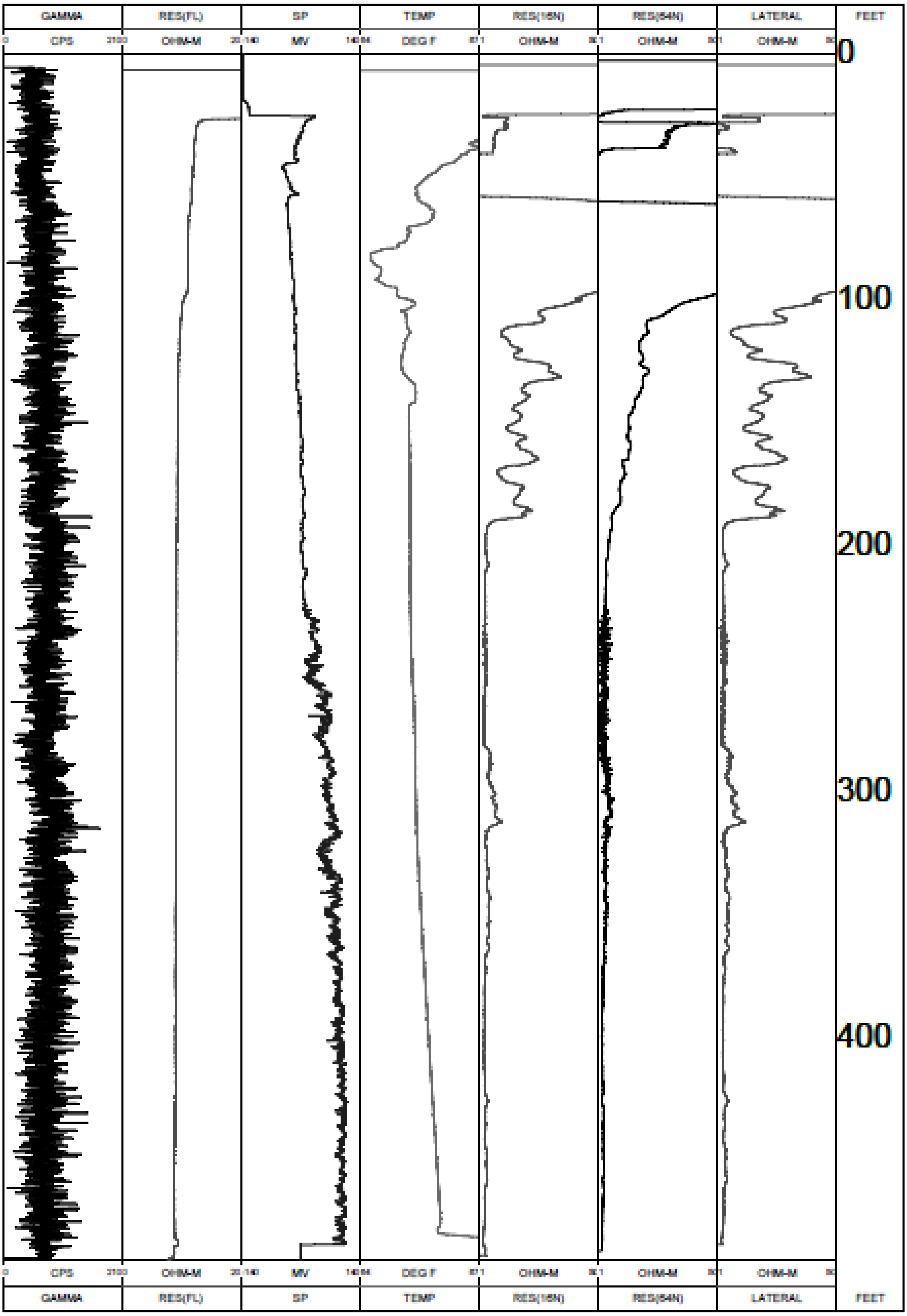


Figure 18. Gama log, SP log, temperature log and resistivity log from the right to the left, respectively.

Moreover, the magnetic properties of the formations from the samples taken by 1m in the borehole are determined and compared with the log results. The magnetic susceptibility results also show that lithology does not change in the borehole.

