Impact of Fluid circulation in old oceanic Lithosphere on the seismicity of transfOrm-type plate boundaries: neW solutions for early seismic monitoring of major European Seismogenic zones

Chair of the Action: Dr Christian HENSEN
Editors: Paola Vannucchi, Astrid Ulbrich

Booklet of Short Term Scientific Missions

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Table of Contents

Report on the cruise participation CalaQuake14 in the Ionian Sea in May 2014 within the FLOW project

Katja Lindhorst

Within the frame of the FLOWS project I participated on the cruise CalaQuake14 with the Italian research vessel URANIA from May 9th to May 25th, 2014 in order to undertake sedimentological and geochemical sampling on sediment cores and to analyze relationships between active tectonics, fluid flow, and sedimentation. The working area was the Ionian Sea (Fig. 1). The main objectives of the cruise were to get a better understanding of the structural geology, active faulting, and historical earthquakes in the Calabrian Arc (Ionian Sea). During the cruise we covered an area of about 850 km² by means of multibeam data and sub-bottom profiles (CHIRP) were recorded over a total length of 2300 km (Fig. 1). The geophysical data sets were used to find suitable coring location in order to meet the scientific objectives of the cruise.

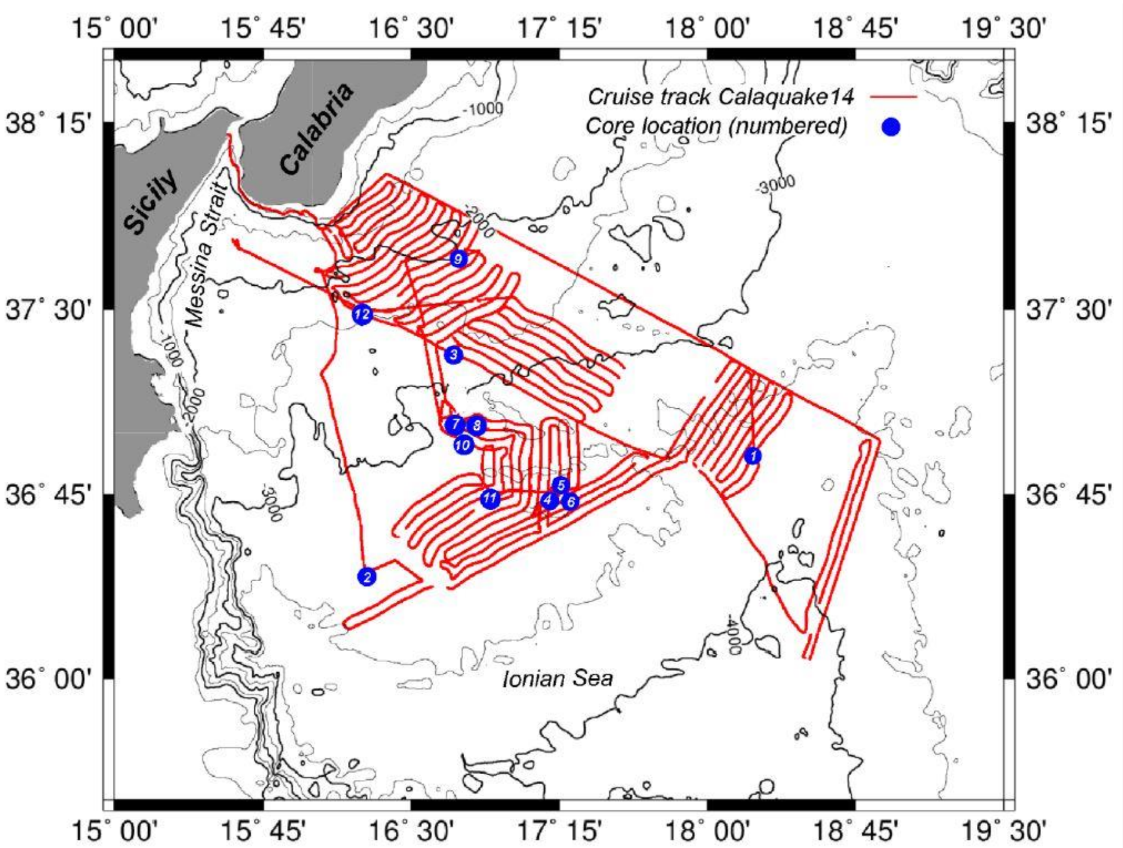

Figure 1: Track map of the cruise CalaQuake14 in May 2014 with the Italian Research Vessel URANIA.An overview of the sampled cores can be found in a table below.

The study area is a complex geological region because affected by active tectonic processes related to the convergence between Africa and Eurasia along the Calabrian Arc. This produces a wide area of deformation where three main deeply rooted fault systems accommodate shortening and margin segmentation (Polonia et al., 2011; Polonia et al., 2012). The subduction complex shows two distinct structural lobes characterized by different deformation rates and depth of the detachment level. The Ionian basin contains sedimentary sequences spanning from Jurassic to the present, that includes, in its upper part, about 2 km of Messinian (Late Miocene) evaporites overlain by Plio-Quaternary sediments mainly represented by turbidite layers.Sediment remobilization during the last millennia are mainly related to active tectonics and seismic shaking (Polonia et al., 2013a; Polonia et al., 2013b). The area is also well-known for several mud volcanoes that have been identified on the seafloor Praeg et al., 2009; Panieri et al., 2013; Ceramicola et al., 2014). However, ages of such mud volcanoes are uncertain. Coring during Calaquake14 aimed to get insights for a better understanding of fluid flux and the origin of methane within the sediments. In total, 12 sediment cores were recovered and sampled at the bottom of each 1m-section immediately after cutting the entire sediment core on deck. Sedimentological sampling included 3 ml sediment extracted by a cut-off syringe and stored in a glass bottle with 9 ml saturated salt water. The glass bottle had to be closed tidely to prevent any loss of methane and other gases from the sediments. Additionally, 3 ml of sediment was stored in a pre-weighted plastic tube to obtain the porosity of the sediment at each section. Unfortunately, we ran out of those pre-weighted cups while sampling core CQ14_07. Hence we took some more sample material in the plastic bottle that was meant to analyze the absorbed gases (10 g). The first step onboard in the lab was the measurement of magnetic susceptibility on each section by means of a Bartington MS2. Values for magnetic susceptibility were then used as a first tool to guide pore-water sampling and stratigraphic correlation because pattern of magnetic susceptibility curves within this region are well-known and can be correlated to the stratigraphy of the uppermost sediments. For example, the so called HAT, a Megaturbidite that can be found in the deeper parts of the Ionian Sea is characterized by gently increasing values of magnetic susceptibility with a sudden decrease below its base (Polonia et al., 2013a). Using this interpretation we assumed to cover the entire HAT in core CQ14_01. This specific core were subsequently sampled every 10 cm by means of pore-water sampling. All remaining cores were sampled 3 times within each section and, with some exception in very short cores, we sampled at 25 cm, 50 cm, and 75 cm core depth of each section. All pore-water samples were subsampled onboard in order to extract material for measuring the content of isotopes, trace metals (ICP-AES), and the geochemistry of the sediments. All samples were stored in a fridge onboard and shipped to GEOMAR Kiel immediately after arriving in Naples.

Geochemical analysis of pore water and sediments can contribute to explain the origin of methane in the sediments, e.g. by their isotopic signature. High methane content is a good indicator for recent activities and fluids rising up along active faults and subsequently erupting in mud volcanoes.

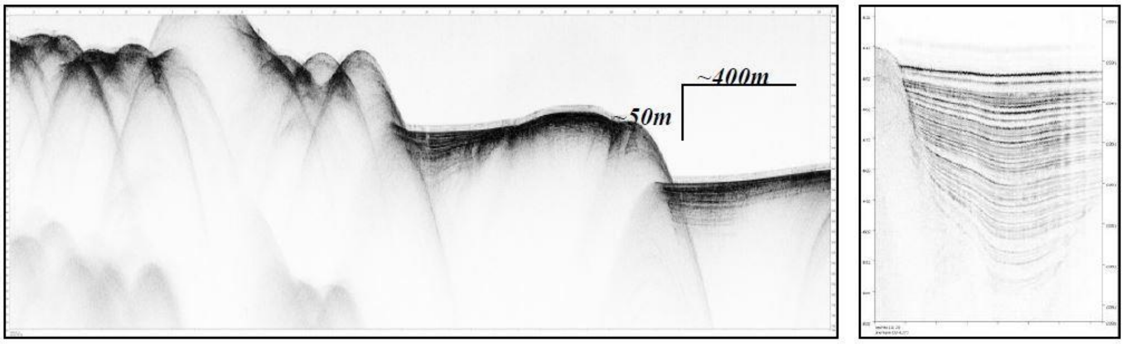

Figure 2: Example of a Chirp profile. (left) tectonically induced basins filled by sediments within an overall hummocky topography. (right) example of an infill characterized by layered sediments within a basin.

Figure 3: Photograph showing the pore water sampling in the lab on board of RV URANIA. We took samples every 10cm on the first core. In subsequent cores only 3 times per section were sampled.

NAME	LON(ddmm.)E	LAT(ddmm.) N	Depth	Heading	Penet.(m)	Recover (m)
CQ14_01	1814.146828	3654.80146	3793	258	10	8.4
CQ14_02	1617.627214	3626.28346	3356	185	7	6.7
CQ14_03	1642.950897	3720.962858	2752	247	10	7.16
CQ14_04	1712.448302	3645.354277	3473	327	10	7.6
CQ14_05	1711.786741	3645.430651	3472	280	10	8.05
CQ14_06	1714.433312	3645.140663	3417	271	10	7.76
CQ14_07	1645.723147	3702.436100	3465	144	10.2	7.44
CQ14_08	1645.538338	3703.041039	3310	102	7.8	7.22
CQ14_09	1646.693486	3743.850847	2273	106	8	5.54
CQ14_10	1645.349874	3704.085527	3090	237	10	7.8
CQ14_11	1654.430564	3644.133826	3333	283	10	8.38
CQ14_12	1615.945932	3729.404166	2257	322	3.5	2.14

Table3: Cores collected during CALAQUAKE2014, location, penetration, etc.

.

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Isotopic Analysis on Peridotites from Ronda Massif

Maria Isabel Varas Reus

Purpose of the STSM

Peridotite massifs represent pieces of subcontinental mantle emplaced into continental crust. Through the combination of structural, petrological and geochemical investigation of these massifs exposed on surface, it is possible to put constrains on the composition and the processes occurring in the deep mantle lithosphere. The data obtained from peridotite massifs are complementary to the data provided by geophysical observations and indirect geochemical evidence, provided by extruded primitive volcanic rocks. The scope of my FLOWS STSM was to investigate the interaction between fluids and lithospheric mantle through the use of geochemical tracers in the Betic-Rif peridotite massifs (western Mediterranean region). These massifs constitutes the largest exposure of Subcontinental Lithospheric Mantle (SCLM) in the world, and hence offers unparalleled opportunity to unravel how fluids interact within the upper mantle, trigger melting and modify its rheological and seismic properties. Previous research (Reisberg and Zindler, 1986, Reisberg, 1988, Marchesi et al., 2012, Varas-Reus et al., 2014) has shown that the Betic-Rif lithospheric mantle interacted with large amount of fluids, likely of crustal origin, placed in a supra-subduction setting.

Description of the work carried out during the STSM

During the three months of my stay at the Géosciences Montpellier lab (Montpellier, France), I have performed the preparation and analysis of the radiogenic isotopes of Sr-Nd-Hf-Pb in a large scale sampling of the Betic-Rif peridotite massifs. First of all, it was necessary to carry out a mineral separation in the selected samples to obtain pure separates of clinopyroxenes. The samples were crushed and sieved in the dependences of the Instituto Andaluz de Ciencias de la Tierra (IACT, Granada, Spain), recovering the mineral fraction 180-250 μm mesh, followed by magnetic separation. This separation was done using the Frantz isodynamic separator©, located also on the premises of the IACT. The necessary weight for each mineral fraction was determined by the concentrations of Sr, Nd, Pb and Hf in the clinopyroxene, and was approximately 100 to 200 ng. These concentrations were measured by Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS) in the Geósciences Montepellier Lab. The processing of the samples continued during my STSM in Montpellier, though a selection of ultra-pure mineral grains, in this case, clinopyroxenes, which are handpicked in alcohol under a binocular microscope. The grains of clinopyroxenes were then ultrasonically washed several times in alcohol and Milli-Q water. At this stage, mineral separates were very pure and only flawless minerals, free of cracks and visible inclusions. The last step consisted in crushing the minerals in an agate mortar. After this, samples were kept for isotopic analyses.

After powdering, samples were leached for 30 min at 110ºC with 6N HCL. Then the residues were rinsed two times with purified milli-Q H2O. Subsequent to leaching, samples were dissolved during 36-48 h on a hot plate with a mixture of HNO3, HF and HClO4. After evaporation to dryness, 2 cc of HNO3 13N was added to the residue and put in a hot plate for a second evaporation. Chemical separation of Pb was conducted using the AG1X8 anion exchange resin, 200-400 mesh. After complete evaporation of the samples, 0.1 ml of 8N HBr was added to the samples and kept at 110˚C for another complete evaporation. Following evaporation, 1 cc of 0.5N HBr was added and loaded to the columns. Lead was then eluted in 6N HCl. Sr was separated using an extraction chromatographic method modified from (Pin et al., 1994). Nd isotopes were separated following Richard et al. (1976), including a first step of REE separation (using the AG50X8 cation exchange resin, 200-400 mesh). Hafnium chemical purification followed the method outlined by Blichert-Toft et al. (1997). Average Nd, Sr and Pb concentrations in procedural blanks were less than 8, 36 and 60 pg respectively. Nd, Pb and Hf isotopic compositions were measured by Multi-Collector Inductively Coupled Plasma Mass Spectrometry (MC-ICP-MS). Hf isotopes were measured by a Nu Plasma 1700 instrument, and Pb and Nd isotopes by a Nu Plasma 500 device, both MC-ICP-MS located at the Ecole Normale Supérieure de Lyon (France). Pb isotope compositions were analyzed using the Tl normalization method described by White et al. (2000). Sr isotopic ratios have been measured by a ThermoFinnigan Triton T1 Themal Ionization Mass Spectrometer (TIMS) at the LABOGIS of the Centre Universitaire de Formation et de Recherche in Nimes (France). These analyzes will be completed by the personal in charge of the TIMS during the next weeks.

Description of the main results obtained

With all the obtained data, we will be able to understand the length scales and fluid-lithospheric interactions, and we will manage to put constrains in the fluid migration mechanism in the upper mantle. This study will allow, for the first time, to obtain a direct mapping of migration of crustal fluids in the Betic-Rif lithospheric mantle, and, in combination with the available structural and petrological data, to infer how this type of fluids can modify the structure, composition and seismic properties of the SCLM during subduction initiation.

Future collaboration with the host institution

Géosciences Montpellier is among the world's best reputed geochemical laboratories, equipped with cutting-edge analytical instruments, ultra-clean rooms and sample preparation facilities. This project has represented an invaluable opportunity to be trained in the use of a number of state-ofthe-art geochemical instruments and to develop isotope tracers for the characterization of mantle processes. Dra. Delphine Bosch (manager of the geochemical clean lab in Geosciences Montpellier) is co-director of this PhD thesis, so Géosciences Montpellier is among the world's best reputed geochemical laboratories, equipped with cutting-edge analytical instruments, ultra-clean rooms and sample preparation facilities. This project has represented an invaluable opportunity for the PhD student to be trained in the use of a number of state-of the-art geochemical instruments and to develop isotope tracers for the characterization of mantle processes. . Dr. Delphine Bosch (manager of the geochemical clean lab in Geosciences Montpellier) is co-director of this PhD thesis, so her participation in the development and completion of this research is guaranteed. Collaborative work between the host institution and our scientific group in Spain will continue in the next years in this and other research projects.

Foreseen publications/articles resulting from the STSM

Once the data obtained during the STSM will be processed and interpreted, they will be published in several papers in highly internationally-reputed journals in Earth Sciences ((e.g., Journal of Petrology, Geology, Chemical Geology) and presented in international geological congresses (e.g., American Geophysical Union Fall Meeting, European Geosciences Union General Assembly, Goldschmidt Conference) .

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Advanced processing techniques applied to MCS profiles across large structures of the Alboran Sea (Western Mediterranean)

Laura Gómez de la Peña

Purpose of the STSM

The objective of this STSM was to perform Pre-Stack Depth Migration (PSDM) in selected multichannel seismic profiles (MCS) from the Alboran Basin (Western Mediterranean). The seismic dataset was acquired during the TOPOMED-GASSIS cruise (Fall 2011), with a long streamer and large source and are of high quality. The aim of doing PSDM is to obtain the real geometry of the tectonic and sedimentary structures in depth. Having an image in depth, our objectives are (i) to characterize theses important fault zone areas, (ii) to identify active structures and its seismogenic potential and (iii) to study fluid flow related processes. Due to the acquisition geometry, these seismic data have good resolution and they are especially interesting to image the depth structure. For this reason, the detailed analysis of this dataset is a great opportunity to relate the regional processes that led to the basin formation and active tectonics with the lithosphere dynamics.

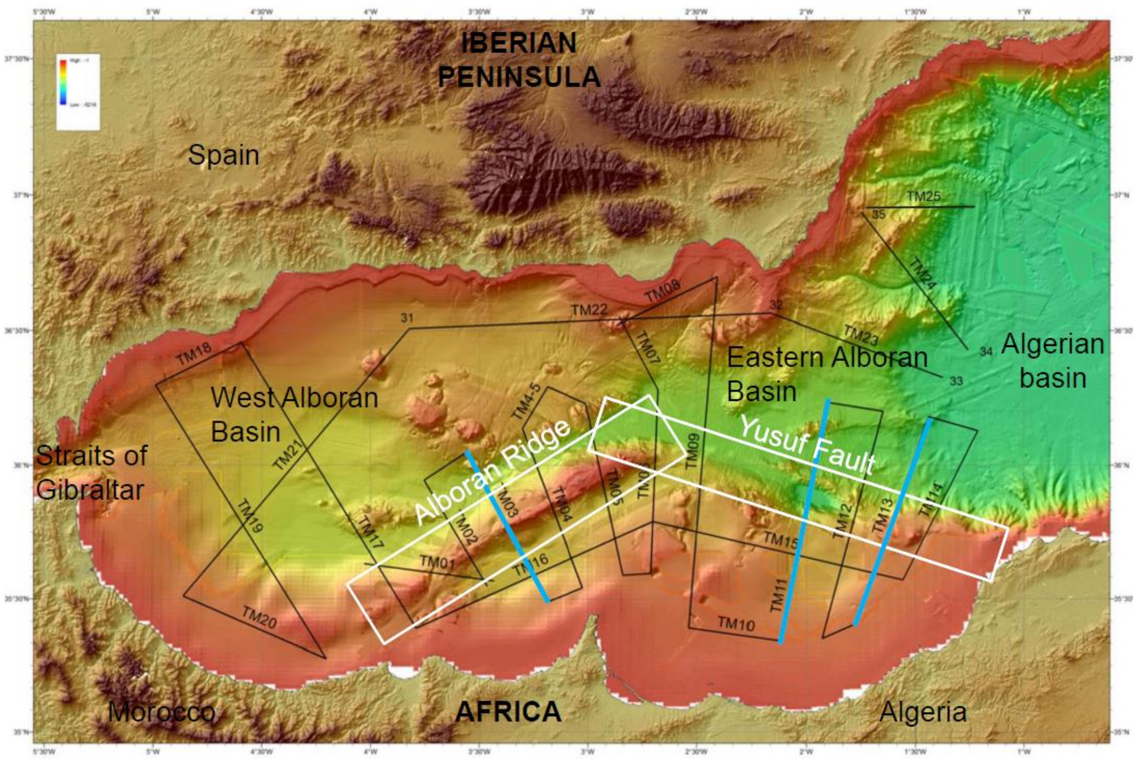


Fig. 1: (previous page) Bathymetric map of the Alboran Basin, with location of the TOPOMED-GASSIS (2011) multichannel seismic profiles. Main basins and structures are located. The thick blue lines correspond to the proposed MCS for PSDM.

Because of the complexity of the Alboran Basin, we focus our study in two areas: (i) the Alboran Ridge (TM03, Fig.1) and (ii) the Yusuf Fault (TM11 and TM13, Fig.1), in order to characterize these important active fault zones involving the basement of the basin.

The main goals of this STMS were

-Learn how to use the software “Echos”, in order to obtain seismic images in depth.

-Perform PSDM of the selected profiles, to characterize the main structures and fluid related processes in these two important fault zones.

Description of the work carried out during the STSM

Along these two months working at the Istituto Nazionale di Oceonagrafia e di Geofisica Experimentale (OGS, Trieste, Italy), mainly I had learnt how to deal with the seismic processing software “Echos”. To obtain a better result, we also had performed some additional processing to my data using Seismic Unix (SU). All this work had been done under the supervision of Dr. Michela Giustiniani and Dr. Umberta Tinivella.

The base of a good PSDM is a good velocity model. Velocity analysis had been carried out in three steps, in order to obtain the better results as possible:

1) Velocity analysis in time domain.

2) Velocity analysis in time migrated domain.

3) Velocity analysis in depth migrated domain.

This velocity analysis has been done with the module “Geodepth velocity modeling”, trough semblance analysis. This analysis consists on finding out the right velocity looking for the maximums of energy. Once we have our first velocity model in time, we can update it using the residuals analysis. This is a precise analysis in which we are looking for the difference between our current velocity model and the real one, doing a semblance analysis. In this way, we are able to adjust little variations of the velocity, improving our velocity model in order to obtain the better result as possible. The residuals analysis is done in time domain, time migrated domain, and, finally, in depth domain.

All this work with the velocities is necessary because having a good velocity model is essential to have a good final image in depth. The output of the PSDM are Common Reflection Point gathers (CRP). The last step to obtain a PSDM migration section has been processing and stacking this CRP. To sum up, the whole processing flow applied to the data is shown in Table 1

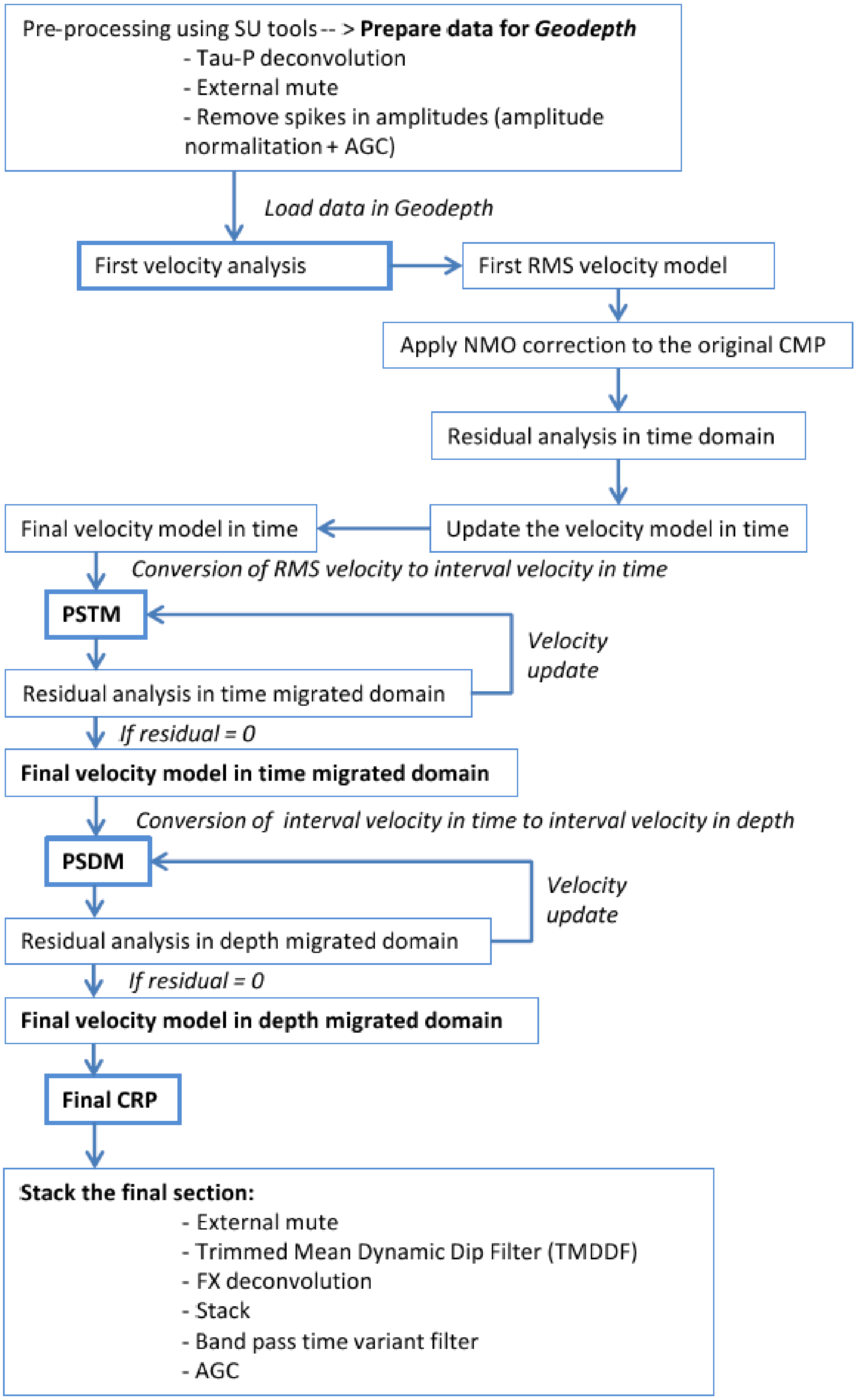


Table 1: Main steps of the processing flow done in order to obtain a PSDM. PSTM: Pre-Stack Time Migration. PSDM: Pre-Stack Depth Migration.