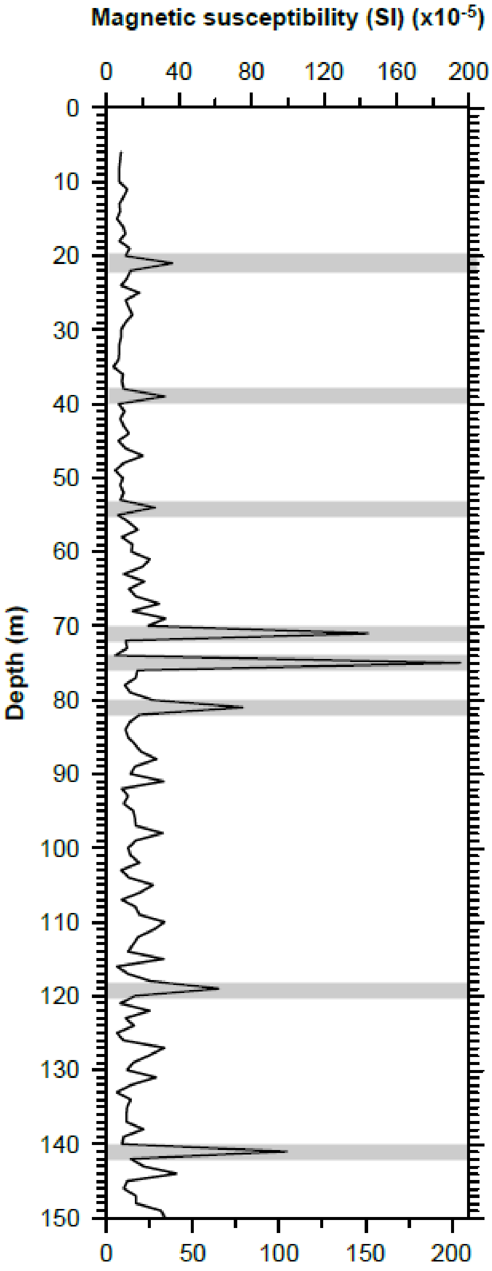


Figure 19. Magnetic susceptibility results

2.3.4. Borehole Instrumentation:

As for the borehole instruments; the design of seismometer, accelerometer, temperature meter, tilt meter are completed. The description of the work carried out for the multi-disciplinary borehole system is as follows.

The design and production of the first version of the borehole system is complete. The data for the first version borehole system after being tested in the GURALP test borehole has been presented in various Marsite meetings. The required and specified sensor noise performance, including the very high frequencies was achieved. The strong motion sensor that will be incorporated with in the borehole sensor is also finalised.

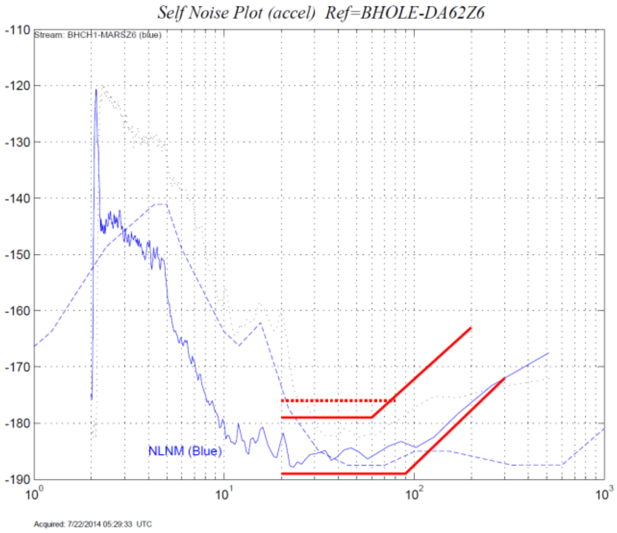


Figure 15: Noise performance for the very broad band seismometer in the borehole.

The tilt meter that will be used as part of the multidisciplinary borehole system is manufactured with the final assembly work being conducted. The sensor hole lock section is complete and has been tested with satisfactory results.

Both very broadband borehole sensor and the tilt meter “cable strain” relief mechanisms have been designed and manufactured. The cable strain-relief mechanism incorporates the power supply and the all the electrical transient protection circuitry for the sensor outputs and the control lines.

The cabling for all the sensors has been designed and the cables have been manufactured with all the appropriate waterproof connectors. Manufactured cable length is 200 meters for a 150-meter borehole.

The surface electronics, peripheral equipment and the acquisition systems have been manufactured and are ready to be shipped to Turkey

Two versions of the dilatometer design have been finalised and manufactured. The initial design after evaluation had to be redesigned so that the sensitivity of the strain gauge is increased and the dependence of the device to temperature variations is reduced.

- The increased sensitivity was achieved by reducing the diameter of dilatometer stainless-steel bellows in relation to the main detection reservoir diameter.
- The reduced temperature sensitivity was achieved by reducing the volume of silicone oil reservoir without changing the diameter or the length of the reservoir.

The second version of the dilatometer parts have all been manufactured and being assembled. The dilatometer will be ready to be installed at the end of 2014

These instruments were transported to Istanbul in October 2014 and meanwhile, drilling of the borehole was completed simultaneously with the installation of the systems. This process have been completed and in operation beginning from 19th October, 2014. The data are flowing to the Marsite Project server in KOERI and reachable for the project partners.

The further details of the borehole system and the significant results can be found in the second Annual Report 2014 prepared by Guralp Systems and is given in the Appendix.

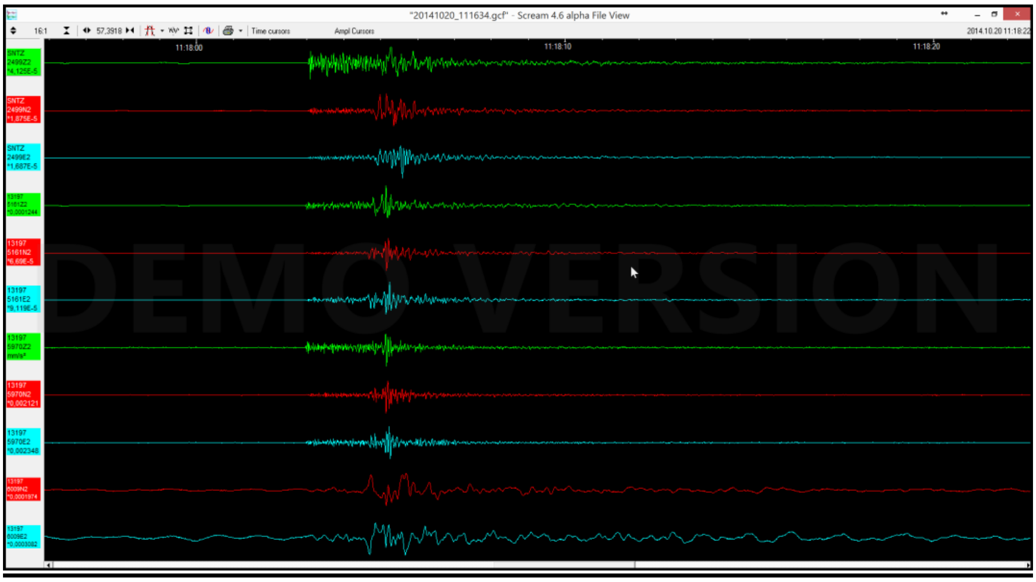


Figure 13: The event (M=1.9 on 20.10.2014) recorded by the borehole system. The top three channels belong to the broad band seismometer at the surface and following 6 channels are accelerometer’s 3-component channels and very broad band seismometer’s channels in the borehole, respectively, and the last two horizontal channels are from tiltmeter

APPENDIX 1

1. Work and Achievements:

- 146 meter deep borehole has been drilled, cased and cemented.
- Very high sensitivity two axis borehole tilt-meter design completed, manufactured and installed.
- Strong motion and weak motion 6 axis borehole very broad band (VBB) seismometer design completed, manufactured and installed.
- Surface borehole hut has been built over the well head as protection and to house the complete surface seismic station.
- All sensor outputs are digitised for a total of 11*24 bit-channels and 6*20 bit-channels and data transmission to Kandilli Observatory is accomplished.
- All installed instrumentation has detailed calibration documents including the measured and the theoretical frequency responses. The calibration values for the three axis accelerometer (TB5970), the very broad band seismometer (T35161), the tilt meter (8288T), the temperature sensor (8288 temp) and the digitisers (6185/A5191, 6186/A6008, 6187/A6009) have been documented in detail. For brevity we do not include any of this material is presented in this report, however the calibration information was provided to Kandilli Observatory.
- The second version of the dilatometer parts have been manufactured and 90 percent of the dilatometer is assembled. The dilatometer will be ready to be installed January/February 2015