Main results obtained

Proposed three profiles for PSDM was an ambitious objective, because of the amount of time necessary to obtain a good result. Furthermore, we had some problems in order to perform the PSDM, technical problems with the software and also problems with noise in the data. Nevertheless, we have worked in the three sections, and we finished two of the three profiles proposed. In addition, I have learnt how to use new processing softwares (Echos and Seismic Unix) and how to perform a good PSDM, developing in this way my skills in seismic processing. For these reasons, I think that the STMS has been satisfactory not only in a scientific approach, but also from a personal point of view.

The main results of this STMS are two profiles in depth, which show an image in depth of two of the main structures in the Alboran Sea – the Yusuf Fault (TM11, Fig. 2) and the Alboran Ridge (TM03, Fig. 3). Depth migration is done with an interval depth velocity model which allows lateral changes in the velocity field. This changes are not well defined in time, so in presence of strong lateral velocity variations (like in our study area) the PSDM is more accurate that a migration in time. These PSDM sections not only image the real geometry of the structures in depth, also allow us to improve the characterization of the sedimentary infill of the basin. In the depth image, the contacts between the different sedimentary units and its internal structure are much clearer than in the previous one in time.

These new data are going to be very useful in the determination of the kinematics of these areas, and also in the characterization of the tectonic and sedimentary processes that are affecting them.

Future collaboration with the host institution

The collaboration with the host institution has been useful and productive. Due to the good results obtained, the host institution has proposed a second stay. The aim of this new collaboration will be to perform real amplitude processing to my data, in order to characterize the fluid content. To do that, I will learn the Amplitude Versus Offset (AVO) analysis technique.

We are considering this possibility, taking into account the objectives of my PhD and the expected results of the AVO analysis.

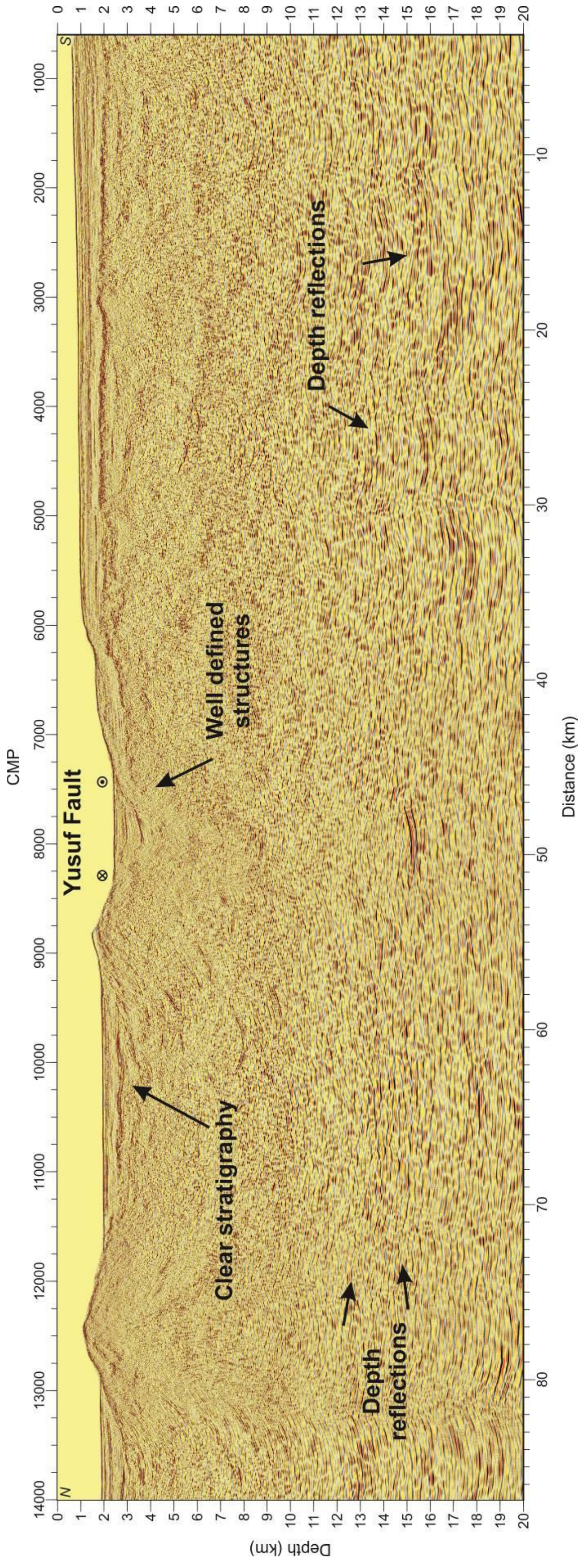


Fig. 2: Result of the PSDM of line TM11. Main structures are depicted.

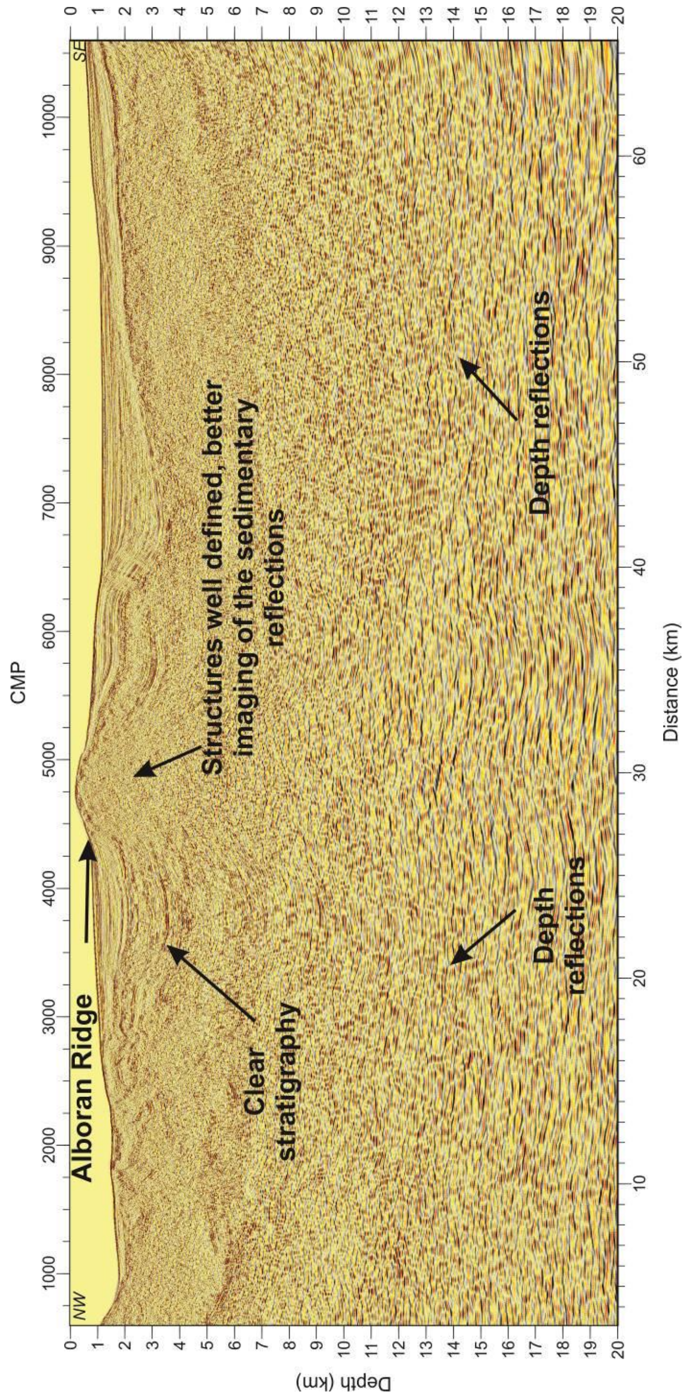


Fig. 3: Result of the PSDM of line TM03. Main structures are depicted.

Foreseen publications/articles resulting from the STSM

Currently, we are working to finish the PSDM of the third section proposed, and also in the interpretation of the sections. These three images are located in an area were no depth MCS is published, so we expect to present the results of the interpretation of this sections in a scientific article.

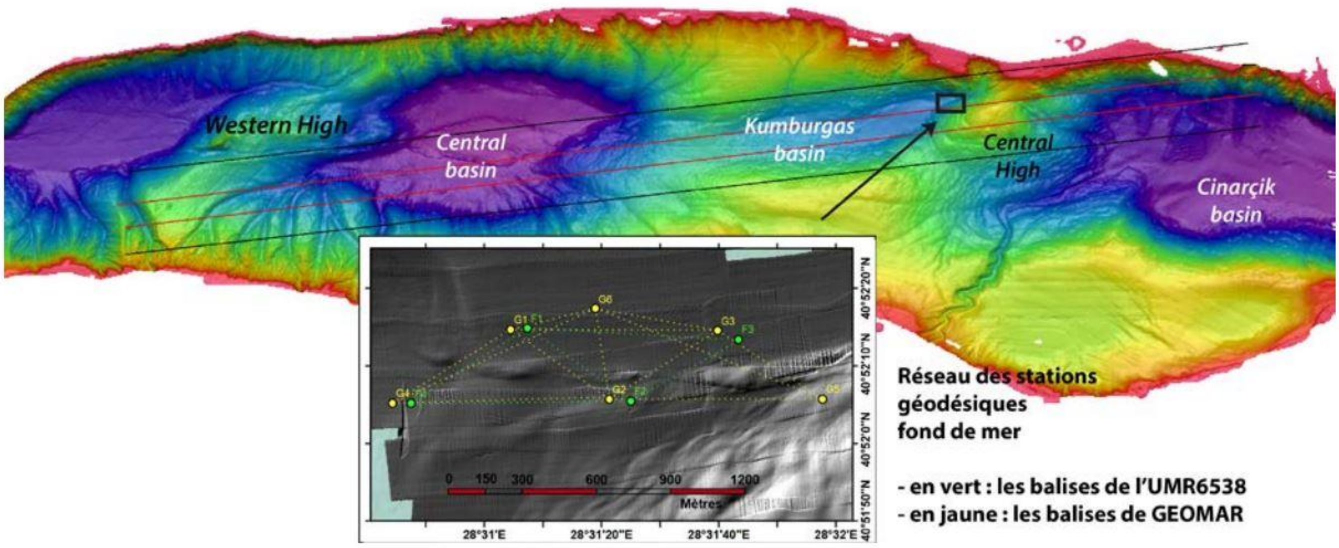
Sea of Marmara geodesy and geohazard

Pierre Henry

The objectives of the short-term scientific missions “Sea of Marmara geodesy and geohazard” were to combine participation to a research cruise on Ifremer vessel « Pourquoi Pas ? » with a stay at ITU to work with Sinan Ozeren, and Nazmi Postacıoğlu to pursue work on data acquired at sea and to set up a new collaborative project between ITU and my institution. The “Pourquoi Pas ?” cruise comprised three Legs. I participated to Leg 1 (Oct 29-Nov2) and lead Leg 3 (Nov 13-Nov 16) as chief scientist. The main objective of Leg 1 was to install a network of acoustic ranging beacons on the Central Marmara Segment of the North Anatolian Fault, which is suspected to present aseismic creep (Ergintav et al., 2014). This deployment, planned for 6 years is the first attempt to measure fault creep with a seafloor geodetic network. Coring aimed (1) at sampling reference stratigraphic horizons to ground truth seismic stratigraphic interpretations and estimations of fault slip rates (Sorlien et al., 2012; Grall et al., 2013) (2) at sampling seismoturbidites at sedimentary basin depocenters for paleoseismological studies. During Leg 2, I stayed in Istanbul to work with Turkish colleagues on fine tuning of the coring plans, on the treatment and interpretation of pressure time series, and on the set up of a project for the 2015 march ANR/TUBITAK joint call for Turkish-French collaborations. Two geodetic networks were jointly deployed in the Sea of Marmara by IUEM Brest (Anne Deschamps) and GEOMAR Kiel (Joerg Bialas) teams and the first three weeks of data downloaded trough acoustic modems during Leg 3. The installation was successful, with all 4 IUEM beacons and 6 GEOMAR operational and communicating. Baseline lengths ranged 400 to 900 m and a precision better than 5 mm was achieved on all baselines, with good stability of bottom water conditions and beacon tripod stands. As the geological fault slip rate is 18±3 mm/yr, aseismic creep occurring at only a fraction of this rate may be detected in the time frame of the experiment. Geomar RV Poseidon will retrieve the first 6 months of data in 2015. A total of 4 long cores were taken for paleoseimological studies in Kumburgaz and Imrali Basin. Long cores wee taken with tubes of nominal length 24 m and recovery was excellent (exceeding 20 m) for three of them (exceeding 20 m). In addition, 3 interface cores about 1 m length were taken at these three sites. Cores targeting reference stratigraphic intervals were also mostly successful. One key horizon, which is hypothetically associated to MIS 5e/5d transition, has been reached at least at three different sites near topographic highs in the western and eastern regions of the Sea of Marmara. Coring of older horizons on eroding slopes was attempted with shorter (12 m) tubes and a total of 9 cores were thus taken for stratigraphic correlation objectives. Cores have been shared between ITU and CEREGE and several Master and PhD students from both institutions (this includes Julia Kende at CEREGE), will be involved in post-cruise work on cores.

At the end of the cruise, a press conference was held at the former French Embassy in Istanbul, which gathered most project partners, and the last two stays of my stay were spent at KOERI (Kandilli Observatory Earthquake Research Institute) for the MARSITE EU FP7 general assembly. Spectral analysis of Differential Pressure Gauge (DPG) time series from

Ocean Bottom Stations deployed in the Sea of Marmara could be initiated during my stay at ITÜ, but then required complementary information on sensor type and calibration from KOERI and GURALP. The records were then compared with absolute bottom pressure records acquired in Tekirdağ basin in 2007. In spite of different sensor specifications, two peaks in the power spectrum (24 and 40 minutes) were observed in both data sets, and likely correspond to resonant oscillations in the water column. The fundamental seiche oscillation mode in the Sea of Marmara is, however, of longer period. The records examined also contain a magnitude 5 earthquake, which induced pressure variations at the sea floor within a broad frequency range, but apparently did not trigger resonant oscillations. Work will be continued with Sinan Özeren and Nazmi Postacıoğlu with the objective to submit a publication in 2015.



The outline of a joint ANR-TUBITAK project has been submitted to the ANR website before the November 18th deadline. The French and Turkish parties must now submit the full proposal in March 2015. Meetings during the cruise and during my stay in Istanbul have been essential to build the partnership on the Turkish side with Namik Çağatay (ITÜ) as coordinator, and to define the main tasks of the project, named MAREGAMI for MARine Earthquake Gap Assessment and Monitoring for Istanbul. This project focuses on specific developments in marine geosciences for earthquake hazard assessment that comprise core analysis, tsunami and sediment transport modeling, geodesy, seismology and long term monitoring.

Sea of Marmara geodesy and geohazard

Julia Kende

The Short Term Scientific Mission I just achieved in Turkey from October 27th to November 19th had many purposes: - Joining the first Leg of the Marsitecruise mission in the Sea of Marmara on board of the N/O Pourquoi Pas ?. During this Leg, focused on the deployment of geodetic sonar beacons, we were planning on acquiring some new sub-bottom profiles to precise the coring targets for the 3rd Leg. - Working at the Istanbul Technical University (ITU) with Mr. Sinan Ozeren on the calculation of the lithospheric elastic thickness in the Marmara area. - Finally, to be fully involved in the 3rd Leg of the Marsitecruise mission for last-minute decision, core recoveries and sub-bottom profile processing on board. Most of this objectives were fully completed and should lead to future work and publications. During the first Leg, I was assigned with a shift at the numerical on board journal: eight hours a day, I was in charge of keeping it up-to-date. I made good use of this duty, using it as a way to enquire about the technical details of the various operations carried on: OBSs and bubble acoustic recorder (BOB) deployment, geodetic beacons deployment, configuration and testing and multibeam surveys. Unfortunately, the Leg schedule and itinerary did not allow us to include some sub-bottom surveys around the 3 rd Leg initial coring targets. However, due to a problem with the ROV/VICTOR (the main cable was damaged), no dive was carried during the first Leg and, as a replacement, we headed to the Kumburgaz basin to retrieve two cores for seismoturbidite studies. After processing and analyzing a sub-bottom profile on the expected locations, we decided to move one of the targets to avoid layers possibly rich with gas. The other core was extract at the same location as the MarnautMNTKS21 core in order to perform some magnetic susceptibility anisotropy analysis on a fresh core. The ship crew was in charge of the coring but, with people from the Mineral Research & Exploration General Directorate in Ankara, Pierre and I took care of cleaning, indexing, cutting and storing the core sections. As the ROV dives had been canceled during Leg 1, I managed to stay in the Pourquoi Pas ? for the first two days of the second Leg. I was included in one of the ROV shift and assisted Hélène Ondréas for image extractions and annotations during the coring of short sediment columns and the verification of the geodetic beacon correct states (straight positioning and not too much sunk in the sediment). While the 2nd Leg was carried on, Pierre and I were working at the Istanbul Technical University. The first days were spent with Gulsen Ucarkus, Namik Çağatay and Kadir Kürşad working on last details for the third Leg, more precisely on the exact location of the eastern cores. As planned, I started working with Sinan Ozeren on the elastic thickness on the Sea of Marmara. He provided me with a software by Jon Kirby and Chris Swain which computes the isotropic elastic thickness from gravity data using wavelet transforms. Unfortunately, the software was not so straight-forward to use and we had little time. We finally manage to run it but didn't had the time to study the first results. However, Sinan showed great interest in the project. I will continue to work on this from Marseille and we are planning on meeting again soon to carry the project all the way to a future publication. During the 3rd Leg, I was a member of one of the "core team". From 8am to 12am and from 8pm to 12pm, if coring was carried on, we were retrieving the core after the coring by the ship crew and preparing the sections for storage. The cores were not opened on board. Moreover, I was responsible for the SIG database and was thus in charge of preparing exact coordinates for sub-bottom surveys, processing the sub-bottom surveys and indexing the trajectory in the SIG software, checking the core coordinates… Before each coring, we gathered with scientists from the ITU and from the Institute of Marine Sciences and Technology in Izmir to validate the final location in regard of the new sub-bottom profiles. The main difficulty we were confronted to was the bending of one core in the Imrali basin. In this area, which shows a beautiful scarp were we were hoping to reach some deep horizons, we probably reached only the first targeted reflector whose age is estimated to be around 105 ky. The rest of the plan went well. Seven cores are targeting horizons estimated to correspond to 100 000yr climatic cycles and we are hoping to have reach further than the first one. Two cores should contain a good recording of Holocene sedimentation and will be used for seismoturbidite studies. During the Mission, Celâl Şengör from ITU wanted to test his idea that the Imrali canyon meanders were actually the result of small bending in that area accommodating a part of the displacement. Thus, we performed sub-bottom profiles parallel to the canyons, on both side, and I have been working with him on mapping small folds and faults that are indeed present all around the canyon. We will keep working on that subject that could lead to an article on how the canyon meanders are controlled by the folds and faults around. All in all, this short term mission was for me a great success both humanly and scientifically. I hope my work with Sinan Ozeren and Celâl Şengör will lead to publications and I am looking forward to work with Gulsen Ucarkus and Kadir Kürşad on the retrieved cores.

Visual seafloor expressions of the active tectonics of the Southeastern Alboran Sea

Manfred Lafosse

Summary

The mission in the Alboran Sea (fig. 1) had many objectives in several fields of marine geology (e.g. active and passed tectonic evidences, fluid escapes, coral mounts). This 5 weeks mission on the SARMIENTO DE GAMBOA vessel was divided in two parts: the LEG-1 from the 22nd April to the 14th May and the LEG-2 from the 15th May to the 24th May. During the LEG-1, the scientific team achieves the very high resolution cartography of the seafloor in seismically active areas and realized gravity cores in order to observe evidences of recent displacements of the seafloor and to date them. The IFREMER has provided two Autonomous Underwater Vehicules (A.U.V.), IdefX and AsterX. Those engines were equipped with a multibeam Echosounder to picture to the seafloor, and from time to time with a Subbottom profiler Parasound. On the high resolution bathymetry, we cartography Quaternary active strike-slip fault zones along a roughly N-S transect (NF, DF, AF, fig. 1). This may demonstrate the distribution of the actual Africa/Eurasia convergence along a discontinuous N-S senestral shear-zone. We also observed the localization of pockmarks along faults which offset the seafloor. During the second leg and during the day time, we realize dives with the ROV Max Rover from Hellenic Center for Marine Research (HCMR) in order to observe fresh tectonics scarps at the seafloor and related fluid escapes with a camera. With this method, we were unable to observe evidences of active fluid seepages on the Tofiño Bank or active pockmarks located on Quaternary faults. During both legs, gravity core have been recovered from either part of major fault zones. Further analysis may provide information on the origin of fluids in the sedimentary cover and on vertical offsets from either part of Quaternary fault zones. We also realized very high resolution seismic surveys with a SPARKER source from a private contractor (Geomarine Inc.) in order to characterize the sedimentary cover. 2D seismic lines have not been fully processed during the cruise and therefore cannot be used to determine the root of pockmarks.

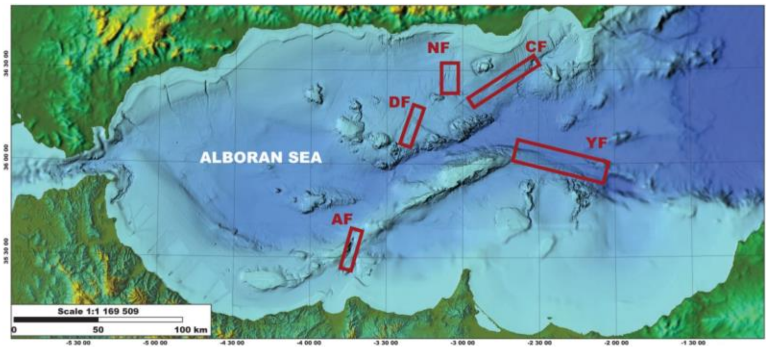


Figure 1 : Map of the Alboran Sea. Red rectangles: locations of studied structures. AF: Al Idrisi Fault; CF: Carboneras Fault; DF: Djibouti Fault; NF: North-South Adra Fault; YF: Yusuf Fault.