Cased borehole

The 146 meter deep borehole was successfully drilled and cased. The internal diameter of the borehole is 155 mm. All sections of the casing are welded to each other to prevent fluid entry. Each weld is sealed with a bitumen based sealant.

The casing is cemented to the well wall for the length of the borehole. At the well head, the top of the casing reaches 30 cm above the cemented well head patch.

The deviation at the bottom of the borehole is less than 2 degrees from vertical. In addition, the complete length of the casing was surveyed with a borehole camera. The attached photo shows a camera of the bottom of the well. A weld seam in the casing and a small amount of water at the bottom of the borehole can be seen. The water level is measured at 145.60 meters depth.

As drilled, the well is consistent with the specification set out at the beginning of the project

High sensitivity two axis borehole tiltmeter

The tilt meter is installed with three jaw hole-lock (see photograph).

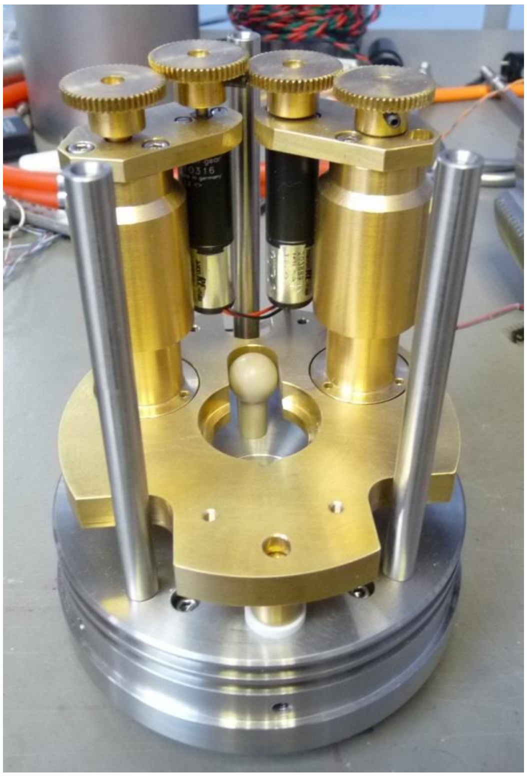
The sensor is installed at 145 meters depth. Immediately above we installed a cable strain relief mechanism with internal transient protection and a DC power supply.

The sensor system is powered from the surface with an isolated 24 volt DC power supply.

The two tiltmeter outputs are differential and transmitted analogue to the digitiser at the well head over a 200 meter long cable

Within the stainless-steel tilt meter housing we included a temperature sensor used to apply temperature correction to the tiltmeter outputs.

The high sensitive tiltmeter can be “zeroed” over a range of ±5 degrees using precision motorised micrometres. Each levelling motor can be controlled manually form the surface.



The internal two axes levelling motors and levelling platform is shown in the attached photo. All the internal parts of the tilt-mere are isolated with ceramic insulators against ground loops and also to provide the DC stability.