Purpose of the STSM

My PhD focus on the relationship between Plio-Quaternary deformation on the southern flank of the Alboran Basin and sedimentary processes. Past missions1 in the AF area has shown the continuity of active strike-slip structures from the Moroccan land to the Alboran Sea1 . However the continuity and the termination of the strike-slip faults remained not clear because bathymetry coverage was loose. In deep marine environment, recent works in Alboran shows that the main sedimentary process is contouritic. Our data show pervasive presence of pockmarks to the top of such seabed features. Such fluid escapes may have different sources. Miocene muds area a possible source. However, the age and the geographic extend of the Miocene muds are not known with precision. A shallower source may be under-compacted fluids trapped by contouritic sediments. The origin of fluids escapes at the seafloor might show the involvement of weak levels in the sedimentary cover or in the basement. My goals in the mission were to observe recent tectonic features and related sedimentary features as pockmark at the seafloor in order to characterize the style of the Quaternary Tectonic style. At the regional scale the aim is to understand how the Africa/Eurasia convergence is accommodated by strike-slip structures, and how fluids influence the deformation.

STSM workload

During the first 3 weeks, I worked during the 4h-8h shift, and dedicated my time to two activities. The morning was dedicated to the A.U.V. watch. In partnership with the engineer team, the goal of exercise is to monitor the A.U.V. during the dive and record all anomalies that produce artefacts on the record of the bathymetry in order to make the processing of the data easier. Along a programmed pathway, the A.U.V. records raw data from the multibeam echosounder. The echosounder send beams toward the seabed with a constant period of time, and records the time of return of the sonic impulse, which is called a ping. The depth of the seabed in the covered area is a function of the velocity of sonic impulse in the water, which is measured by a sound velocity sensor onboard. The A.U.V. also records its position at the moment of acquisition with its internal central inertial. The difference of record between the internal positioning system of the A.U.V and the real position of the A.U.V. is an important source of bias on bathymetric map. This bias is corrected with the Caraibes software (IFREMER). This is the first step of the processing of the bathymetry. The nightshifts were dedicated to the correction of the bathymetry with the CARIS software. After a straight line, the turn of the A.U.V. is not recorded. The roll, the pitch and the azimuth of the A.U.V are not constant: for example the roll may vary within a 0-0.5° range. This provokes artefacts on the bathymetry. After the filtering of the navigation in the QUARIS software (Fig. 2), my job has consisted of cleaning the bathymetry. The signal reflected by the seafloor is not clean: obstacles in the water column between A.U.V and the seafloor noise makes noises in the data. Also, the diffusion of the beam on flat surfaces triggered false records of the time of return, which artefacts could be removed by filtration or manual picking of false pings. The signal/noise ratio also decreases toward the edges of the area covered, and errors in the measure of the speed in the water column leads to misfits between two lines of bathymetry. The misfit is corrected by hand in some case, or by applying a new speed, in other cases. During the second LEG my work consists of watching the during the 2-8am shift and to help to the deployment of the 250m long seismic-streamer.

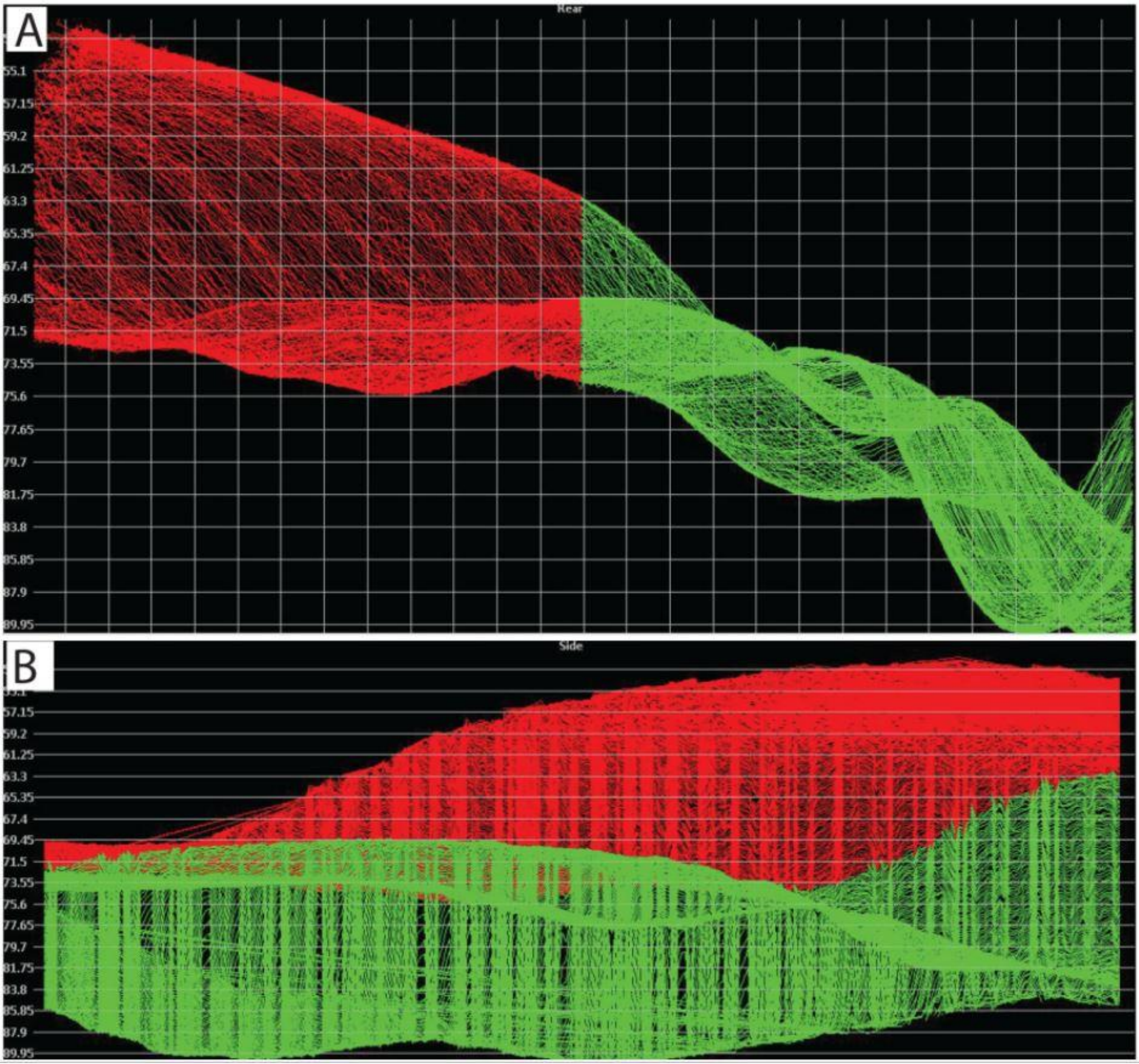


Figure 2: Bathymetry: raw data visualization in the CARIS Software. A : Rear view of a transect; B: Side view.

Preliminary Results

The High Resolution (HR) bathymetry provides us the most Figure 2: Bathymetry: raw data visualization in the CARIS Software. A : Rear view of a transect; B: Side view important results during the cruise. ROV dives did not allow to observe recent faults scarps or fluid escape in Quaternary basins or fault zones because the time of observation was too short and deep-sea sedimentary structures (coral mounts, contourites or turbiditic systems) may be active. The cartography on the HR bathymetry of the part of the N-S Adra fault zone reveals a small basin bounded by Quaternary faults with important vertical component and with an approximatively N-S azimut. The faults limit the northern part of a rhombohedral graben-like basin. To the north of the area, pockmarks are visible at the seabed with a random position. In the basin, the pockmarks are line up along tectonic escarpments and on top of small horsts. In some places, pockmarks are visible with a Matryoshka Doll configuration. This suggests different generation of fluid escapes. To the south of NF, the Djibouti fault zone (DF) shows 200m wide basin, lining along a decakilometric fault zone. The area presents evidences of recent tectonic offsets of the sea-floor. Some structures are oblique with a 60° angle to the NNE-SSW trend of the fault zone. To the south, we observed similar tectonic structures in the Al-Idrissi Fault zone (AF). Recent small offsets of the seafloor are coherent with the high seismicity in the area. Outcropping fault are oriented as riddle-Shear and evidence of the senestral cinematic along the fault zone. Due to the lake of time Dr. Gràcia decided not to investigate volcanic structures to the south of AF. From a sedimentary point of view, contouritic deposits influence the morphology of the seafloor. The fault zone crosses the contourite which seems to localize some pockmarks. Here again, it appears that the tectonic influences fluids behavior. However, the trigger of fluid escapes is not clear because we didn't neither observe the active faults nor active fluid escapes with the ROV or with other sensors. Consequently, the relation between pockmarks and active faults should be more investigated. However, the fluid thematic seems restricted to fluid from the most superficial origin, as pockmarks appeared to be contouritic related. DF, NF, and IF are lining-up and show the same global cinematic. Those are active faults, running from the Adra Area to the Al-Hoceima Area near the Moroccan coast line. This mission confirms the presence at the seafloor of a strike-slip structure crossing the Alboran Sea. Evidence of Quaternary active faults has been seen in YF and CF. Nonetheless, the last activity on those faults is not dated. The geometry of faults at the seafloor shows evidence of a strong strike-slip component for the recent deformation. In YF, we observe bulges at the seafloor that are likely to be folds associated with the recent strike-slip faults. The folds may be related to the stress loading during the interseismic period. It appears that YF and YF and CF are longer and more continuous than IF, AF and DF. But at this point, it is impossible to demonstrate that the discrepancy come from different mechanical behaviors, or from different stages of maturation of those fault zones. In conclusion, the mission provides me observations of Quaternary strike-slip faulting in Alboran. But the relation with fluids escapes at the seafloor has to be more investigated. Further analysis of gravity cores could provide indications of the origin of fluids near the surface and therefore might show a relation between fluid escapes at the seafloor and active tectonic. At this point, there are no evidences that deep fluids or hydrothermal processes are involved in the mechanical behavior at the regional scale. In contouritic environment, the localization of pockmarks along the faults shows that there is a relation between expressed faults at the seafloor and fluid escapes. However, it is impossible to propose a relative dating of those features. A mechanical analysis of the strike-slip fault patterns at the seafloor must be done to move further on the linkage between fluid expulsions and deeply rooted tectonic processes.

Future collaboration including publications resulting from STSM

For now, the collaboration with Dr Gràcia is pending to the decision of my PhD advisor.

References

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Mission Report of the SHAKE scientific cruise

Alain Rabaute

Purpose of the visit

The purpose of the visit was to participate in the second leg of the SHAKE cruise, onboard the B/O Sarmiento de Gamboa, from May 15th to May 23rd, 2015, in the Alboran Sea. The two main purposes of this second leg were 1) to acquire high-resolution Sparker 2D seismic profiles on the active fault systems in the Alboran Sea, and 2) to perform in-situ investigations using the ROV "Max Rover", in order to observe the seafloor expression of active faulting in the area. During the first leg of the SHAKE cruise, very high-resolution bathymetry had been successfully acquired using two AUV from IFREMER. These data, processed onboard, were used to choose the accurate locations for both the seismic acquisition and the ROV dives. Sparker acquisition and ROV dives were to be performed in six chosen locations: the North-South fault system, on the slope of the Adra shelf, the Carboneras fault, south of the Campo de Dalìas promontory, the Djibouti platform, the Al-Idrissi fault in the north Moroccan margin, the Cabliers bank, and the Yusuf ridge.

Description of the work carried out during the visit

The Sparker acquisition was fully handled by the technician from a private contractor (Geomarine Inc.), and was performed during the night time. I was affected to the observation of geological features during the ROV dives. The objective was to find a seafloor expression of active faulting. One direct expression would be a fault scarp. An indirect evidence of activity would be fluid escape at the seafloor, associated to carbonate crust precipitation at the seafloor, triggering appearance of life (corals, mollusca, fishes, crustacean). For each dive, a log was written, detailing the different events of the dive, with associated time and depth, along with the ROV approximate location at the time of observation. Several box-cores (about 30-cm long surface sediments) were recovered using the ROV automated arm. Further analyses on cored samples should provide data about the sedimentary record, the sedimentation rate and a time span of sediment emplacement. At several of the above chosen locations, gravity cores were recovered, of a maximum length of about 2 m, and when possible on both sides of the fault path. Given an average sedimentation rate of 3 cm/ky, this length should give a sedimentary record of about the last 70ky, but also indication of anomalous sedimentation rates, possibly linked to the fault activity.

Description of the main results obtained

Despite our efforts, we were unable to spot any seafloor expression of fault activity using the ROV. The seafloor around the active faults of North-South, Carboneras, Al-Idrissi, and Djibouti was too smooth, and no scarp was seen. At several locations, the ROV crossed back and forth the fault path, but the difference in height between the two compartments of the fault was always expressed as a gentle slope, almost invisible on the narrow aperture of the ROV high-definition video-camera. We could not either spot any active pockmark. At every locations, the fault path was clearly visible on the AUV micro-bathymetry, as well as pockmark fields, with meter to tens of meters-wide pockmarks, but the change in scale of observation was obviously too big between the high-resolution tool and the direct observation. We lacked an intermediate scale, the one we get onland by stepping back from an outcrop to visualize a landscape ranging between hundreds of meters to one kilometer. However, each dive brought a lot of information on the living organisms and habitats perspective. We were able to sample a piece of coral mounds basement on the Tofiño bank, asserting for the first time its beach rock origin. Further dating may provide information on when this structural high emerged and was eroded. From one of the dives on the coral mounds of the Cabliers site we also brought back a piece of volcanic tuff, which can be linked to the recent volcanic activity at Ras Tarf and Tres Forcas Cape.

Future collaboration with host institution (if applicable)

In the framework of habitat mapping, we will provide the multibeam bathymetry acquired on the Tofiño bank during previous cruises (MARLBORO-2 and SARAS in 2012, chief scientist Elia d'Acremont) in order to further interpret the data acquired onboard the IRIS mission, mainly the observations from the ROV dives.

Projected publications/articles resulting or to result from the STSM (if applicable)

One paper on the above mentioned collaboration

New scientific and technological solutions for seismovolcanic monitoring of an active normal fault: the Panarea-Stromboli tectonic link

Sebastiano D'Amico, Francesco Italiano

Purpose of the STSM

The main goal of the STSM aimed to investigate relationship between seismicity and fluid emission in the Panarea-Stromboli area (Southern Italy). We investigated the seismicity through moment tensor computation using broadband waveform inversion. Furthermore few geophysical measurements were taken in the area in order to identify possible polarization effects due to the present of a fault line connecting the islands of Panarea and Stroboli. The chosen test site is located at the Aeolian islands where the management of natural risks (seismic and volcanic) required a special attention in the period 2002-2005 when a low-energy submarine explosion occurred at shallow depths off the coasts of Panarea island (Caracausi et al., 2005). The degassing activity induced by the explosion developed along fissures that opened at the seafloor trending N40°E, the same regional normal fault linking the islands of Panarea and Stromboli. The degassing crisis at Panarea was followed by a huge landslide and a tsunami wave originated at the nearby island of Stromboli (12 miles towards NE). A few weeks later a large eruption started from the flank of Stromboli. The sudden unrest of submarine volcanic activity that occurred off the island of Panarea (November 2002) opened a crater of 20 by 10 meters wide and 7 meters deep. That event dramatically changed the geochemical features and the degassing rate of the submarine hydrothermal vents of the area and pushed the scientists to develop new methods to monitor the sea-floor venting activity. During the unrest period, the huge degassing activity increased the CO2 flow rate by some orders of magnitude, however very little investigations have been carried out on the local seismicity The monitoring of the volcanic activity and seismic activities was carried out by periodical observations of the vented fluids the former and by a local seismic network installed on the island of Stromboli, the latter. A further step over was achieved by the deployment of a sea-floor observatory connected to surface buoy a couple of miles off the coasts of Panarea. The observatory was able to perform real and near-real time measurements of selected parameters (temperature, pressure, acoustics) and allowed to establish for the first time a structural link between the two islands and their volcanic activities (Heinicke et al., 2009). Recently, due to a reactivation of the volcanic activity at the island of Stromboli, new investigations need to be developed on the Panarea-Stromboli fault line. A new observatory is under test in the area and the preliminary data have shown changes in fluid emission (particularly in CO2). In the same period moderate earthquakes have occurred in the area.

Description of the work carried out during the STSM

Analysis of seismicity and moment tensor solutions

During the STSM a lot of seismological data were analyzed. The area investigated in the present study is indicated by a square in the main plate of Figure 1 figure, the smaller frame at the lower right (redrawn from Neri et al., 2009a) shows the CalabroPeloritan Arc region in southern Italy. This smaller frame indicates that while the central portion of the Arc corresponds approximately to the southeast-ward retreating subduction hinge, the northern and southwestern edges of it lie in continental collision zones which developed after local detachment of the subduction system. The northwestward trending arrows in the bottom of the same frame indicate the Nubia– Europe convergence direction (Nocquet and Calais, 2004). The main frame shows the principal fault systems: hatched, normal faulting; half arrow, strike-slip component; COST is supported by the EU RTD Framework Programme Horizon2020 3 dashed, presumed strike-slip but different interpretations in the literature (Fabbri et al., 1980; Finetti and Del Ben, 1986, 2005; Monaco and Tortorici, 2000). The dotted curve in the southern Tyrrhenian Sea marks the high velocity anomaly found by seismic tomography at 150km depth (Neri et al., 2009a) indicating the only part of the subduction system where the slab is still continuous (i.e. detachment has not still occurred).

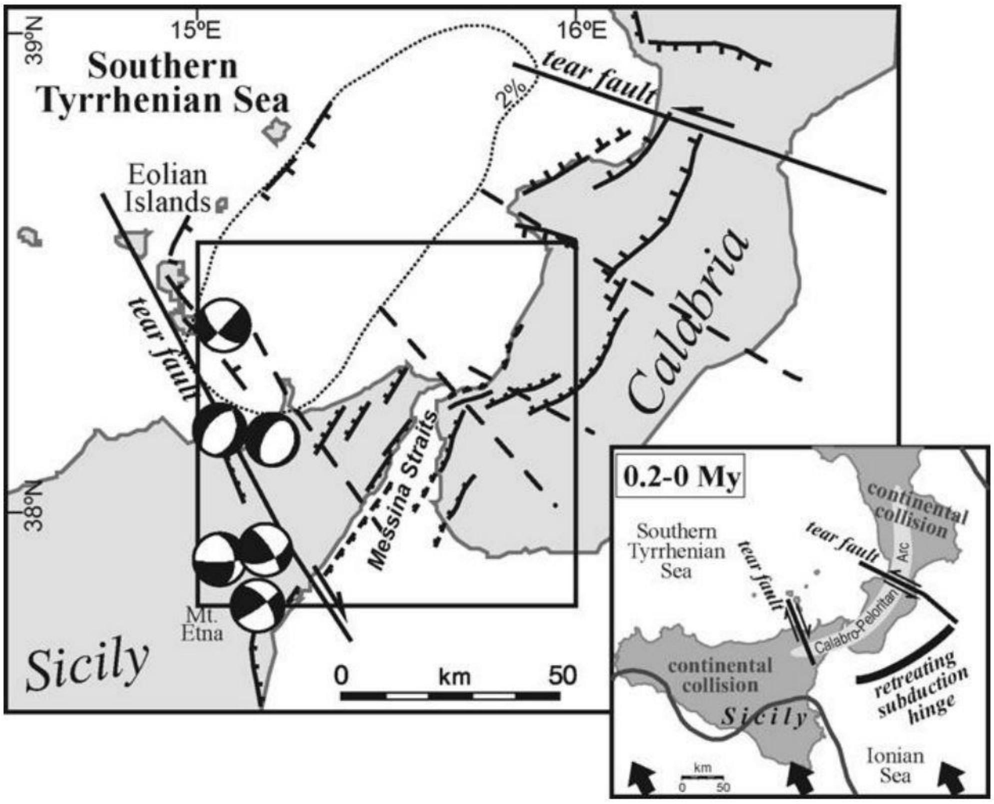

Figure 1: Main seismotectonic features of the study area (modified form D'Amico et al. 2010).

The area is located in the Calabro-Peloritan Arc (Fig. 1), a tectonic structure uplifting at a rate of 0.5–1.2 mm/yr in the last 1–0.7My (Monaco and Tortorici, 2000). The deformation in the area is mainly accommodated by normal faults (Monaco and Tortorici, 2000; Catalano and De Guidi, 2003; Catalano et al., 2003). The dynamics of this area is controlled by two main tectonic factors: the Nubia–Europe plate convergence locally oriented NNW-SSE (Calais et al., 2003; Nocquet and Calais, 2004; Serpelloni et al., 2007) and the southeast-ward rollback of the Ionian lithospheric slab which subducts beneath the Tyrrhenian lithosphere (Malinverno and Ryan, 1986; Faccenna et al., 1996). The Nubia–Europe convergence velocity in this region has been estimated to be about 0.5 cm/yr (Goes et al., 2004; Nocquet and Calais, 2004; D‟Agostino et al., 2008a), and the rollback of the Ionian slab and subduction trench retreat is supposed to be even slower, perhaps a few mm/yr (Devoti et al., 2008; D‟Agostino et al., 2008b). Several authors (Spakman and Wortel, 2004 and references therein) argued that this very low outward migration velocity of the Calabro-Peloritan Arc and its fast uplift could suggest a shallow detachment of the subduction slab. A recent seismo-tomographic investigation (Neri et al., 2009a) focused on the present state of subduction in this region. They suggested that the deep portion of the subducting lithospheric slab has already detached from the shallow body near the edges of the Arc (e.g. beneath northern Calabria and northeastern Sicily) while the slab is still continuous beneath the central part of the Arc, along a 100km long NE-trending segment of the subduction system in southern Calabria (Fig.1). In addition to filling an information gap indicated by the previous investigators concerning the present state of subduction in this area (see e.g. Spakman and Wortel, 2004) the results of Neri et al. (2009a) may help the interpretation of the shallow seismicity in the Arc region through proper contextualization of the seismotectonic process occurring at crustal depths above the subducting lithosphere. Seismogenic stress inversion on a regional scale allowed Neri et al. (2005) to detect a clear change from an extensional domain in southern Calabria and northeastern Sicily to a compressional one in the rest of Sicily. Evidence for this tectonic change was seen in other geological and geophysical investigations (see e.g. Billi et al., 2006, 2007). The transition was approximately located across a belt running from the Eolian Islands SSE to the Ionian coast of Sicily near Mt. Etna (Fig. 1). The transition from the eastern extensional domain to the western compressional area may be explained in terms of joint action of two main factors, plate convergence and rollback of the subducting lithosphere (Neri et al., 2005; Billi et al., 2006, 2007). This view matches the findings of the most recent geodetic and seismological investigations (D‟Agostino et al., 2008b; Neri et al., 2009a)which support the existence of a residual rollback of the subduction slab in southern Calabria and continental collision following slab detachment in western-central Sicily. The Calabro-Peloritan region is one of the areas with high seismic hazard (http://zonesismiche.mi.ingv.it; "Mappa di pericolosità sismica del territorio nazionale"). Based on the historical earthquake records the area has suffered intensity X or higher several times in the past centuries [for example in 1638, 1659, 1783, 1870, 1905, 1908, see Boschi et al. (2000) and CPTI Working Group (2004)]. In the last thirty years, crustal seismicity has been recorded in a low-to-moderate activity with just a few events having magnitude above 5 ["Catalogo della Sismicità Italiana" (CSI Working Group, 2001), "Bollettino Sismico Italiano" at http://bollettinosismico.rm.ingv.it/, ISIDE at http://iside.rm.ingv.it, and the catalogue of the regional seismic network of the University of

Calabria]. The study area is also characterized by an intermediate and deep seismicity clustered and aligned along a narrow (less than 200 km) and steep (about 70°) Wadati-Benioff zone striking NE-SW and dipping towards the NW down to 500 km of depth (Piromallo and Morelli, 2003; Neri et al., 2009). In the last thirty years, about a dozen, subcrustal earthquakes with magnitude greater than 5 occurred in the study area. In particular, in this study we use seismic data collected and recorded by Italian National Seismic Network managed by the Istituto Nazionale di Geofisica e Vulcanologia (INGV). The investigated are for the setting of the seismological area is presented in Figure 2. The data set is comprised of more than 4,500 regional earthquakes of local magnitude (ML) ranging from 1.0 to 4.3, recorded between January 2005 and August 2015 (the geographical boundaries are between 38.00 and 38.8 for latitude and 14 to 15.5. for longitude).