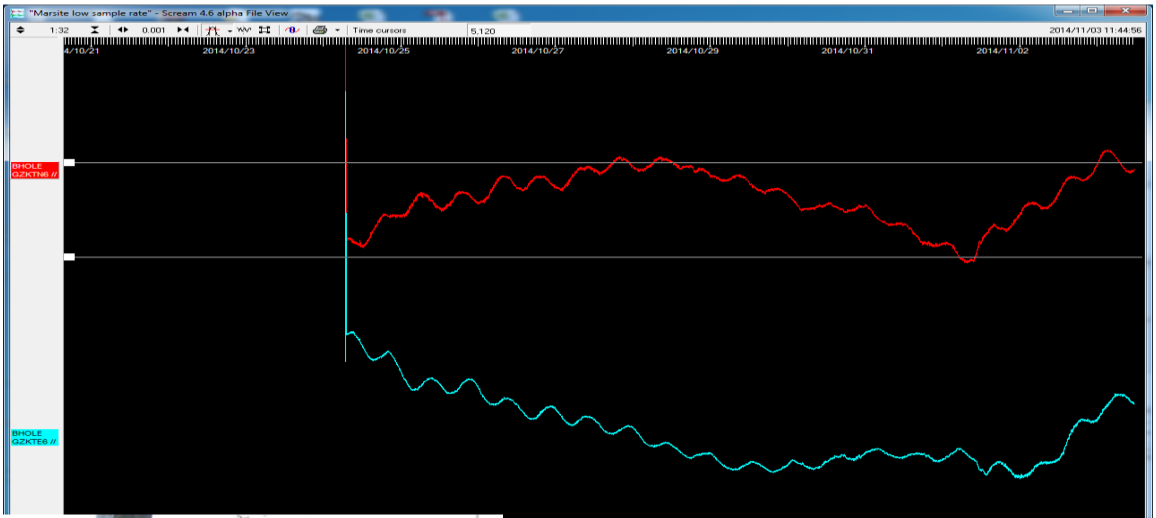
The sensor is lowered to depth with a 3mm diameter stainless-steel cable. This load bearing cable is attached to the signal cable every 5 meters.

The surface electronics consists of a break box with control switches to operate the levelling motors.

The breakout box provides a convenient method of connecting the tilt-meter to the surface 24 bit digitiser and the isolated power source.

The initial results form the measurement are very encouraging with the following conclusions:

- The sensor system was very easy to install and centring of the tilt meters could be accomplished down to the mV level.
- The stability of the tilt-meter is adequate to record “Earth tides”. The provided plot shows 10 days of data for both the X and Y axis of the tilt meter.
- Within the next three months the performance of the system will be characterised further.



Very wide frequency response VBB and 200 dB dynamic range borehole seismometer

The seismometer has the following specifications:

- 360 sec to 100 Hz Velocity Response. Plots of the sensor outputs are provided.
- ± 2 g strong motion sensor
- Broad band sensor and strong motion sensor outputs are differential. (balanced outputs)
- 89 mm diameter sensor housing for both sensors, as standard for GSL borehole sensors.
- ±4 degrees tilt compensation for all axes. The horizontal sensors have no cross axis component while the vertical even though is centred has cross axis component of maximum of 4 degrees.
- The CMG-5T stack signal ground is isolated from the sensor casing. Isolation is

simple with single Mylar sheet placed as a diaphragm between the 5T bulkhead and the 5T stack.

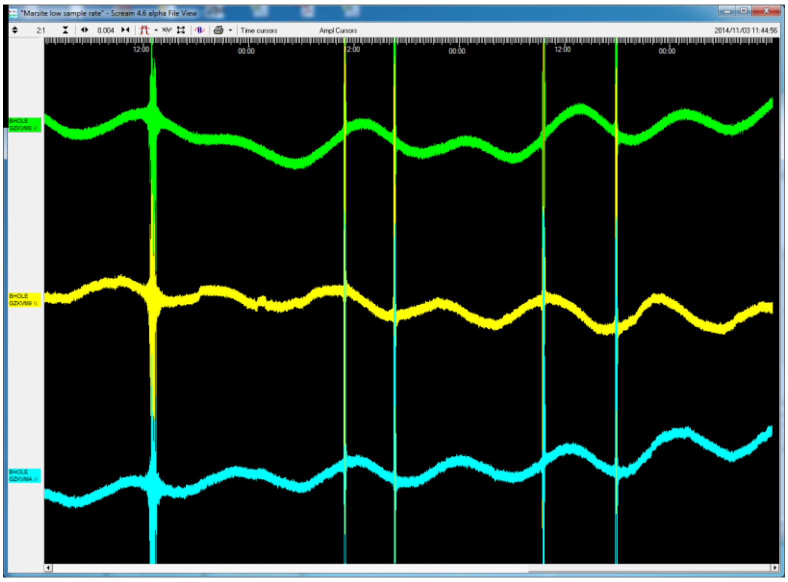
- Skids are installed at the top and the bottom of the sensor with parasitic resonances outside passband of the sensor.
- Single jaw hole lock suitable for 155 mm diameter borehole.
- Internal low resolution tilt-meter to measure the borehole casing tilt prior to installation.
- Installed with cable strain relief mechanism with transient protectors.
- Cable pass through mechanism to ensure that the tilt meter cabling can pass between the broadband sensor and the casing

Photographs showing the top of the borehole sensor with upper skids engaged in the borehole supported by the hole-lock. This photo also shows the cable pass through mechanism where the tilt meter cabling is passed without affecting the broad band sensor hole-lock operation.

The water proof connector and the cabling with moulding provided the system to operate in a wet borehole.

The cable strain- relief mechanism and the transient protector is installed about 1.5 meters above the broad band sensor.

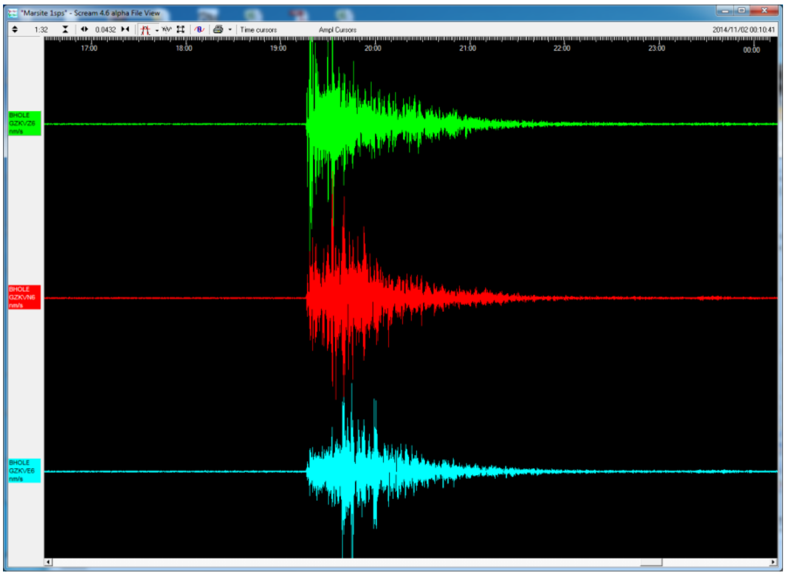
The broad band sensor mass position output for three days shows the recorded Earth tides. The 360 second sensor can record Earth- tides and frequencies up to 100 Hz. Many events have already been detected both with the broadband sensor and also the accelerometer. Given plots show the capability of the system.



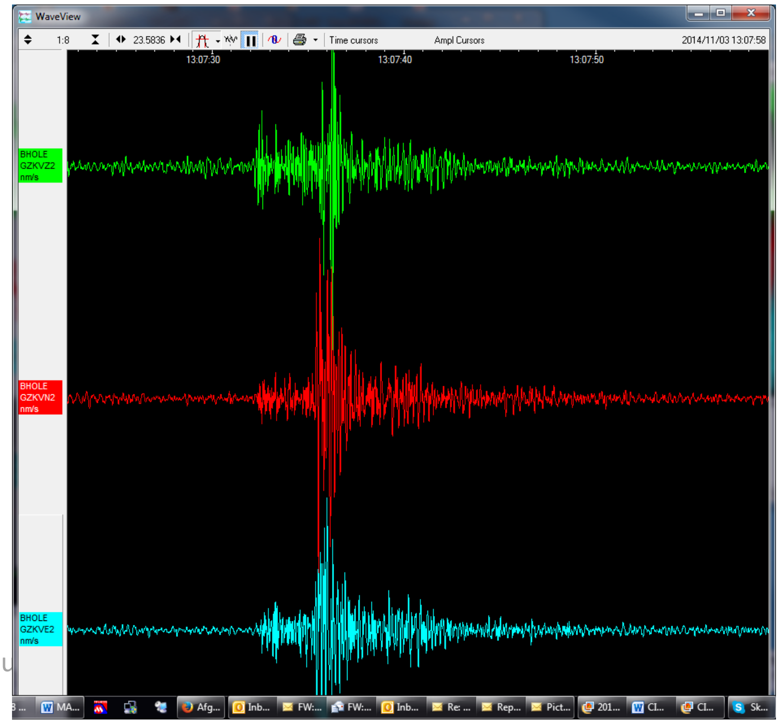
Tele-seismic event

7.1 in the Fiji Islands region;