Figure 2: Study area

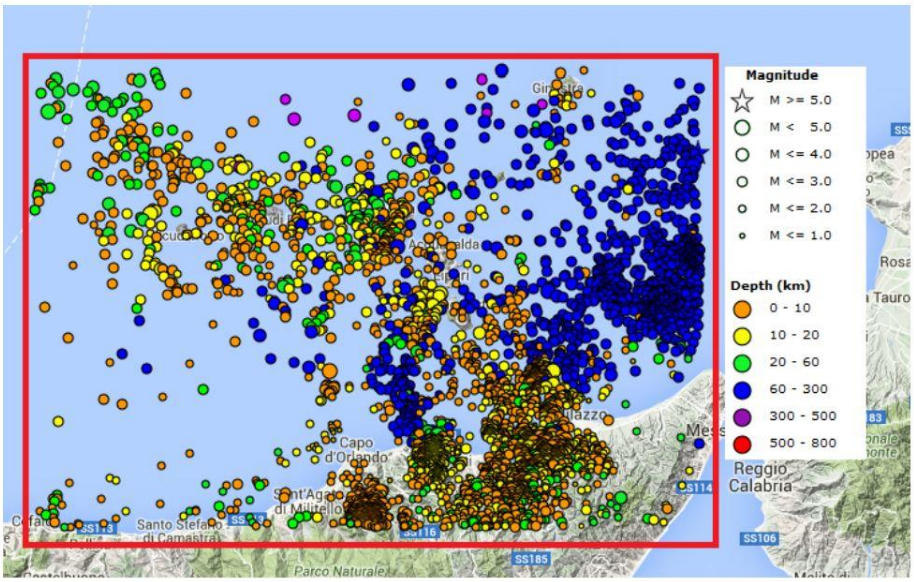

Figure 3: Seismicity of the area

As shown in Figure 3 the area is characterized by very shallow seismicity confined within the first 20km. However several deep events (more than 300km) can be found and their mechanism is linked with the subduction zone present in the area. In order to characterize the seismotectonic setting of the area we focused our attention on few seismic events with focal depths less than 25km and local magnitudes larger than 3. The dataset has been restricted to the earthquakes recorded at a minimum of 4 three-component seismic stations. This selection brings the dataset to about 60 events. Each waveform has been examined to eliminate recordings with spurious transients or low signal-to-noise ratios and corrected for instrument responses to yield to ground velocity. Finally the picking of P-arrivals were reviewed and the horizontal recordings rotated to radial and transverse components. The main parameters of the analyzed earthquakes are listed in Table 1 as well as with the moment tensor solution obtained for each event The moment tensor solution computation was performed by using the CAP method originally proposed by Zhao and Helmberger (1994) and later modified by Zhu and Helmberger (1996). The method allows time shifts between synthetics and observed data in order to reduce dependence of the solution on the assumed velocity model and on earthquake locations. The source depths and focal mechanisms are determined using a grid search technique. For any fixed depth, the procedure attempts to find the best fit by aligning automatically the data with the synthetics. In the CAP method each waveform is broken into the body and surface wave segments that are weighted separately (see for details Tan et al., 2006). The Green‟s functions were computed using a 1-D velocity model with the frequency-wave number method described by Zhu and Rivera (2002) and stored in a separate library in order to reduce the computational time. The use of the appropriate regional velocity model is important not only to match the waveforms, but also to define the moment magnitude of the earthquake because the theoretical amplitudes at high frequencies depend very strongly on the velocity model. To compute the Green‟s functions we used a specific velocity model developed for the area (Barberi et al. 2004). Green‟s functions have been computed for a distance range from 1 to 200 km with a spacing of 1 km and a focal depth range from 1 to 50 km. To take into proper account the lithospheric heterogeneities, we used the most detailed 3- D velocity models available for the study region (Barberi et al., 2004; Neri et al., 2011) to derive a specific 1-D velocity model for each target area. To compute such 1-D model, we define sets of synthetic events and stations located at sea-level on regular two-dimensional grids covering the respective target area. For each pair of synthetic event-stations, we computed the theoretical travel times using the 3-D velocity models cited above and we used these data to build the relative plot of travel times versus epicentral distances. The data envelope may be fitted by a few piecewice continuous linear segments. Following the theory of travel-times in layered media (see e.g., Lay and Wallace, 1995), we estimated both velocity and thickness of the layers needed to build the 1-D velocity model. With this approach, we may reconstruct a 1-D velocity model “equivalent” to the 3-D one for a specific set of synthetic ray-paths. The chosen configuration of events and stations allows us to sample the investigated region with a high density of seismic paths also showing a very robust ray crossing and therefore the “equivalent” 1-D velocity model may be considered a good approximation of the local 3-D structure. In the CAP method each waveform is cut into Pnl (defined as the first arrival from seismic source in the crust corresponding to waves reflected and multireflected from the top of the sharpest discontinuity) and surface wave segments that are weighted differently in the misfit calculation since body and surface waves are sensitive to different parts of crustal structure and have different amplitude decay with distance. The surface waves, although large in amplitudes, are easily influenced by shallow crustal heterogeneities while the Pnl waves are controlled by the averaged crustal velocity structure and therefore are more stable (Zhu and Helmberger, 1996). For this reason we weighted the Pnl segments 2–3 times more than the surface wave segments. Use of only surface waves permits a good estimate of the solution but requires a good azimuthal coverage around the source which makes the application less effective in case where only a few stations are available. In our analysis we used ground velocity instead of ground displacement in the CAP inversion as the magnitudes of the majority of the events are smaller than four and we needed to avoid the influence of long-period noise embedded in ground displacements. Synthetics and observed ground velocity were filtered in the same frequency bands chosen accordingly to the magnitude of each event. In this study we used, for earthquake around magnitude four, a frequency band from 0.02 Hz to 0.1 Hz for the surface waves and from 0.05 Hz to 0.3 Hz for the Pnl. These frequency bands were chosen to maximize signal-to-noise ratios of data and to avoid short-wavelength structural heterogeneities. However, to determine the moment tensor solution of smaller earthquakes, it is necessary to use higher frequencies. Fig. 4 reports an example of waveform fit obtained by applying the CAP method. We can see that the synthetic matches well the observed both in shape and amplitude. The use of many stations increases the reliability of the focal mechanism because a large number of waveforms are inverted simultaneously. In general, Table 1 shows that normal faulting is the main style of seismic deformation in the study area. The polar plot of P- and T-axes shows a roughly NWSE preferential orientation of the extension axes. In addition, we may note from the map that the regime of faulting significantly changes from north to south: normal faulting prevails clearly in the north while it appears mixed to strike-slip in the south. The present application of the CAP method fills a remarkable lack of knowledge existing on the seismogenic mechanisms in the study area and provides a tool for further studies in the whole region. However, the network geometry used for focal mechanism studies is limited by the lack of OBSs in the wide offshore sectors of the study region and this is a major factor reducing the quality of these solutions. Thus, it is extremely important to plan a proper OBS campaign in order to better investigate the local seismicity and its pattern which will help to better highlight the connection among several physical parameters such as seismicity and fluid circulation in fault zone areas.

Installation of portable seismic stations and polarization analysis

The area is an interesting natural laboratory and during the STSM we installed seismoters in different locations between the islands of Panarea and Stromboli. Using the seismic data collected during the STSM we aim to compute the polarization of the seismic signal with the final goal of gain evidences for the presence of the inferred fault in the area as well as to characterize the potential site effects at the investigated site.

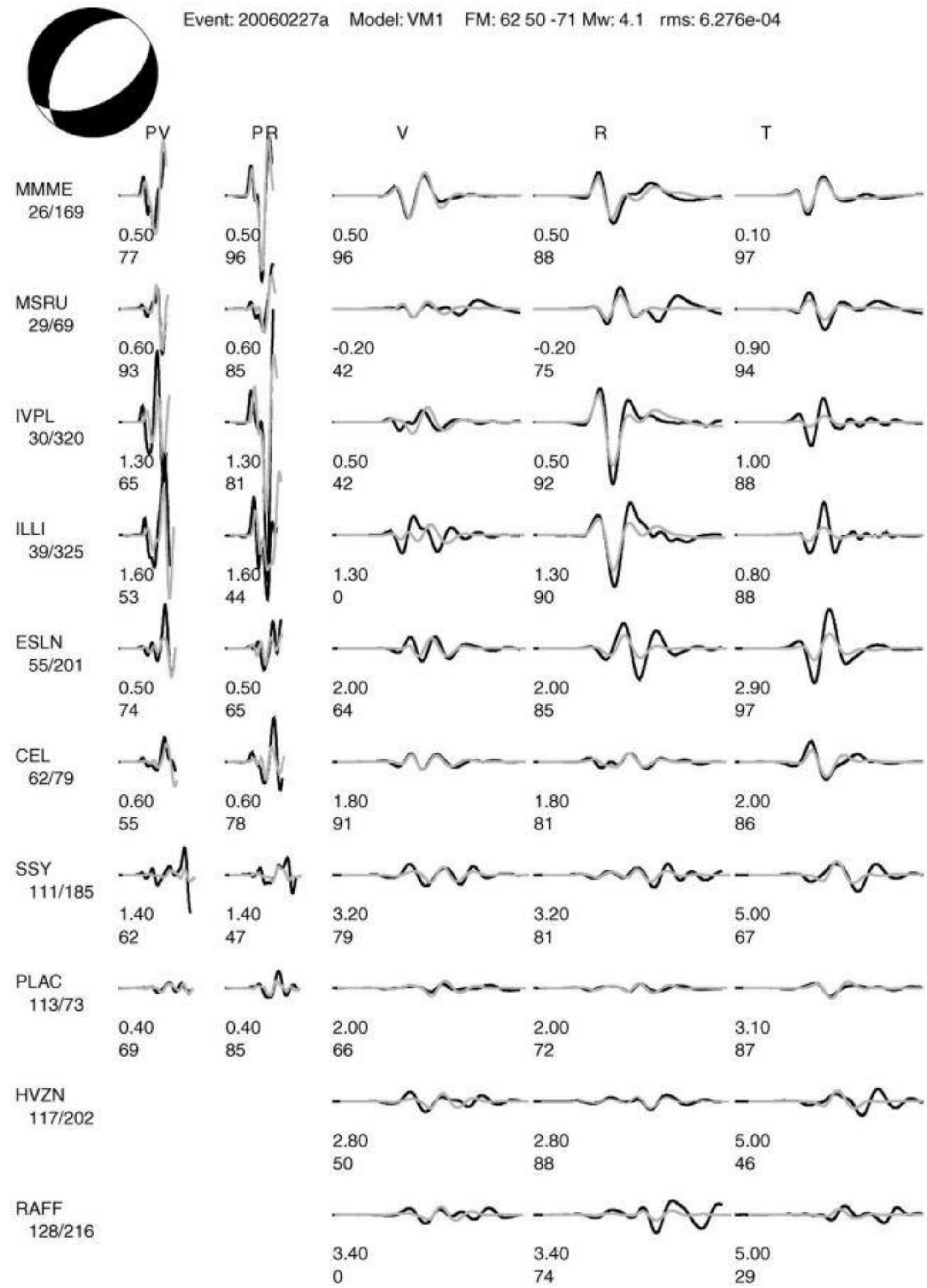

Figure 4: Example of waveform fit for the event ID 20060227a (see also Table 1). Data are indicated by black lines, synthetics are represented by gray lines. The left two columns show the waveform fits for the Pnl waves, while the next three ones show the waveform fit for the surface waves: vertical (V), radial (R), and tangential (T) component, respectively. The numbers below each trace segment are the time shift (in seconds) and the cross-correlation coefficient, respectively. The name of the station is reported on the left side of each trace fit; the numbers just below it represent the distance from the station and the azimuth (modified from D'Amico et al. 2010).

Ambient noise measurements were taken at 4 different points over the study area (Figure 5) covering a wide range of geomorphological states. Ambient noise was recorded using a three-component seismometer (TrominoTM, www.tromino.eu). The Tromino is a compact, lightweight and self-contained instrument, and its ease of use makes it ideal for performing a large number of measurements in rugged terrain that are accessible only on foot (in this particular case we made use of a boat to reach all the small rocks). Time-series were recorded at a sampling rate of 500 Hz and, following the guidelines suggested by the SESAME project (Bard 2005) these were divided into non-overlapping time windows of 20 s each. The Fourier spectrum of each window was computed and smoothed, and after „cleaning" the traces from spurious noise event windows, the resulting H/V, in the frequency range 0.5–64.0 Hz, was derived using the geometric mean of the spectral ratio obtained for each time window.

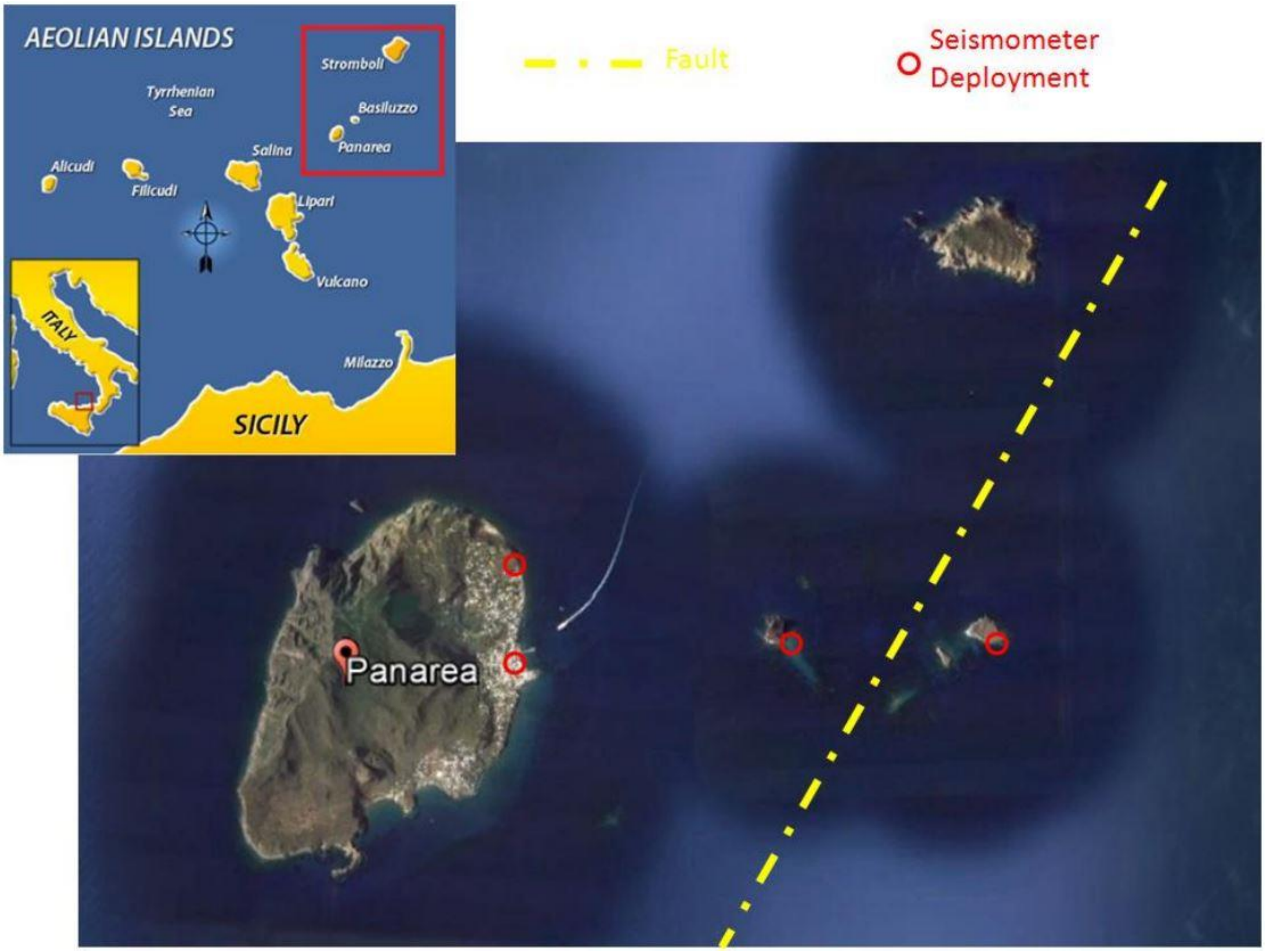

Figure 5: Location of measurement sites

The use of the H/V method was first proposed by Nogoshi &Igarashi (1971) for the estimate of seismic site response. Nakamura (1989) eventually made this method widely popular as a costeffective and reliable means of predicting the resonance frequency of a site, particularly when low shear-wave velocity layers present a sharp impedance contrast with the bedrock. The presence of a resonance peak in the H/V ratio has been interpreted both in terms of SH-wave resonance in soft surface layers, or in terms of the ellipticity of particle motion when the ambient noise wave train is made up predominantly of surface waves (Bonnefoy-Claudet et al. 2006). In practice, the wavefield is expected to be a combination of both types, and the H/V curve contains information about the shear wave velocity profile in shallow sediments. In order to infer the presence of the fault we also perform polarization analysis using the data collected during the campaign. Polarization analysis was carried out using the method of Burj´anek et al. (2010) which is based on the complex covariance matrix method of particle motion polarization analysis, and generalized to the time-frequency domain by adopting a continuous wavelet transform (CWT). The particle motion is characterised at a given time and frequency by an ellipse in 3-D space. The WAVEPOL package outputs the analysis of an ambient noise time-series in visual representations of combined angular and frequency dependence. Histograms of strike of the ellipse major axis are represented as circles on a polar plot, in which the frequency increases along the radius, and colour is used to denote amplitude in each histogram. The ellipticity of the particle motion is defined as the ratio of the semiminor axis to the semi-major axis of the ellipse, and is therefore equal to 1 for circular particle motion and equal to zero for purely linear motion, and is thus a good indicator of polarization effects. It is represented as a 3-D histogram of ellipticity versus frequency. Figure 6 shows the H/V curves obtained in the present study. It is possible to notice that no clear picks can be observed in the lower portion of the spectra while more clearer peaks are evident around 10 Hz and above. These have been interpreted with very shallow local geological structures or, as in the case of Dattilo rock, linked with the natural vibration of the it. However the latter case needs to be better investigated also through numerical modelling.

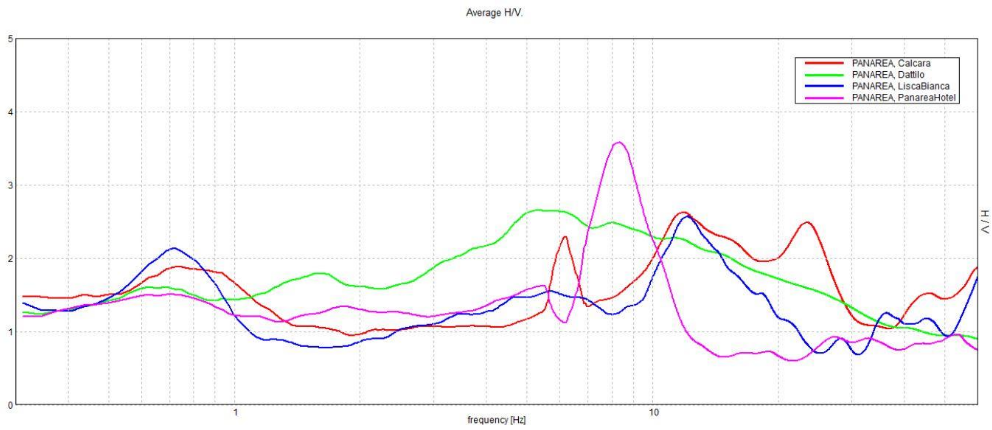

Fig. 6: H/V curves, measured during the surveys.

The polarization analysis shows strong characteristics in direct correspondence with these H/V peak frequencies. The polar plot shows directivity of particle motion approximately, while the ellipticity diagram shows a corresponding sharp drop to zero at the same frequencies, indicating a high degree of linearity in the particle motion. This could be related to the presence of the fault in the study area (Fig. 5) however further investigations are needed.

Future collaboration with the host institution

The two Institutions involved in this STMS intend to submit a common research proposal. In particular, the authors are considering the calls explicitly disegned and directed to facilitate

Italian-Maltese scientific collaborations. On this framework we are going to propose a project that deals with innovation technologies in order to investigate the sea floor using several geochemical and geophysical parameters collected purposely during the project. Independently from this, we hope to have many future occasions to perform integrated studies and improve the ongoing collaborations.

Foreseen publications/articles resulting from the STSM

We would like to publish our results at national and international conferences, as well as on international journal. At the moment, the next occasions for publishing part of the data are the next ESC and EGU conferences.

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Report for the Cost Flows STSM in the Bullard Laboratories of the Department of Earth Sciences of Cambridge University

Evangelia Batsi

Summary

A Short Term Scientific Mission (STSM) of four weeks within the COST-FLOWS programme, was carried out in Bullard Laboratories of the Department of Earth Sciences at Cambridge. The purpose of this mission was to interact with the group of Professor Robert White who is working on magma-induced seismicity in Iceland and to work with Louis Géli, researcher of Ifremer, who is currently in sabbatical leave at the University of Cambridge. During this mission several goals were achieved and the results obtained were in light of the objectives of the COST-FLOWS Action. Special focus has been given to the verification of the results of the automatic picking provided by Early-Est, on the seismic data recorded by the temporary seismic network deployed by Ifremer in September 2014, in the Sea of Marmara (SoM). The detected events by Early-Est were classified into three different families according to signal characteristics. One family, Family 3, corresponds to aseismic events, hence events that could not be part of the final seismic catalogue. The discussion with the group of Professor White on their studies regarding the induced seismicity associated with geothermal systems in Iceland, was really enriching and helpful for my current work, which is based on the study of induced seismicity associated with gas reservoirs in the SoM.

Introduction

Since the last devastating earthquakes of 1999 in Turkey, the submerged part of the North Anatolian Fault (NAF) in the Sea of Marmara called Main Marmara Fault (MMF), is considered as a seismic gap. In order to assess the seismic hazard of the area, it is essentially important to determine the mechanical behaviour of the different submarine fault segments, by particularly studying the micro-seismicity. The MMF has been shown to exhibit clusters of seismicity, where their origin has been interpreted until now only in terms of tectonically driven. However, recent studies have shown that the MMF cuts a hydrocarbon reservoir, as part of the Thrace Basin (e.g. Géli et al, 2008, Bourry et al, 2009, Dupré et al, 2015) and therefore gas induced seismicity should be also considered for the interpretation of these seismicity clusters. The purpose of the current STSM in Cambridge University was : (i) The verification on the results obtained by Early-Est , by processing the seismic data recorded by the temporary seismic network of ten Ocean Bottom Seismometers (OBS) deployed by Ifremer in September 2014 and (ii) The interaction with the group of Professor Robert White, who is working on the magmainduced seismicity in Iceland.

Objectives of STSM in Bullard Laboratories

Verification of Early-Est results

The processing of the seismic data was performed by Early-Est (e.g. Lomax A. and Michelini A., 2012), which is a software package for phase picking, phase association and event detection-location. The first objective of this STSM was the verification of all the events that were associated-located by Early-Est for (i) assuring that the results of automatic picking were correct and (ii) for creating a final seismic catalogue, with correct picking phases and hence reliable earthquake locations. Our results indicate that Early-Est has detected three different families of events : (i) Family 1 : Corresponds to seismic events with clear P and S phases (see Figure 1) (ii) Family 2 : Corresponds to seismic events, where the P phase was not well identified (see Figure 2) (iii) Family 3 : Corresponds to aseismic events of weak amplitude with weird signal, produced simultaneously on all OBS stations where they are observed (see Figure 3) Every single event was individually examined and classified into Family 1 to 3 according to its signal characteristics. Events that did not have a clear signal on some stations, were deleted to ensure that the final catalogue contains only well resolved events. Manual corrections were applied to automatic picking to improve either the picking phases on P or on S wave.