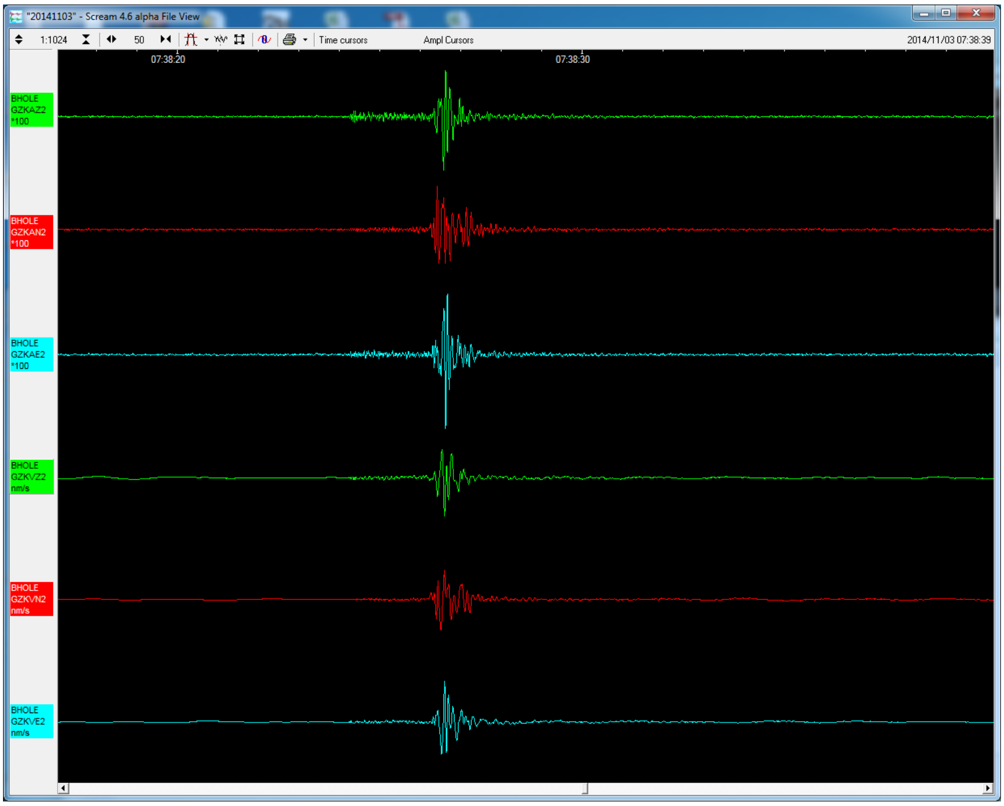
http://ds.iris.edu/ds/nodes/dmc/tools/event/4813335



Short period local event

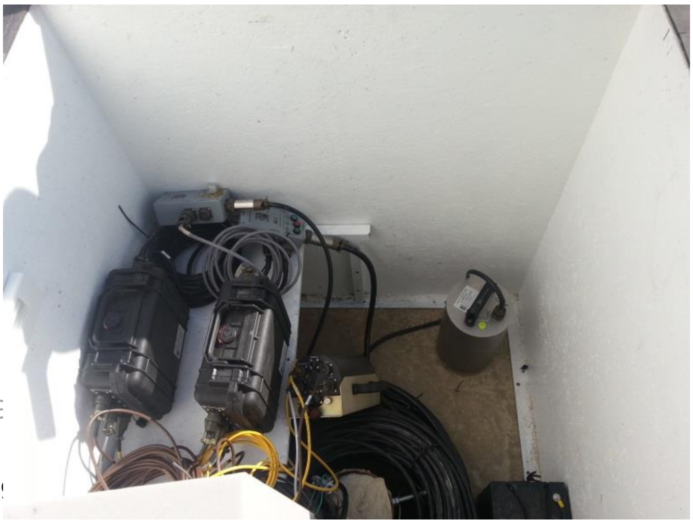


- **Short period local event recorded both the velocity sensor and the accelerometer**

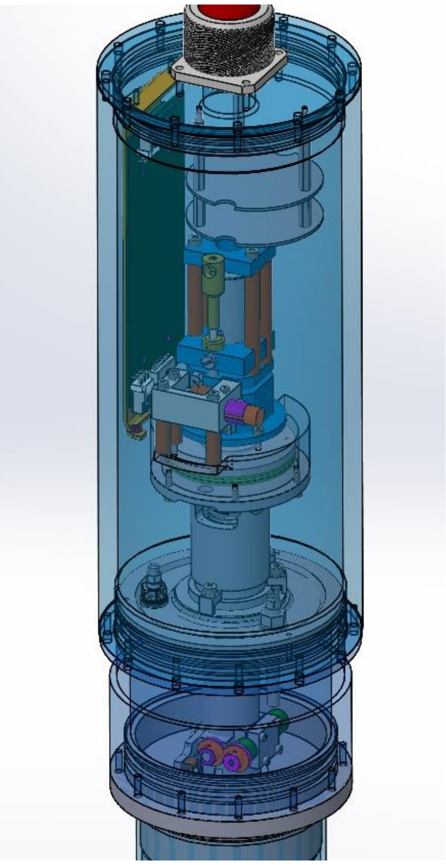


Surface borehole hut has been built over the well head

All digitisers, the data transmission system and the power supplies for the station are stored inside the borehole hut see photograph. The hut also houses a surface seismic, which is being used to compare signal gathered downhole with signals gathered at the well head. It was also used to determine the orientation vs. North/South of the borehole tilt meter and the borehole broad band sensor. The details of the complete station will be given beginning of 2015 once the dilatometer is installed.



Dilatometer



"*Two versions of the dilatometer design have been finalised and manufactured. The initial design after evaluation had to be redesigned so that the sensitivity of the stain gauge is increased and the dependence of the device to temperature variations is reduced.*

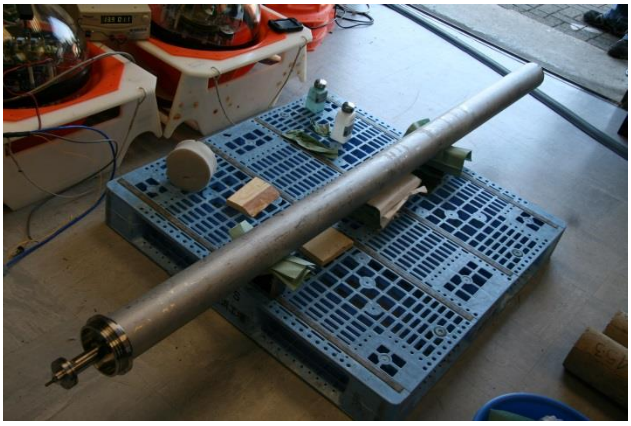
- *The increased sensitivity was achieved by reducing the diameter of dilatometer stainless-steel bellows in relation to the main detection reservoir diameter.*
- *The reduced temperature sensitivity was achieved by reducing the volume of silicone oil reservoir without changing the diameter or the length of the reservoir"*

The dilatometer gauge is being assembled for January/February 2015 installation.

The following photographs show three sections of the dilatometer, the reservoir one, reservoir two, and the capacitive linear displacement transducer mechanism.

The main reservoir which holds the silicone oil consists of 3 mm thick stainless steel casing with an internal tubing to create an annular space in between the inner tube and the outside casing.

Two sections of the reservoir are welded and there are no “O” ring or seals which can be compressed during “strain measurements.



The second reservoir section is used to bleed in or out the excess oil during the installation. Motor operated needle valve is used to equalise the internal and the external pressure during the installation stage of the gauge. Once installed and the installation cement has stabilised this needle valve in the second reservoir will be closed permanently. The photograph below shows the second reservoir and the motorised needle valve with limit switches.

The capacitive linear displacement transducer has sensitivity of 10,000 V/m.

The transducer can be nulled over a range of ± 5 milli-meters. The motorised transducer mechanical nulling device is operated form the surface break out box.