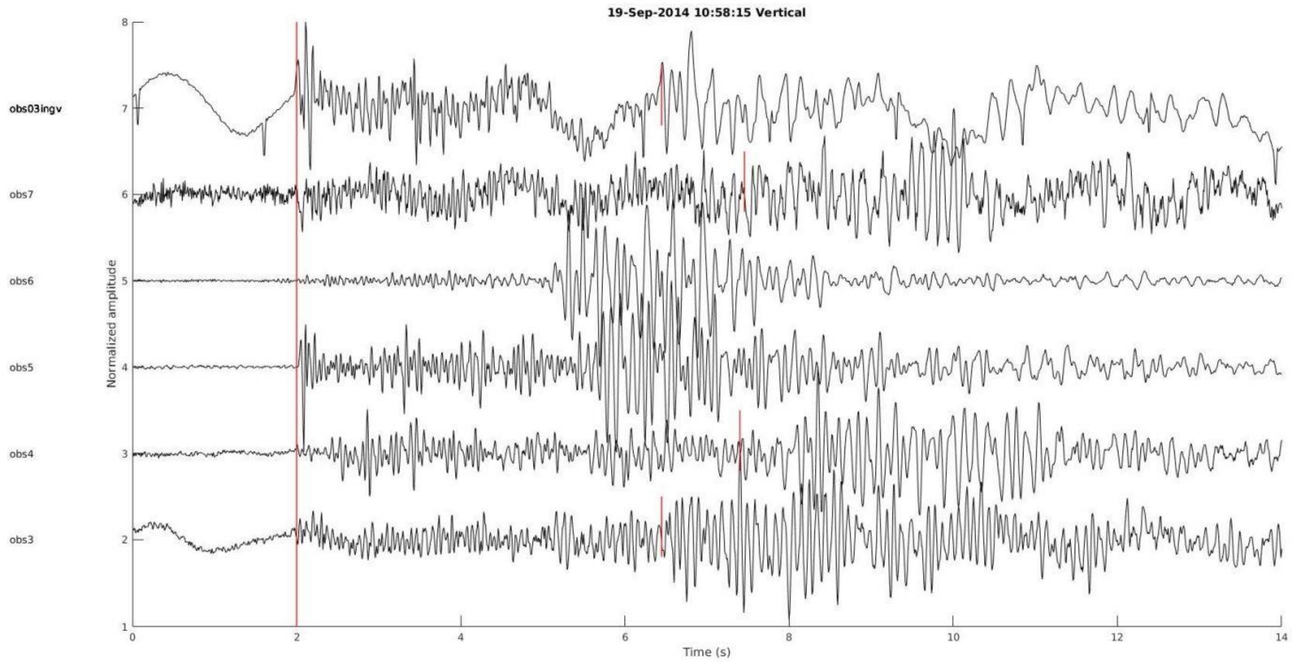

Figure 1 : Seismic event of Family 1, shown on the vertical component, recorded by different OBS stations, aligned on the P-phase identified by Early-Est (red vertical line).

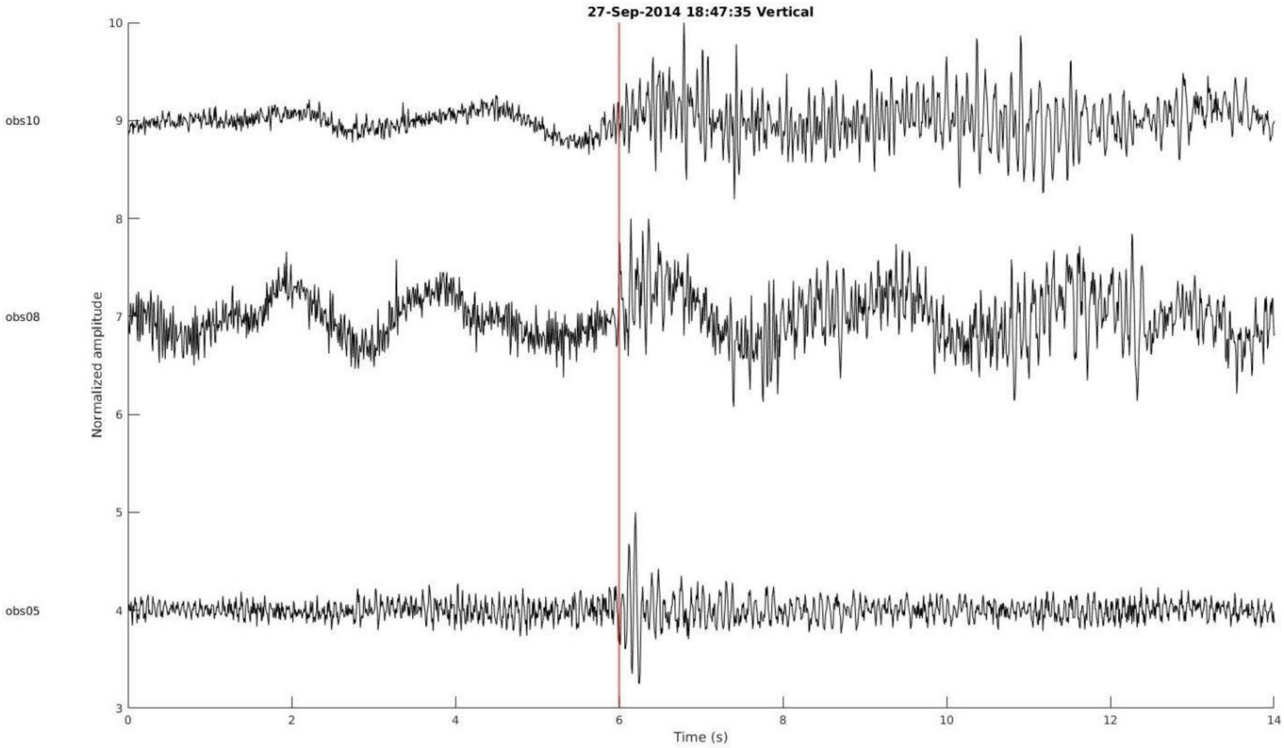

Figure 2 : Seismic event of Family 2, shown on the vertical component, recorded by different OBS stations, aligned on the P-phase identified by Early-Est (red vertical line).

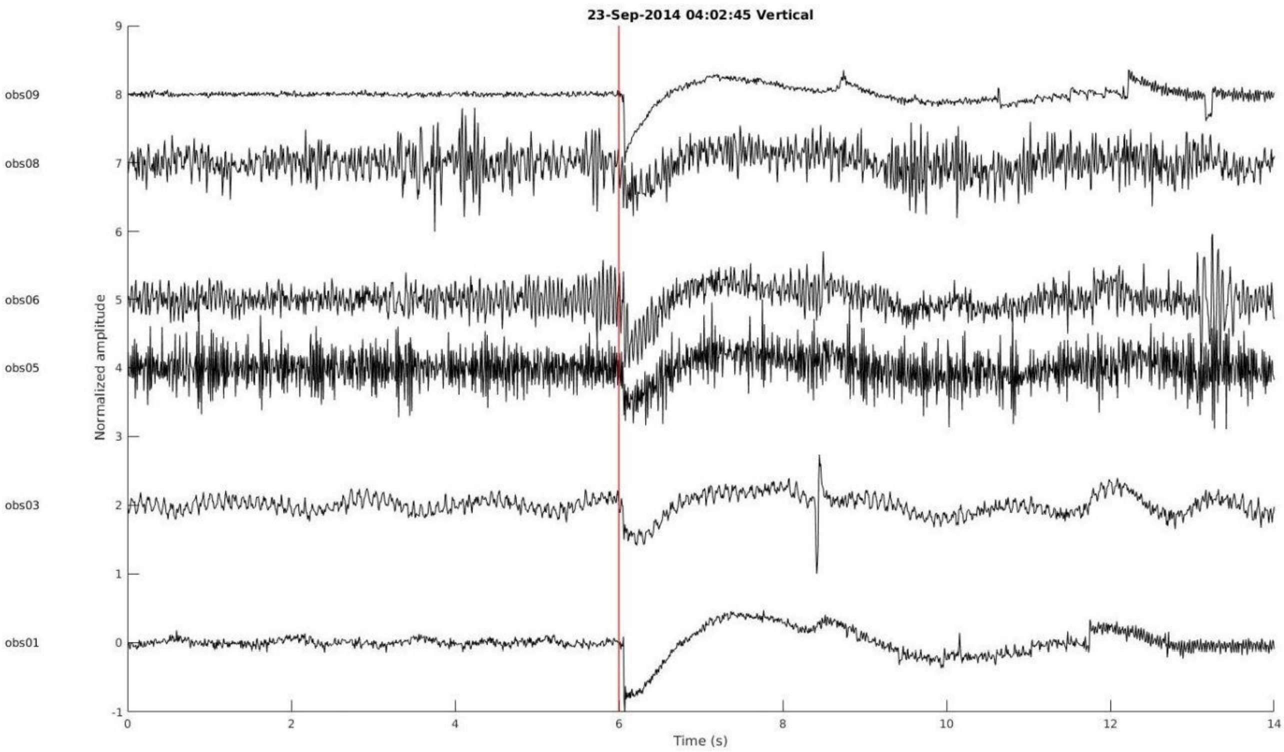

Figure 3 : Aseismic event of Family 3, shown on the vertical component, recorded by different OBS stations, aligned on the P-phase identified by Early-Est (red vertical line).

Comparison of seismic signals collected in different geological environments

The second objective of this STSM was to work on gas-induced seismicity along the NAF in the Sea of Marmara (SoM) and to interact with the group of Professor Robert White, who is working on magma-induced seismicity in Iceland. One of the main difficulties of my work regarding the seismicity in the western SoM is the discrimination-classification of the different types of seismicity (e.g. natural tectonic earthquakes vs gas-induced earthquakes). Therefore, the comparison of different seismic signals collected in different geological environments as well as the methodologies and algorithms used by the group of Professor Robert White were really useful for my work. The scope in the future is to adopt their algorithms on my study area for improving my current results.

Results

The submerged section of the North Anatolian Fault within the Sea of Marmara is one of the current working areas of FLOWS members. The results obtained during the STSM, were in light of the objectives of the COST-FLOWS Action. These results will enhance our current knowledge for better understanding the interplay between seismic activity and fluid dynamics at the NAF transform plate boundary and were relevant with the goals of COSTFLOWS and of the four Working Groups within the FLOWS Action.

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Molecular analysis to study microbial communities in deep sea sediments

Vanessa Oliveira

Purpose of the STSM

Expedition 351 of the International Ocean Discovery Program (IODP) recovered a 1461 m-long sedimentary sequence of Amami-Sankaku Basin (ASB) that records the volcanic eruptions related to the subduction of the Pacific lithospheric plate under the Philippine Sea plate. The subduction-related volcanic debris have accumulated in the ASB for the last c. 50 million years, and now sit below the Philippine Sea at a water depth of 4700 m. In this expedition, 25 sediment samples were collected for onshore microbiological analyses at selected depths, until 880 m below seafloor (mbsf). In the University of Aveiro, molecular biology analyses have been done which include epifluorescence microscopy counts of prokaryotic cells with Acridine Orange Direct Counts, identification of active bacteria community using a nested PCR approach to amplify the 16S rRNA gene sequence, and characterization of Bacteria community structure using a 16S based barcoded pyrosequencing approach. In order to complement the microbiological dataset produced so far in the University of Aveiro, this STSM was held in ETH Zürich to implement new extraction methods for further molecular biology analyses which include next-generation sequencing of bacterial and archaeal 16S rRNA gene sequences, and the preliminary analysis and interpretation of the corresponding DNA sequence data. In addition, interstitial water samples were extracted to quantify the concentration of dissolved nitrate which is a potentially important electron acceptor in these highly oligotrophic sediments.

Description of the work carried out

During the five weeks that I stayed in ETH Zurich, I have performed the DNA extraction of 25 samples collected in Expedition 351 of IODP and their preparation for next-generation sequencing of bacterial and archaeal 16S rRNA gene sequences. First, I did a quantification PCR (qPCR - Real time PCR) in DNA samples previously extracted in Aveiro to have an idea of the number of bacterial and archaeal 16S rRNA gene copies and subsequently comparing with the results obtain after using a new extraction method implemented by Doctor Mark Lever. After that, a few sub-samples of each sample were chosen and the same variations in the method described in Lever et al., 2015 were tested. To check the extraction procedure, qPCR analysis of Bacteria and Archaea 16S rRNA gene copies number were performed. The extraction procedure was performed in a clean room and a blank sample was always included for contamination control. After obtaining the DNA extracted, the next step was to prepare DNA amplicon library to nextgeneration sequencing of bacterial and archaeal 16S rRNA gene sequences using Illumina MiSeq Personal Sequencer at Genetic Diversity Centre (GDC; http://www.gdc.ethz.ch/) located in the Department of Environmental Systems Sciences at ETH Zürich. The samples were prepared according to procedures implemented by GDC.

Briefly, extraction samples were first amplified using a boost PCR and then a tailing PCR was made using primers with barcodes. After that, a first clean up (AMPure beads) was done and Qubit quantification was performed to verify product quantity. In the next step, the Nextera XT index adaptors with the barcode were attached to the amplicon (Index PCR) and then a second clean-up was made. To control the cleaned up sample a Qubit quantification was realized. The last step consisted in the library normalization (putting the libraries in the same concentration) and then pooling. Finally, the pooled library was quantified with the Qubit and qPCR to check if the concentration was between 2 and 4 nM. The next step is to run the samples in Illumina MiSeq Personal Sequencer, which will be done in the next 2 weeks, after the end of this STSM.

Preliminary results

Unfortunately it was not possible to do all the work planned in the five weeks. We had some problems in the extraction which needed to be solved, particularly due to contamination. Nevertheless, the main purpose of this proposal was mostly completed. Moreover, in this STSM I have acquired new and important skills in molecular biology. The main result of this STSM was the obtained amplicon library to next-generation sequencing of bacterial and archaeal 16S rRNA gene sequences using Illumina MiSeq. The qPCR results (Figure 1) show that samples extracted in ETH Zurich have a higher bacterial and archaeal gene copies number comparing with those obtained in the University of Aveiro. These results suggest that in these samples the extraction method tested in ETH Zurich is more efficient than the kit method used in the University of Aveiro.

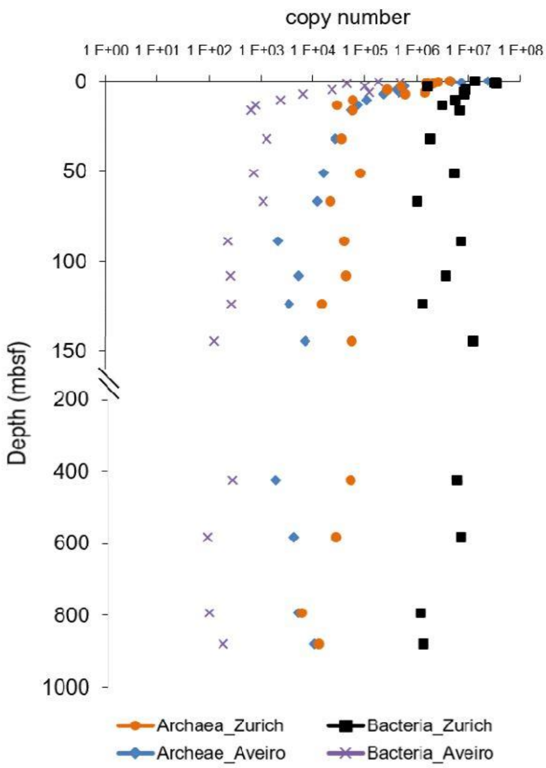

Figure 1: Bacterial and archaeal 16S rRNA gene copy number

Future collaborations including publications

The results of this STSM are going to be integrated in the post-cruise work carried out by Clara Sena, who participated in IODP Expedition 351, and together with Mark Lever, from ETH Zürich, and other colleagues from the University of Aveiro, we will compare the results attained now with the results already published for deep-sea areas with active fluid flow, in order to identify the major differences in the microbial communities and biogeochemical processes that occur in contrasting geological contexts, in terms of fluid flow in deep-sea sediments. In this context, a scientific paper will be prepared to be published in an international journal of the Citation Index.

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Lever MA, Torti A, Eickenbusch P, Michaud AB, Šantl-Temkiv T and Jørgensen BB (2015) A modular method for the extraction of DNA and RNA, and the separation of DNA pools from diverse environmental sample types. Front. Microbiol., 19 May 2015 | https://doi.org/10.3389/fmicb.2015.00476

Sedimentary records of earthquake and fluid activity in the Sea of Marmara

Namik Cagatay

The main objective of the ongoing collaborative studies between ITU-EMCOL (Istanbul, Turkey) and CEREGE (Aix-en-Provence, France) is to date the past earthquake, mass transport, tsunami and fluid expulsion events, and determine slip rates on different segments of the North Anatolian Fault (NAF) by determining ages for some key seismic reflectors by establishing a reliable chronostratigraphy of cores and correlating it with seismic sections. The studied cores were recovered from the Sea of Marmara on board the Ifremer vessel RV "Pourquoi Pas?" during the Marsite cruise held from October 28th to 17th November, 2014 (Fig. 1). The cores is estimated to extend a few hundred thousand years before present. The results of the collaborative studies between ITU and CEREGE will have important implications for seismic risk assessment for the different segments of NAF, and for deciphering the relations between earthquakes and fluid activity. This Cost short-term scientific mission 30321 was carried during 15-20 November, 2015 at CEREGE to contribute mainly to the ongoing core chronostratigraphic studies at ITU and CEREGE.

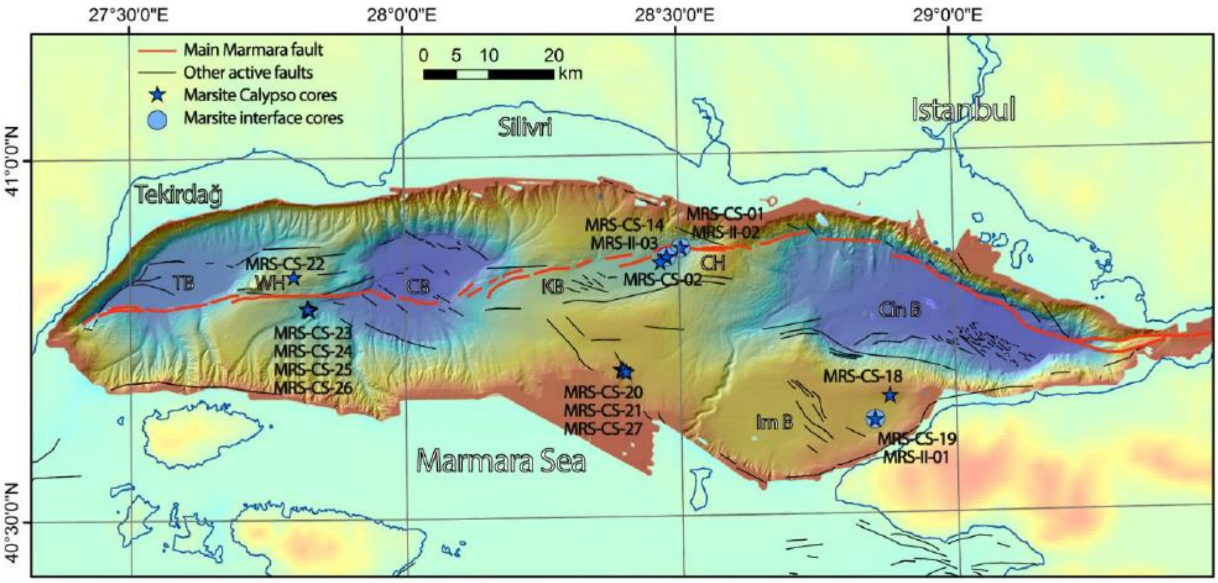

Figure 1: Multibeam map of the Sea of Marmara, with northern branch of NAF (red lines) and location of Calypso and Interface cores recovered during MARSITECRUISE in Oct.-Nov. 2014 (cores MRS-CS 17 to 21 in Imali Basin (Im B) in the east and MRS-CS-01, MRS-CS02, all cores in Kumburgaz Basin (KB) are at ITU-EMCOL; cores MRS-CS-22 to 26 on the Western High (WH) are at CEREGE).

Two sets of cores in Istanbul and Aix-en Provence are being studied by the ITU-EMCOL and CEREGE groups involving one PhD student (Julia Kende) in CEREGE and one PhD

(Nurbike Sağdıç) and one MSc (Nurettin Yakupoğlu) students in ITU. The STSM study at CEREGE involved lithostratigraphic description of up to 23 m-long cores MRS-CS-22, MRS-CS-23 and MRS-CS-26 and their correlation with the cores MRS-CS-18, MRS-CS-19 and MRS-CS-27 in Istanbul, using lithology (tephra, sapropels) and physical properties (MSCL magnetic susceptibility and gamma density). Some cores (e.g., MRS-CS-19, MRS-CS-22) extend back to Marine Isotope Stage 5 (MIS-5) while the base of others (e.g., MRS-CS-18) are possibly as old as MIS-7. The study group involved Namik Çağatay, Pierre Henry, Kadir Kürşad Eriş and Julia Kende.

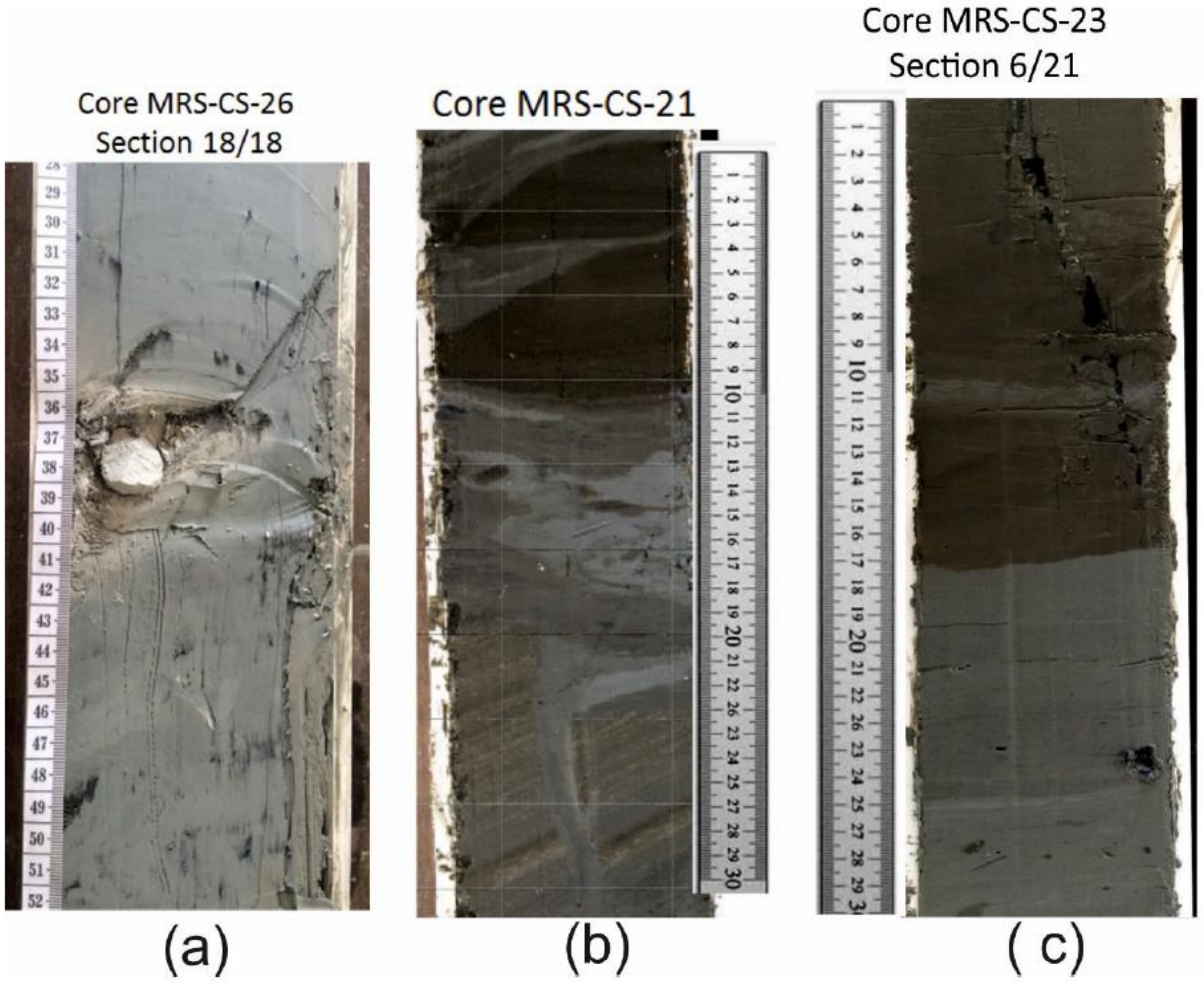

Figure 2: (a) A diagenetic carbonate nodule surrounded by a beige carbonate rich zone in lacustrine mud, possibly formed at methane/sulphate boundary. Note also the 4-5 mm-thick dark elongated sand pipes. (b) A vertical fluid vent, which is infilled with grey mud, cuts through tilted laminated sapropel. It is overlain by deformed grey mud possibly supplied by the pipe, which is in turn overlaid by deformed marine and lacustrine sediments. The whole sequence is part of a slumped sedimentary succession. (c) Grey lacustrine mud is overlain by the dark green sapropel that is dissected by a gas escape structure which is partially filled with coarse silt-sand and black sulphide globules. This interval is characterized by high magnetic susceptibility and density.

The core studies were made mainly for the PhD thesis work of Julia Kende and her training in core description, including the identification of key stratigraphic marker horizons (e.g., marine/ and lacustrine transitions, tephra, sapropels), early sediment diagenesis and diagenetic structures (e.g., redox fronts, carbonate nodules, Fe-monosulfide bands, spots and patches) and other sedimentary structures (e.g., soft sediment deformation, gas escape, turbidites) (Fig. 2).

A meeting involving a series of seminars was held on Wednesday afternoon, 18th November 2015, with participation of Pierre Henry, Edouard Bard, Laurence Vidal, Kazuyo Tachikawa, Julia Kende, Namık Çağatay and Kadir Kürşad Eriş. Seminar presentations were delivered and discussions were held on the results of the ongoing studies on the cores in CEREGE and İstanbul. Plans for feature studies were discussed especially regarding Julia Kende's PhD thesis work. In addition to developing stratigraphic age models based on analyses of especially core MRS-CS-22 and core MRS CS-01 recovered in the Kumburgaz Basin for the seismoturbidite studies, Julia will do µ-XRF analysis of the cores and calibrate total organic carbon analysis with µ-XRF Br and µ-XRF Ca with ICP-MS Ca. Friday, 20th November 2015 was devoted to smear slide study of samples prepared from the described cores to identify lithology, tephra and nannofossils. This STSM helped the effective coordination of the studies and discussion of the results obtained by the two groups at ITU and CEREGE. It was also important for the training of Julia Kende at CEREGE and planning of future work.

Sedimentary records of earthquake and fluid activity in the Sea of Marmara

Kürşad Kadir Eriş

The collaboration between ITU-EMCOL (Istanbul, Turkey) and CEREGE (Aix-en-Provence, France) is based on examining the past earthquake, mass transport, tsunami and fluid expulsion events in the Sea of Marmara. Beside this objectives, our aim is to determine the slip rates on different segments of the North Anatolian Fault (NAF) by determining ages for some key seismic reflectors. These stratigraphic horizons can be dated by establishing a reliable chronostratigraphy of cores and correlating it with seismic sections. For these purposes, we recovered 11 piston cores and 3 gravity cores from the Sea of Marmara on board the Ifremer vessel RV "Pourquoi Pas?" during the Marsite cruise held from October 28th to 17th November, 2014 (Fig. 1). The core sediments are estimated to cover the time period of few hundred thousand years before present. The results of the collaborative studies between ITU and CEREGE will have important implications for seismic risk assessment for the different segments of NAF, and for deciphering the relations between earthquakes and fluid activity. This Cost short-term scientific mission 30321 was carried during 15-20 November, 2015 at CEREGE to contribute mainly to the ongoing core chronostratigraphic studies at ITU and CEREGE. Two sets of cores in Istanbul and Aix-en Provence are being studied by the ITU-EMCOL and CEREGE groups involving one PhD student (Julia Kende) in CEREGE and one PhD (Nurbike Sağdıç) and one MSc (Nurettin Yakupoğlu) students in ITU. The STSM study at CEREGE involved lithostratigraphic description of up to 23 m-long cores MRS-CS-22, MRSCS-23 and MRS-CS-26 and their correlation with the cores MRS-CS-18, MRS-CS-19 and MRS-CS-27 in Istanbul, using lithology (tephra, sapropels) and physical properties (MSCL magnetic susceptibility and gamma density). Some cores (e.g., MRS-CS-19, MRS-CS-22) extend back to Marine Isotope Stage 5 (MIS-5) while the base of others (e.g., MRS-CS-18) are possibly as old as MIS-7. The study group involved Namık Çağatay, Pierre Henry, Kürşad Kadir Eriş and Julia Kende. The core studies were made mainly for the PhD thesis work of Julia Kende and her training in core description, including the identification of key stratigraphic marker horizons (e.g., marine/ and lacustrine transitions, tephra, sapropels), early sediment diagenesis and diagenetic structures (e.g., redox fronts, carbonate nodules, Femonosulfide bands, spots and patches) and other sedimentary structures (e.g., soft sediment deformation, gas escape, turbidites) (Fig. 2). Related to earthquake activities in the Kumburgaz Basin, core MRS-CS01 is being studied by İTU group to define past earthquake records that have been appeared as seismoturbidite layers in the core (Figure 3). Precisely dating these unique layers together with core-seismic correlations allow us to development of stratigraphic age models for sedimentary infills of the Kumburgaz Basin. Based on the sedimentological and paleontological observations by İTU group on core MRS-CS18, different lithostratigraphic units have been subdivided that extends back to MIS-8 (prior to 300 ka BP) (Figure 4).

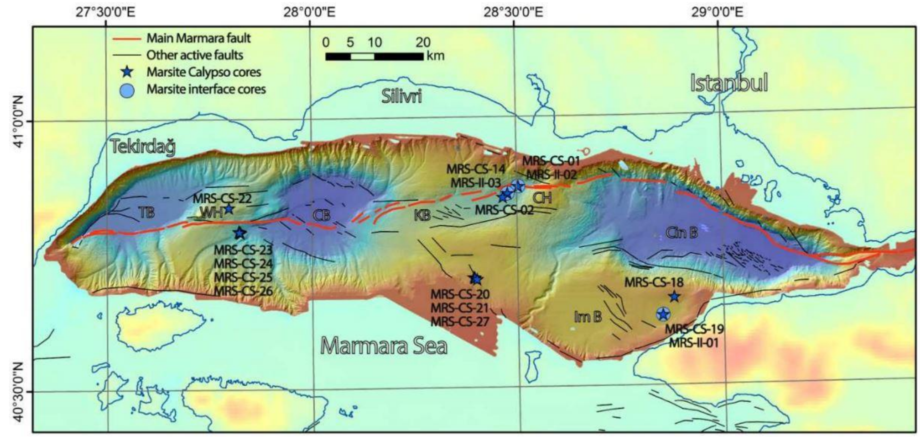

Figure 1: Multibeam map of the Sea of Marmara, with northern branch of NAF (red lines) and location of Calypso and Interface cores recovered during MARSITECRUISE in Oct.-Nov. 2014 (cores MRS-CS 17 to 21 in Imali Basin (Im B) in the east and MRS-CS-01, MRS-CS02, all cores in Kumburgaz Basin (KB) are at ITU-EMCOL; cores MRS-CS-22 to 26 on the Western High (WH) are at CEREGE).

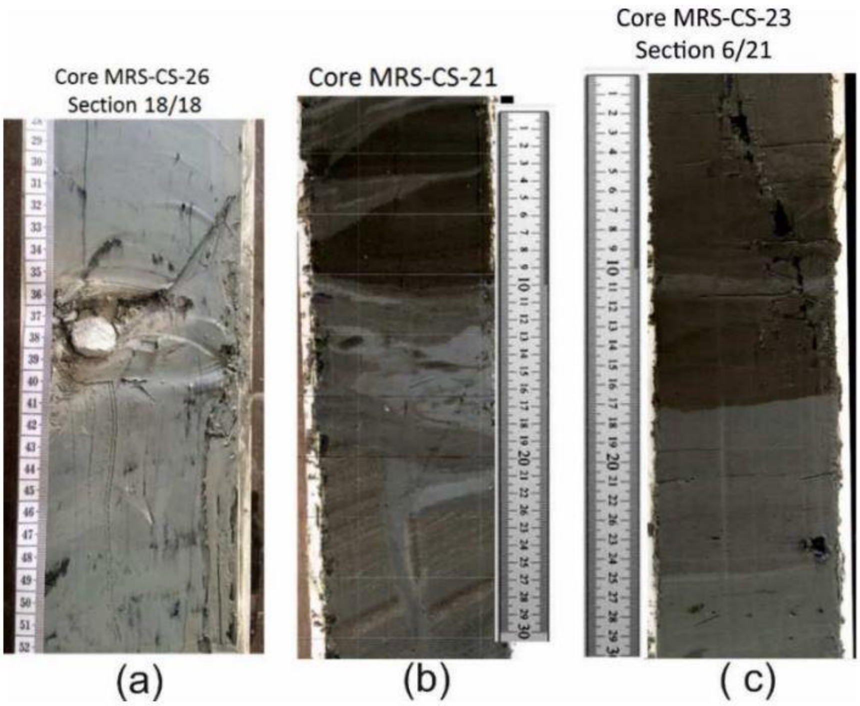

Figure 2: (a) A diagenetic carbonate nodule surrounded by a beige carbonate rich zone in lacustrine mud, possibly formed at methane/sulphate boundary. Note also the 4-5 mm-thick dark elongated sand pipes. (b) A vertical fluid vent, which is infilled with grey mud, cuts through tilted laminated sapropel. It is overlain by deformed grey mud possibly supplied by the pipe, which is in turn overlaid by deformed marine and lacustrine sediments. The whole sequence is part of a slumped sedimentary succession. (c) Grey lacustrine mud is overlain by the dark green sapropel that is dissected by a gas escape structure which is partially filled with coarse silt-sand and black sulphide globules. This interval is characterized by high magnetic susceptibility and density.

During our STSM study in CEREGE, this core has been decided to correlate with cores MRS-CS22, -CS23 and -CS26 in order to determine lithological similarities. Such correlations allowed us to define chronostratigraphies of the core sediments (MRS-CS22, MRS-CS23 and MRS-CS26). Related to earthquake activities in the Kumburgaz Basin, core MRS-CS01 is being studied by İTU group to define past earthquake records that have been appeared as seismoturbidite layers in the core (Figure 3). Precisely dating these unique layers together with core-seismic correlations allow us to development of stratigraphic age models for sedimentary infills of the Kumburgaz Basin. Based on the sedimentological and paleontological observations by İTU group on core MRS-CS18, different lithostratigraphic units have been subdivided that extends back to MIS-8 (prior to 300 ka BP) (Figure 4). During our STSM study in CEREGE, this core has been decided to correlate with cores MRS-CS22, -CS23 and -CS26 in order to determine lithological similarities. Such correlations allowed us to define chronostratigraphies of the core sediments (MRS-CS22, MRS-CS23 and MRS-CS26).

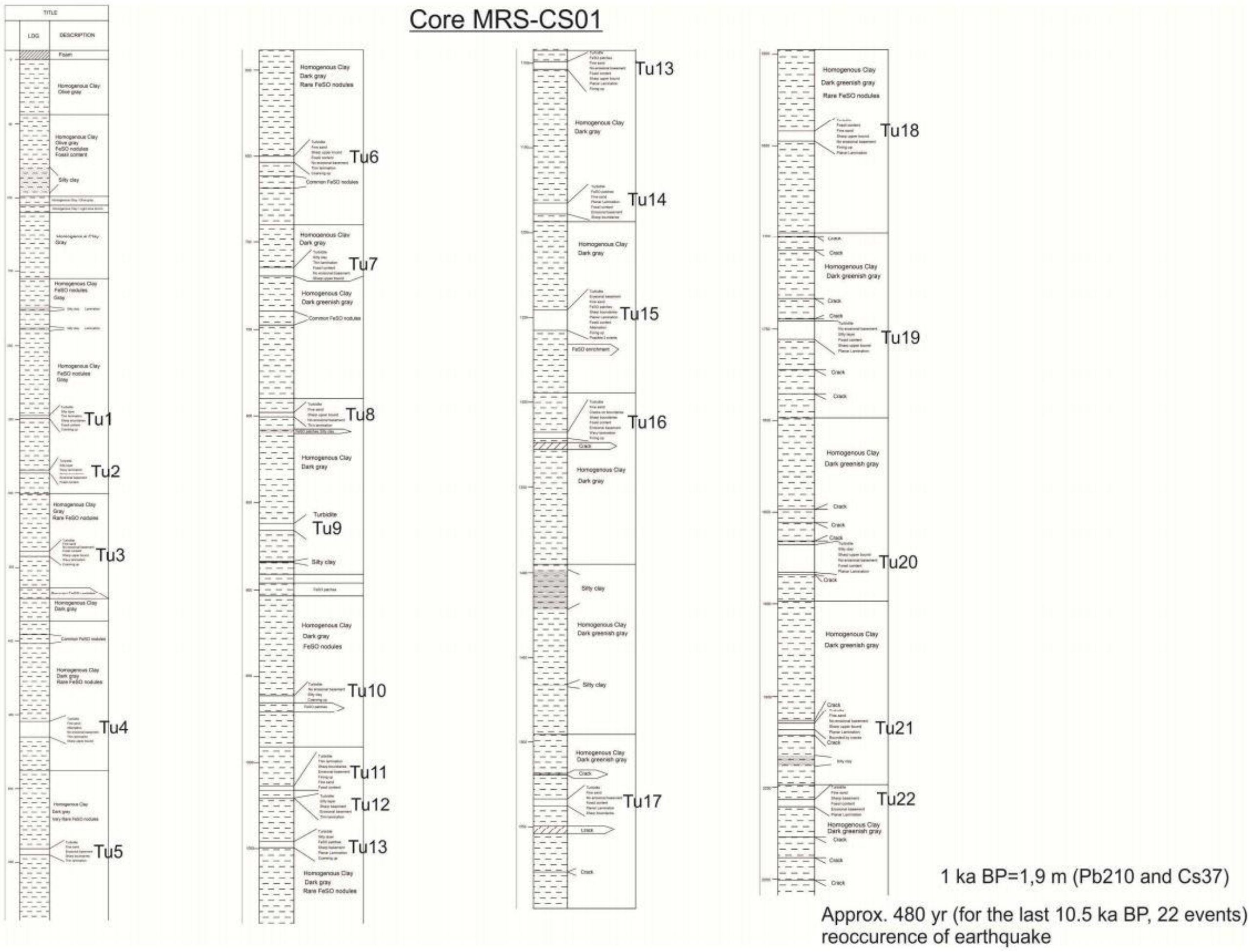

Figure 3: Lithologic description of Core MRS-CS01 recovered from the Kumburgaz Basin showing differentiated twenty-two seismo-turbidite layers covering the last 10.5 ka BP.

A meeting involving a series of seminars was held on Wednesday afternoon, 18th November 2015, with participation of Pierre Henry, Edouard Bard, Laurence Vidal, Kazuyo Tachikawa, Julia Kende, Namık Çağatay and Kürşad Kadir Eriş. Seminar presentations were delivered and discussions were held on the results of the ongoing studies on the cores in CEREGE and İstanbul. Plans for feature studies were discussed especially regarding Julia Kende's PhD thesis work. In addition to developing based on analyses of especially core MRS-CS-22 and core MRS CS-01 recovered in the Kumburgaz Basin for the seismoturbidite studies, Julia will do µ-XRF analysis of the cores and calibrate total organic carbon analysis with µ-XRF Br and µ-XRF Ca with ICP-MS Ca. Friday, 20th November 2015 was devoted to smear slide study of samples prepared from the described cores to identify lithology, tephra and nannofossils.

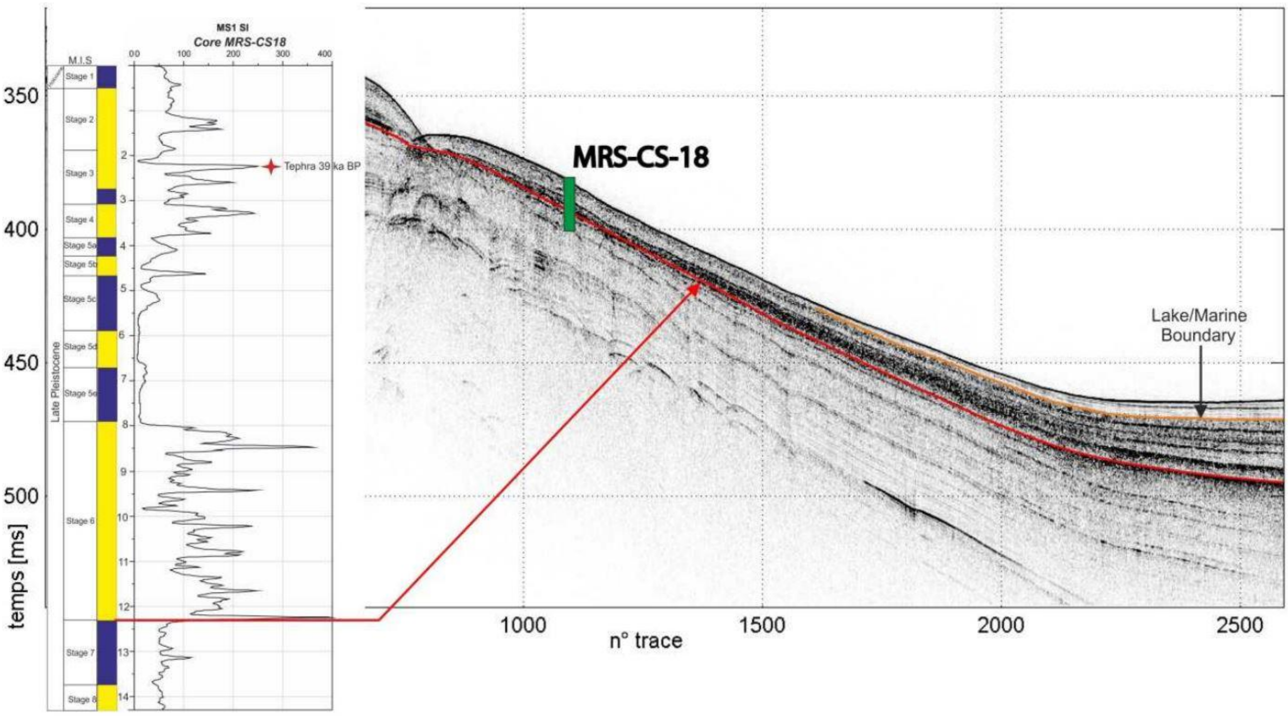

Figure 4: The studied core MRS-CS18 recovered from the eastern İmralı Basin has been examined in order to match with the seismic profile. Through the core we differentiated different lithological units on the basis of sedimentological observations together with magnetic susceptibility data. Yellow colour bar corresponds to lacustrine sediments whereas dark blue represents marine phase of the Sea of Marmara. Alternations of marine and lacustrine litho-units can be well correlated with Marine İsotope Stages that extends back to stage 8 in the core. This core can be very well correlated with core MRS-CS22 and Cs23 studied in CEREGE.

This STSM helped the effective coordination of the studies and discussion of the results obtained by the two groups at ITU and CEREGE. It was also important for the training of Julia Kende at CEREGE and planning of future work.

Mud breccia/deep fluids – sediment-fluid interactions beneath mud volcanoes from the Alboran Sea

Carmina López-Rodríguez

Purpose of the STSM

Mud volcanoes are geological structures that expel large volumes of detrital material (rock and clast fragments), together with hydrocarbon-rich fluids (e.g. methane), representing "natural windows to the deep geosphere". This eruptive behavior provides key geological and geochemical information on the nature of deep sources feeding the mud volcanoes, and offers insights into the diagenetic processes operating at depth, such as the formation/dissociation of gas hydrates, mineral transformations, the degradation of organic matter and high pressure/temperature-reactions (e.g., Dählmann and de Lange, 2003; Haese et al., 2006; Hensen et al., 2007; Scholz et al., 2009; Magalhães et al., 2012).

In mud volcanoes, the upward migration of hydrocarbon-rich fluids is conditioned by overpressurized material from deeper sedimentary layers. The venting activity in a seepage field is not always homogeneous and can vary from site to site (Haese et al., 2006). In the same field of mud volcanoes, individual and neighboring structures can have different scales and intensities of fluid discharge, which not only controls the level of seepage activity but also affects the composition of the expelled fluids.

Mud volcanoes in the Alboran Sea occur under a convergent tectonic setting, and hence constitute key settings to explore the interplay between tectonics, detrital sediments, authigenic mineral precipitation, deep fluids and the deep biosphere under active plate boundary. The scope of this FLOWS STSM has been focused in investigate the interaction between active seepages and deep fluids from geochemical proxies and isotopic compositions of mud breccias from the Carmen mud volcano from the Alboran Sea (westernmost Mediterranean). At the time we have also evaluated the main diagenetic processes that may affect the fluid composition through its ascending transport by the application of numerical modeling using integrated datanof pore water analyses, in combination with sediment data from the mud breccia.

Description of the work performed during the STSM

During the 35 days of my stay at the Department of Earth Sciences at Utrecht University (Utrecht, the Netherlands), I have performed the preparation, analysis and interpretation of the organic carbon and nitrogen content as well as stable carbon isotopes of solid phases of mud breccia samples (matrices) from the Carmen mud volcano (Alboran Sea).

For this aim and prior to the geochemical analysis, all discrete samples of mud breccias were previously dried in an oven at 40 ºC and later ground and homogenized in an agate mortar. For total organic carbon (TOC) 1000 mg of each sample was decalcified using 1 M HCl. The decalcified samples were again dried at 40 ºC and finely ground using an agate mortar at the facilities of the Andalusia Earth Sciences Institute (CSIC-UGR; Granada, Spain). During my stay in the Earth Science Department at Utrecht University I run the specific preparatory method for total organic carbon (TOC), total nitrogen (TN) contents as well as for carbon isotope compositions of the organic carbon (δ13Corg (‰)). Thus decalcified samples were afterwards put into specific silver cups and carefully weighted in a high precision microbalance.

For TOC and TN contents samples were weighted between 5-20 μg whereas for stable carbon isotopes weights were between 0.5-4 μg. After weighing, TOC and TN were determined on a Fisons Instruments NCS NA 1500 analyzer using dry combustion at 1030ºC. In addition, the carbon isotope compositions of the organic carbon (δ13Corg (‰)) was determined with a VG SIRA 24 mass spectrometer in the shore-based laboratory at the Department of Earth Sciences, Geochemistry (Utrecht University). The isotope data were reported in the conventional delta notation with respect to VPDB. Precision (≤0.1‰) and accuracy were established using international (Graphite quartzite standard NAXOS (GQ)), and in-house standards (Ammonium Sulphate (ASS), Acetanilide, and Atropine).

Description of the main results obtained

The total organic carbon (TOC) content and the stable carbon isotopes on mud volcano-related sediments from Carmen mud volcano are particularly useful to determine the origin of the organic matter and their influence on fluids generation. During this FLOWS STSM these analyses have been successfully performed. Preliminary results have shown that all mud breccia samples have similar geochemical characteristics. Total organic carbon (TOC) content in the mud breccia samples has demonstrated that the extruded materials in Carmen MV are rather similar among them and consequently show constant distribution in depth. Similarly, nitrogen content also exhibits similar values. All these findings provide key information about the geochemical signatures of the solid phases of the extruded materials from Carmen MV.

Preliminary results obtained during this FLOWS STSM are also being compared with previous obtained pore water data, in order to understand the potential impact of organic matter degradation on sediment-water interactions and constrain the mechanism of fluid migration. In addition, during this FLOWS STSM I also had the opportunity to work in collaboration with the specialist researcher Dr. J. Mogollón, running a numerical-reaction model, in order to estimate variations in methane fluxes as well as the timing of the mud eruptions. With all the new obtained data as well as with the use of previous geochemical data on both solid and fluids phases we will be able to estimate the origin and quantify migration rates of deep fluids. This study will allow understanding how this type of fluids can influence the mud volcano activity, composition and generation of deep fluids as well as their linkage with microbiological and geochemical reactions.

Future collaboration with the host institution

The Department of Earth Sciences is the largest academic Earth Sciences institute in the Netherlands, and among the larger ones in Europe. The shore-based Geo-Lab is the main laboratory facility of the Faculty of Geosciences which has a wide range of lab facilities available for measuring bulk rock geochemistry, bulk rock stable isotopes (H, C, N, S), in situ stable and radiogenic isotopes (U,Pb-dating), in situ major and trace elements and crystallography. The development of this research project has been an excellent opportunity to be trained in preparatory methods for specific geochemical analyses as well as to be formed in discusses and interprets geochemical data. It has permitted to collaborate with Dr. José Mogollón and also closely work under the supervision of Prof. Gert De Lange, ensuring the well development and completion of this research. This short-term scientific mission has enormously contributed in the ongoing collaboration between the host institution and our scientific group in Spain, favouring new discussions and geochemical issues which will be the target of further short-term scientific missions.

Scientific contributions and publications resulting from the STSM

All data that have been obtained during the development of this short-term scientific mission are being processed and corrected. Once results will be interpreted they will be integrated as part of a scientific manuscript which will be submitted in highly internationally-reputed journal in Earth Science (e.g., Geochimica e Cosmochimica Acta, Chemical Geology or Earth and Planetary Science Letters) and presented in international geological congresses (e.g., European Geosciences Union General Assembly, Goldschmidt Conference).

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Study of the focal mechanism of the 1.5 years seismic data from the 31 seismometers network installed in Indonesia

Karyono Karyono

Summary

Karyono STSM took place from the 30 of March to the 29th of April. During this period Karyono collaborated with experts in seismology at the ETH-Zurich under the guidance of Anne Obermann. The STSM focused on three main activities: • Completion and submission of the manuscript "Bridging surface and subsurface observations from the geysering Lusi eruption, Java, Indonesia" to the journal Terra Nova. The submitted manuscript focusses on a multidisciplinary study completed at the Lusi eruption site combining visual observations and subsurface data acquired with 5 seismic stations positioned around the Lusi crater. Results reveal insights about the different modes of geysering activity. • Preparation of poster and oral presentation for attending the EGU conference (16-23April). Karyono presented his results with a poster describing the results of the manuscript submitted to Terra Nova and gave an oral presentation on the focal mechanism study of the seismicity in NE Java. • Study of the focal mechanism of the 1.5 years seismic data from the 31 seismometers network installed in Indonesia. This study has been one of the core activities during the STSM trip and Karyono scanned through a large database and learned the use of new softwares and techniques.

Purpose of the STSM

The STSM completed by Karyono had multiple purposes that included 1) the submission of a manuscript, 2) attending and presenting at the EGU conference, and 3) actively processing acquired data. More specifically the main goal was to get familiar with the software for earthquake location and focal mechanism determination. For the event localization, he aimed to complete a relative relocalisation and improve the velocity model of the region. The pourpose of Karyono's work was to: 1)Analyse nearly two years of seismic data recordings obtained from 31 seismic stations deployed around Lusi and reaching the volcanic arc, including the fault zone. Karyono needs to adapt triggers and various scripts for event localization and various other routines for seismic data processing; 2) Refine the velocity model of the area 3) Localize seismic events and invert moment tensor solutions to determine the seismic activity occurring in the area.

Description of the work carried out during the STSM and relevance for flows

The first accomplishment of Karyono STSM was to complete his work on the combined surface and subsurface observations of the geyser behavior of Lusi. He successfully defined four activity phases of the Lusi activity related to geysering. In addition he managed to characterize the tremor events associated to the rise of mud and gas mixtures in the conduit. For this purpose, the seismic activity associated with the geysering cycles has been studied and linked to camera recordings of the surface activity. We could characterize the geysering cycles and identify volcanic tremor events that are associated with rising gas pockets in the column during the geysering activity. This novel study has been compiled in a manuscript that was submitted ("Bridging surface and subsurface observations from the geysering Lusi eruption, Java, Indonesia" and submitted to the journal Terra Nova). The second important goal of Karyono's visit was to attend his first international conference: EGU in Vienna. He contributed with two papers submitted at the session "Ten years of Lusi eruption - lessons learned about modern and Side 2 ancient piercement systems". He presented his new manuscript results with a poster "(Monitoring and Characterizing the Geysering and Seismic Activity at the LUSI Mud Eruption Site, East Java, Indonesia") and gave on oral presentation on the data processed during his STSM experience ("Analysis of Focal Mechanism and Microseismicity around the Lusi Mud Eruption Site, East Java, Indonesia"). Both contributions gathered relevant interest by the audience attending the session. The most important goal of karyono's STSM to investigate the relationship between seismicity, volcanism, faulting and Lusi activity, a network of 31 seismometers had been deployed in January 2015 (still running) within the framework of the ERC-Lusi Lab project. This network covers a large region that monitors the Lusi activity, the Watukosek fault system and the neighboring Arjuno- Welirang volcanic complex.

Data

The local seismic network is shown in Fig. 1, consisting of 10 broadband (blue) and 21 short-period (red) seismic stations covering the Arjuno-Welirang volcanic complex, the Watukosek fault system and Lusi. As a first step, we evaluated the local site conditions by studying the seismic background noise at each station. For this purpose we study the power spectral density from each individual station and check whether it lies in between the USGS High and Low noise model (Peterson 1993). The USGS Noise Model summarize the lowest/highest observed vertical seismic noise levels throughout the seismic frequency band. It is extremely useful as a reference for assessing the quality seismic stations and for predicting the detectability of small signals. In Figure 2, we show an example of a „good" and a „noisy" site. With the red square we indicate the frequency band of interest for the study of local earthquakes. The „good" sites are mostly broadband stations located on bedrock within the volcanic arc, whereas the noisy sites are mostly shortperiod sensors on sediments close to populated areas (around Lusi).

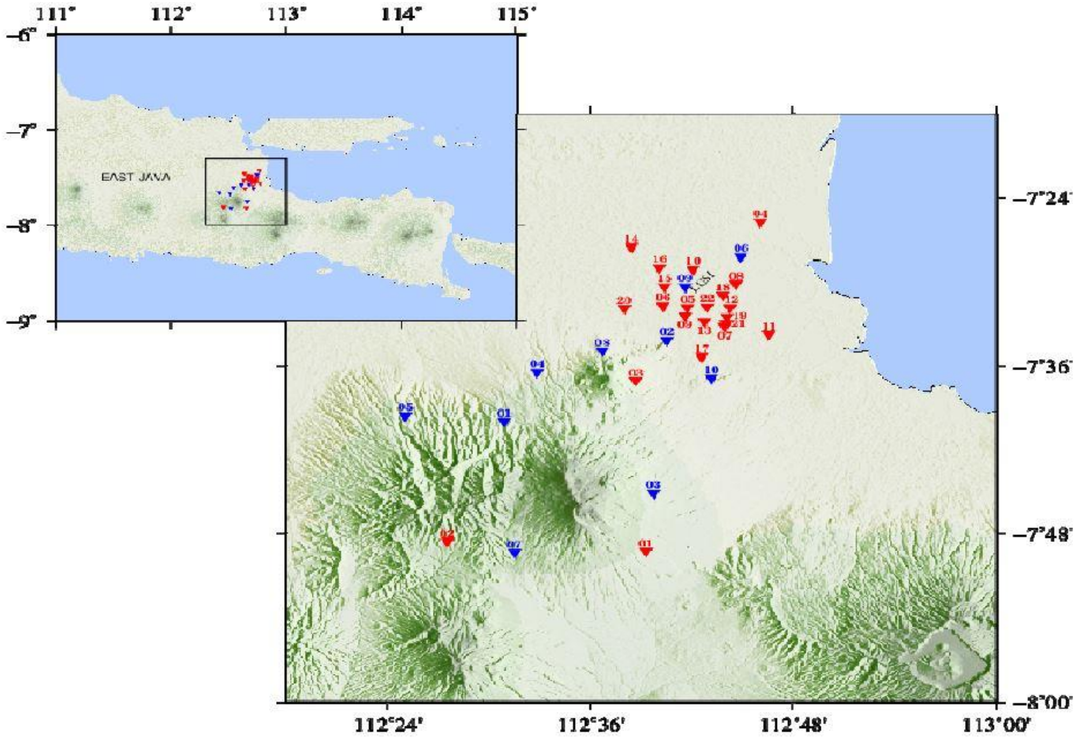

Figure 1: The seismic network consisting of 10 broadband (blue) and 21 short-period (red) seismic stations around the Lusi site.

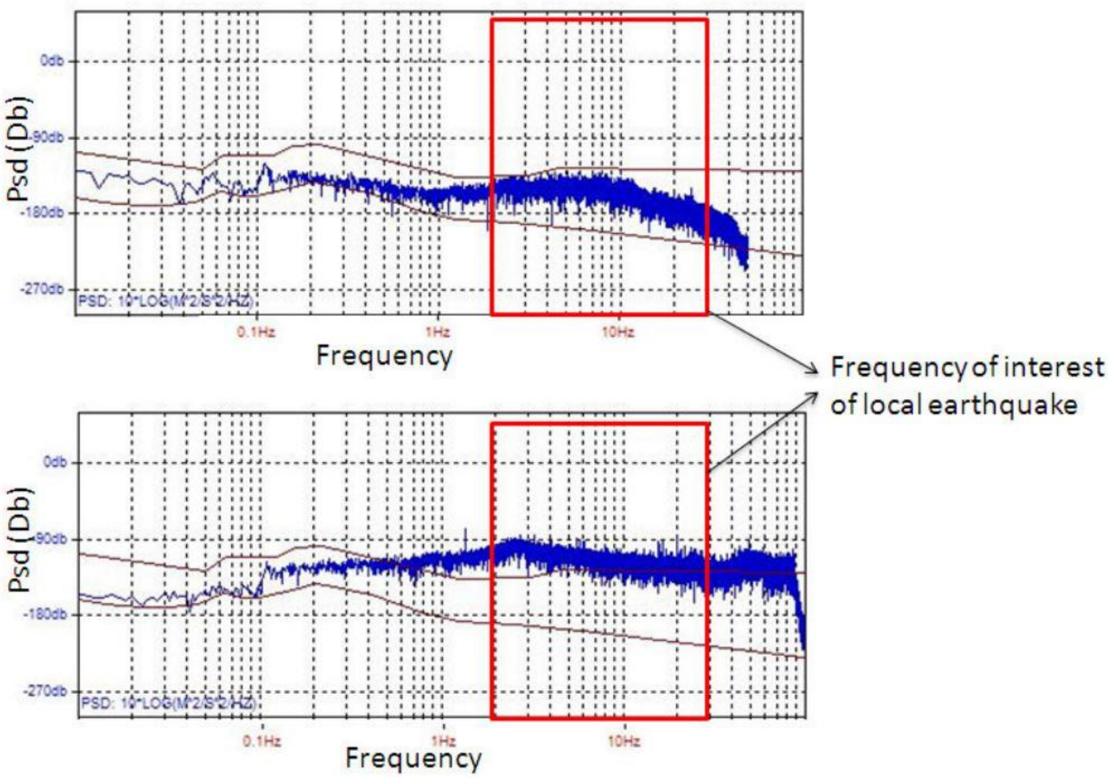

Figure 2: Background soise levels at two sites (a) typical example of a broadband station (BB08) on bedrock. (b) typical example of a shortperiod station (SP13) on sediment close to a populated area.

Methods

Earthquake detection and picking

The first and most time consuming step is the detection and picking of local earthquakes in the continuous records. This very important step is done manually. We have to differentiate between local, regional and distant earthquakes, of which only the local ones are of interest for us. We use the seiscomp3 software for this procedure and follow a couple of criteria to obtain good quality picks: (a) We use a bandpass filter of 1-30 Hz; (b) A clear P-phase must be detected on at least 8 stations; (c) The picks are assigned manually; (d) We assign picking uncertainties to have a quality control for the later studies. An example of this picking procedure is shown in Figure 3.

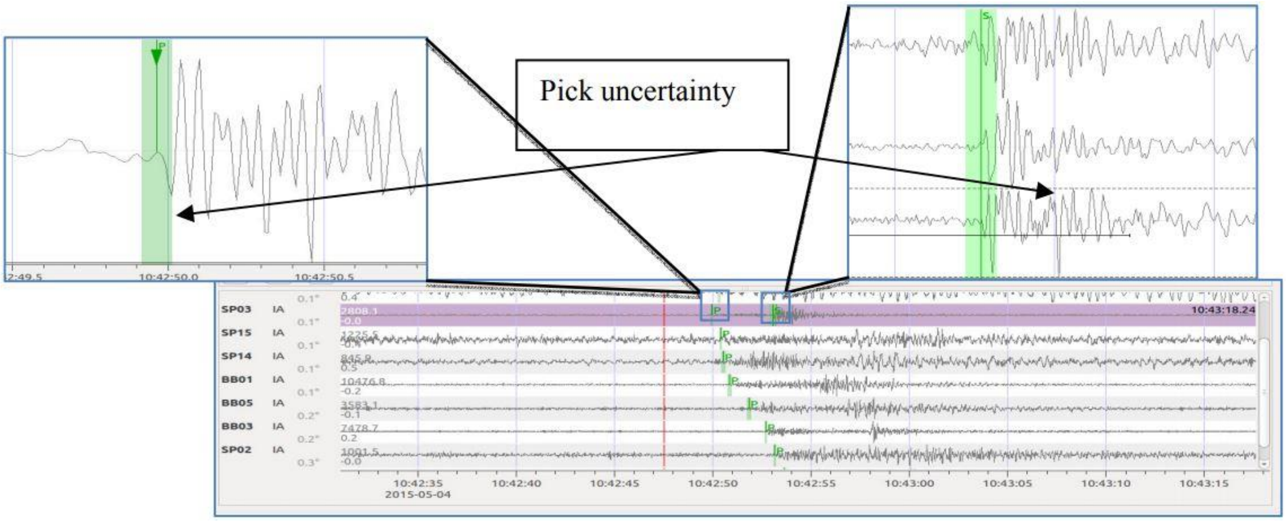

Figure 3. Picking earthquakes with the seiscomp3 software with assigned uncertainties.

Minimum 1-D velocity model

The next step is the localization of the seismic events. As the seismic velocity model in the area is unknown, we first use the data to determine a minimum 1-D velocity model that will be used to assess the quality of the stations and relocate the seismic events. We use the software Velest (Kissling et al. 1994) for this purpose. We first select a subset of the clearest (strongest) local earthquakes under following criteria:

Azimuthal gap < 180°	Station number > 8	Rms < 0.5 seconds

These criteria left us with 70 events. For these events we simultaneously invert for hypocenter location, velocity structure and station quality. In Figure 4, we show the resultant averaged 1D velocity model for the region (red) compared with the averaged velocity model for the island of Java (black). We notice substantial differences at depths from 10-15 km.

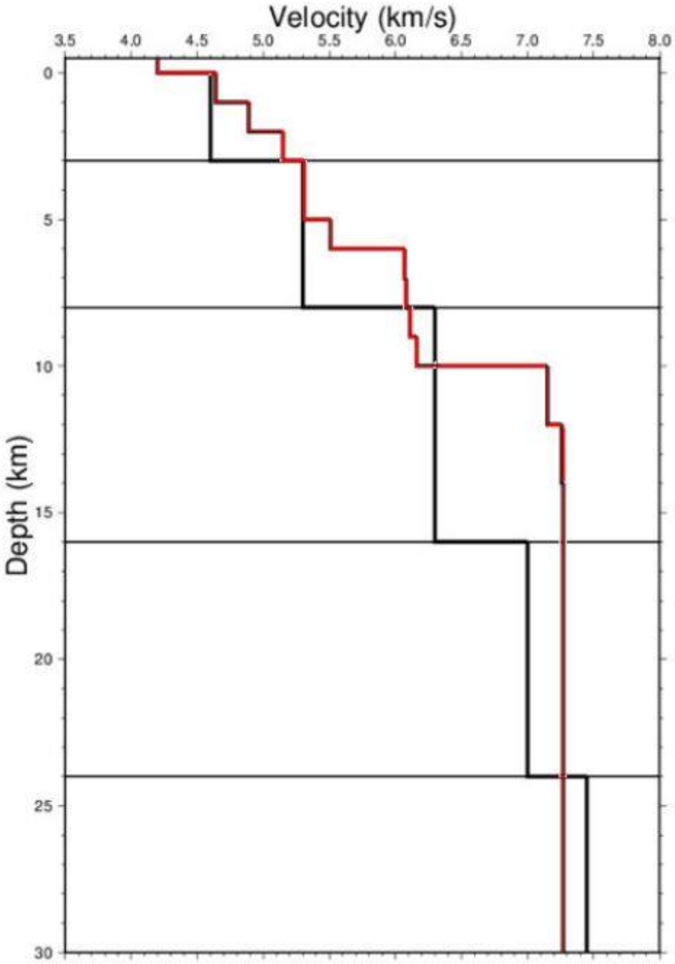

Figure 4 : Minimum 1-D velocity model averaged for the region (red) and compared with the 1D velocity model for the entire island of Java (black).

From the inversion we also obtain station corrections, which are basically the delay times of the individual seismic station compared to a reference station (marked with a star in Figure 5). These station corrections are interesting parameters as they can be used to get an idea of the geology of the area and to assess systematic shift in the location of seismicity. Negative station corrections mean that the real velocities are faster than the 1D velocity model, positive station corrections indicate that the local velocities are slower than 1D velocity model. As we can see in Figure 5, the Lusi area has higher values of station corrections, indicating that this area has slower velocities than the rest of the region. This is not surprising seen the amount of uncosolidated mud ejected by Lusi.

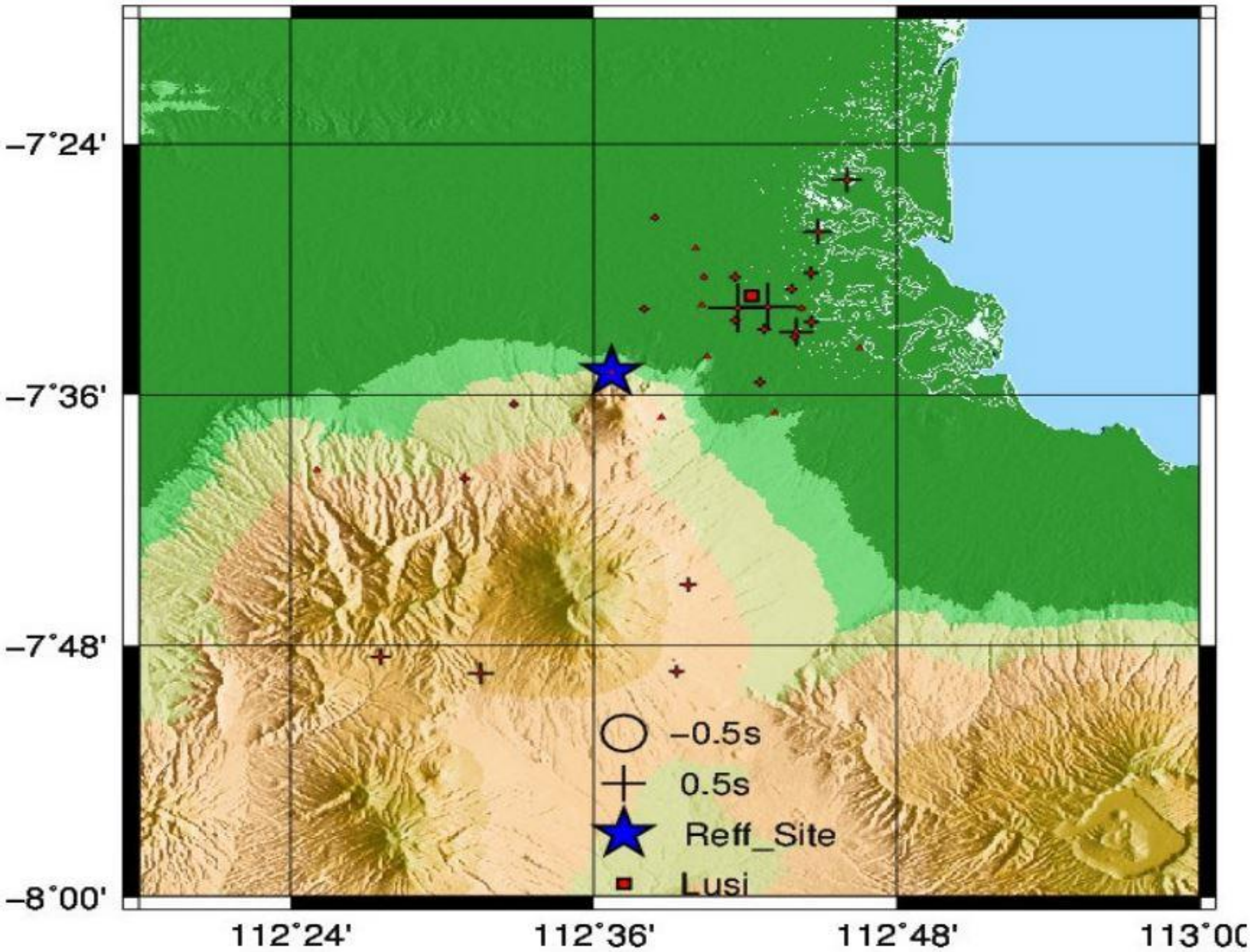

Figure 5: Station corrections in and around Lusi indicating delay times of the individual stations compared to the obtained minimum 1D model obtained at the reference site (blue star).

Relocation of seismicity

We use the 1D velocity model obtained in the previous section to relocate all seismic events. The preliminary locations are shown in Figure 6. We notice that there are hardly any events below Lusi. The seismicity clusters around the ArjunoWelirang volcanic complex. The events depth varies between 10-15 km, the two events at 45 km might be errors and will be reinvestigated.

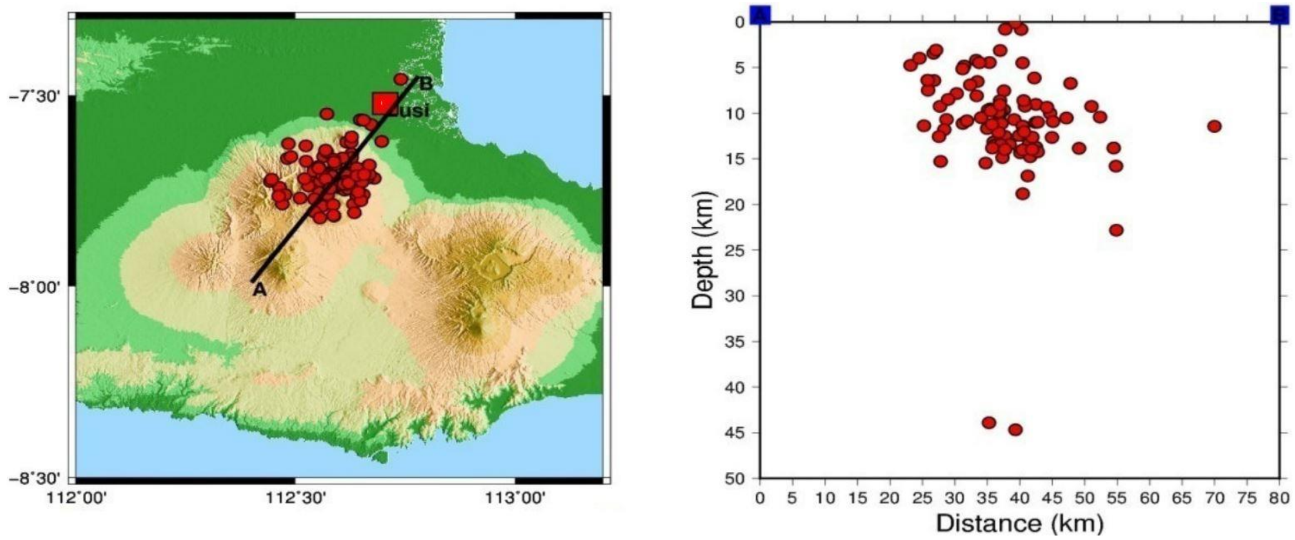

Figure 6 : Relocated seismicity in the Lusi area. The events cluster below the Arjuno-Wlirang vocanic complex. The depth of the events is mainly between 10-15 km.

3.4. Focal mechanism

We take the best three events to determine the focal mechanisms that are a proxy for local tectonic settings. All three events are shown in Figure 7 and indicate a strike slip mechanism with right lateral movement of the fault. This is consistent with the general tectonic settings in this area.

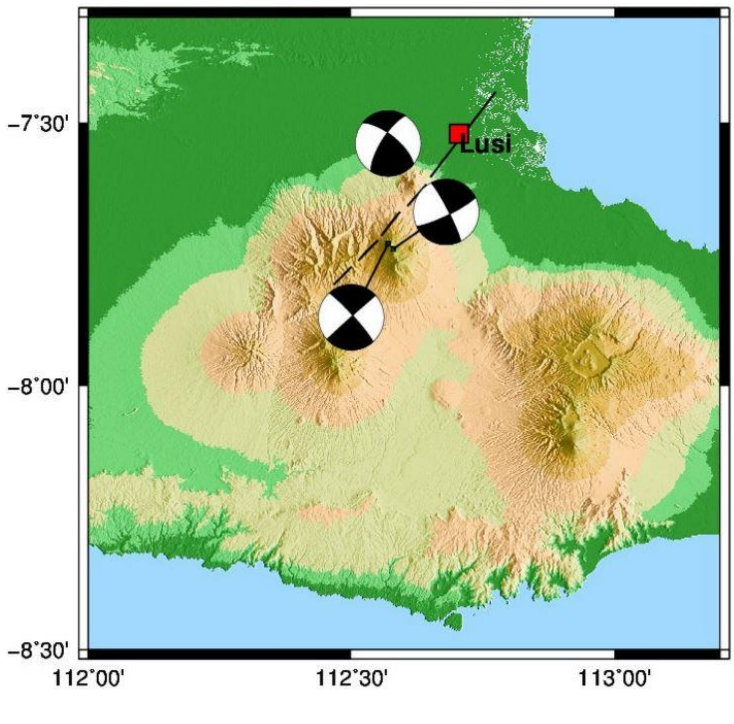

Figure 7 : Focal mechanism of the three strongest events in the area indicate strike slip motion.

3.5 Preliminary conclusion and future work

From an analysis of the data from 1 year, we are surprised by the overall low rate of microseismicity in the region (90 events with M0.6-M2). We notice that most of the seismicity falls into the volcanic complex and occurs within shallow depth (10-15km). The local noise conditions (high noise especially around Lusi) make it complicated to detect microseismicity and might bias the study. The preliminary analysis of the source mechanism of some selected events indicates strike-slip, which is consistent with the general tectonic settings in the area.

Description of the main results obtained in light of the objectives of the FLOWS action

Understanding the interaction between seismicity, volcanism, fluids seepage and strike-slip phenomena is indeed extremely relevant and pertinent for the FLOWS activities. Karyono's work encompassed the various aspects of these geological phenomena. In particular, he aimed to understand the consistent pattern of the source mechanism, relative to the general tectonic stress in the study area.

Future collaboration with the host institution

The collaboration between CEED and the ETH in the framework of the Lusi Lab project is already ongoing since a couple of years. Karyono's PhD and visit is one of the main positive outcomes of this successful cooperation. There is no doubt that the collaboration between these institutes will continue in the following years. As a next step, we will analyse the remaining 6 months until June 2016 and finalize our study.

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Preparation of in situ monitoring of radioactive gases (radon/thoron) emanation upon shallow pockmarks in Eckernförde Bay, Baltic Sea, Germany

Dionisis Patiris

Summary of the report

During this STSM Dr. Dionisis Patiris, postdoctoral researcher of HCMR, was hosted by the GEOMAR Helmholtz Centre for Ocean Research at Kiel for a period of one week (29 May – 5 June 2016). According to the proposed work plan, all necessary preparation works for common deployment of the gamma-ray spectrometer KATERINA of HCMR along with GEOMAR flow-through sensors and field utilities were accomplished. KATERINA was adapted on a platform containing a CTD meter and battery pack. Dr. Dionisis Patiris and PD Dr. Mark Schmidt joined in two daily cruises of RV Littorina on May 31st and June 2nd into the Eckernförde Bay and data of radon/thoron radioactive gases along with data of water conductivity and temperature were acquired upon a pockmark area of the bay. The scope of the first trip was to obtain spatial profile of radon/thoron and radioactive potassium along a predetermined transect covering the area of pockmarks. In three regions, the temperature and the number of gamma rays were increased with a simultaneous decrement of water salinity. These observations indicated groundwater emanation from the seabed. The scope of the second trip was to gather gamma-ray spectra upon an area of groundwater emanation with the aim to quantify radon, thorn and potassium activity concentrations. The scopes of both trips were achieved and a first dataset of in situ observation of radioactive gas emanation was obtained. The analysis of the data is still in progress (concerning the quantification of radon concentration) and the final results is expected to constitute the scientific base for upcoming publications in the form of article and/or conference presentations. Moreover, the basis for future common operational actions between HCMR and GEOMAR was established concerning the identification of submarine groundwater sources.

Purpose of the STSM

The scope of the proposed mission was the accomplishment of all necessary preparation works for common deployment of the gamma-ray spectrometer KATERINA of HCMR along with GEOMAR flow-through sensors and field utilities. Also, it was planned to carry out a first deployment at specified areas upon shallow pockmarks in Eckernförde Bay. The deployment provided in situ radioactive gas emanation data obtained simultaneously with seawater parameters in the area. Thus, new scientific information was provided regarding identification of groundwater seepage from an area of pockmarks based on in situ radio-tracing technique.

Description of the work carried out during the STSM

The work carried out during this STSM could be summarized under the following tasks:

a. Adaptation of gamma-ray spectrometer on an appropriate platform: During this STSM the gamma-ray spectrometer of HCMR KATERINA was transported to GEOMAR's facilities at Kiel with the aim to be adapted onto a platform for in situ measurements simultaneously with a Conductivity Temperature and Depth (CTD) logger. Prior the STSM, continues communication between the involved researchers and technicians had the aim to determine the technical needs (e.g. sensors physical characterises, dimension, weight, power needs, and communication ports) for the adaptation. The task was successfully achieved by the valuable contribution of GEOMAR's technical support team. On the figure 1 the preparation stages are presented.

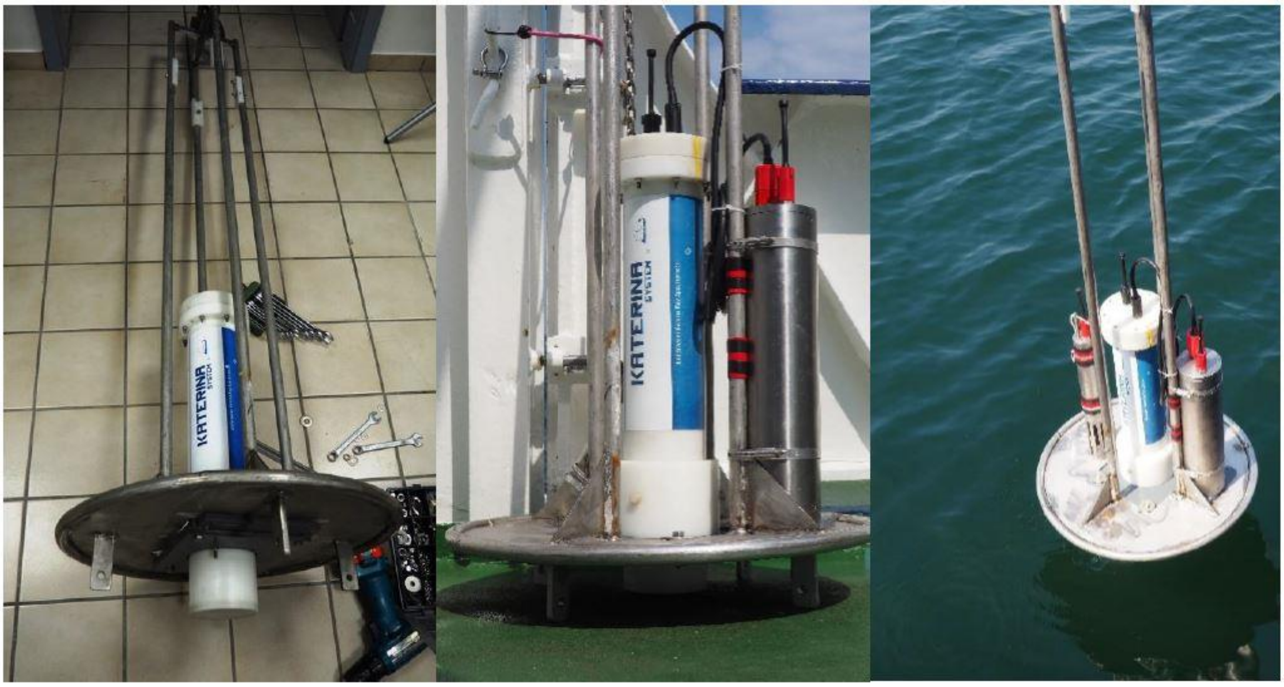

Figure 1. Adaptation of the gamma-ray spectrometer KATERINA onto application specified platform along with CTD meter and battery pack. Attention was paid to the proper exposure of the detection crystal to seawater and its protection from accidental bump on the seabed

b. Trip day 1, 31 May 2016, spatial profiling of gamma-ray along transect: The scope of the first trip was to obtain spatial profile of radon, thoron and radioactive potassium along a predetermined transect covering the pockmark area presented in the figure 2. The platform with the sensors was held by RV Littorina winch and remained constantly 2 meters upon the seabed. At this distance, the contribution of gamma-rays emitted from the seabed sediment is minimized while the sensors still can gather data from the seawater. The profiling plan was based on acquiring gamma-ray spectra every 200sec while RV Littorina will travel along the transect with minimum speed (0.5knt or 15m min-1). By this way, every spectrum contains the sum of gamma-rays obtained from a spatial interval of approximately 50m (orange marks on the figure 2). As indicator of radon/thoron presence the total gamma-ray counts and the counts on energy windows (specified according to gamma-ray energy emitted by radon and thoron progenies) were used. As indicator of groundwater emanation water salinity and temperature records of CTD were used. The results are presented in figure 3.

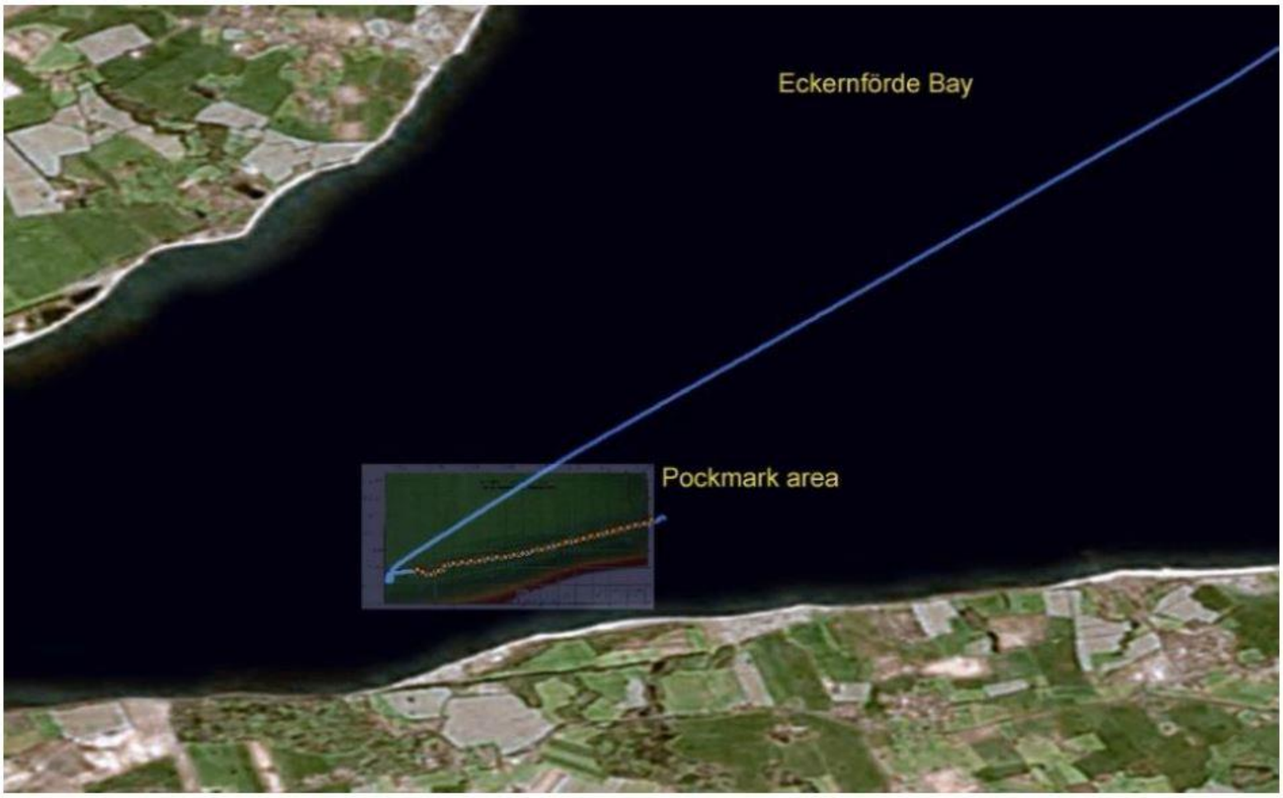

Figure 2. Study area, the transect and the position of gamma-ray spectra acquisition are presented

The background of total gamma-ray counts represents the total gamma-ray record received in a location of the bay that is not influenced by the pockmarks. For that, another gamma-ray spectrum received (acquisition time 3167sec) in a location away from the pockmark area at the same depth as the profiling phase. At the figure 4, the spatial profiling of the total counts of gamma-rays is depicted where three regions of enhanced number of counts can be observed. The area of groundwater emanation that strongly contribute to the gamma-ray counts is also depicted in the figure 4 and it was selected as the area of measurements for the next trip. During the trip, a total of 30 spectra acquired with acquisition time of 200sec. The spectrum obtained from the sum of the 30 spectra was used for a first estimation of an average value of radon, thoron and potassium activity concentrations in the area. For this end, the full spectrum analysis (FSA) method [Androulakaki et al., 2016] was used. The method is based on the reproduction of the experimental spectrum (which contains gamma-ray peaks of all radioisotopes) with a number of theoretically obtained spectra (each one of them contains gamma-ray peaks of only one radioisotope). For the reproduction, theoretically obtained spectra of the following radioisotopes were used; corresponding to thorium series, actinium 228Ac and thalium 208Tl (thoron daughter), corresponding to uranium series 238U, bismuth 214Bi and 214Pb lead (both radon daughters) as well as the radioactive isotope of potassium 40K. The reproduction process are summarized in the figure 6.

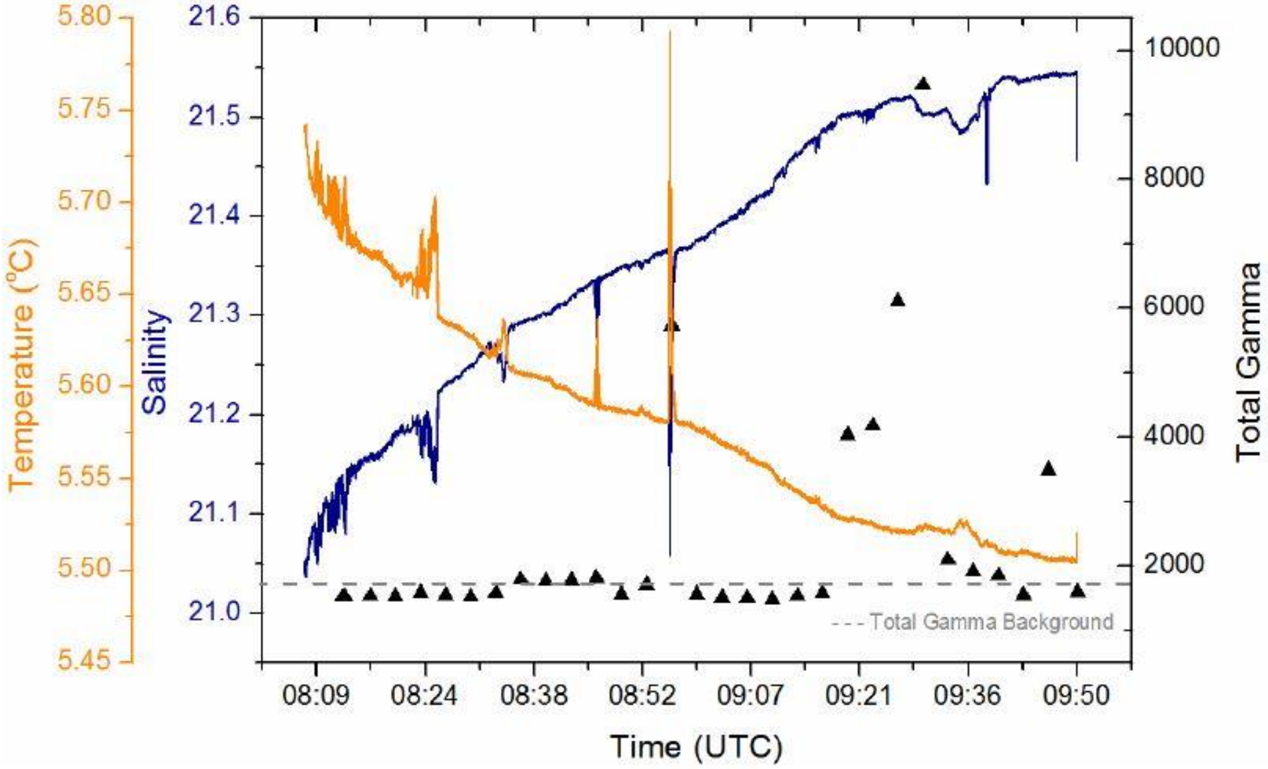

Figure 3. Results of total gamma-ray counts profiling along with salinity and temperature

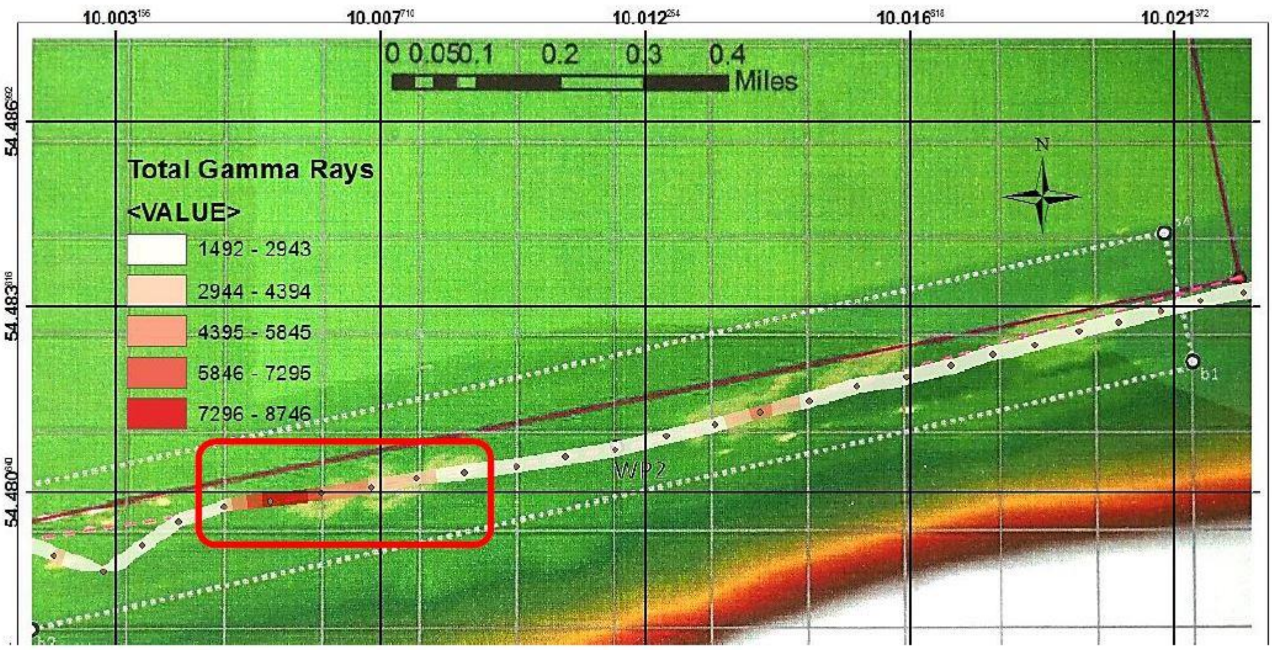

Figure 4. Total gamma-rays profiling map where three regions with enhanced counts can be observed

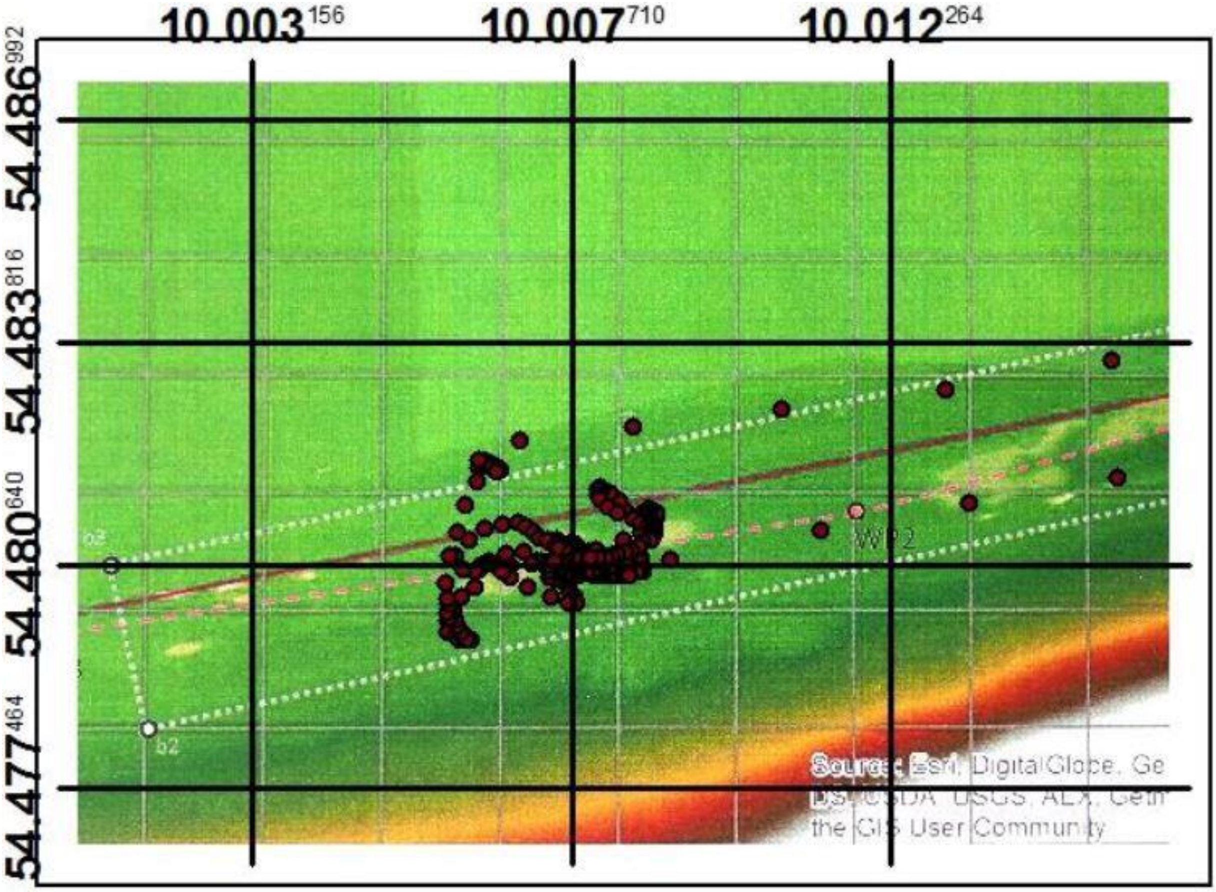

Figure 5. Positions of RV Littorina upon selected the area

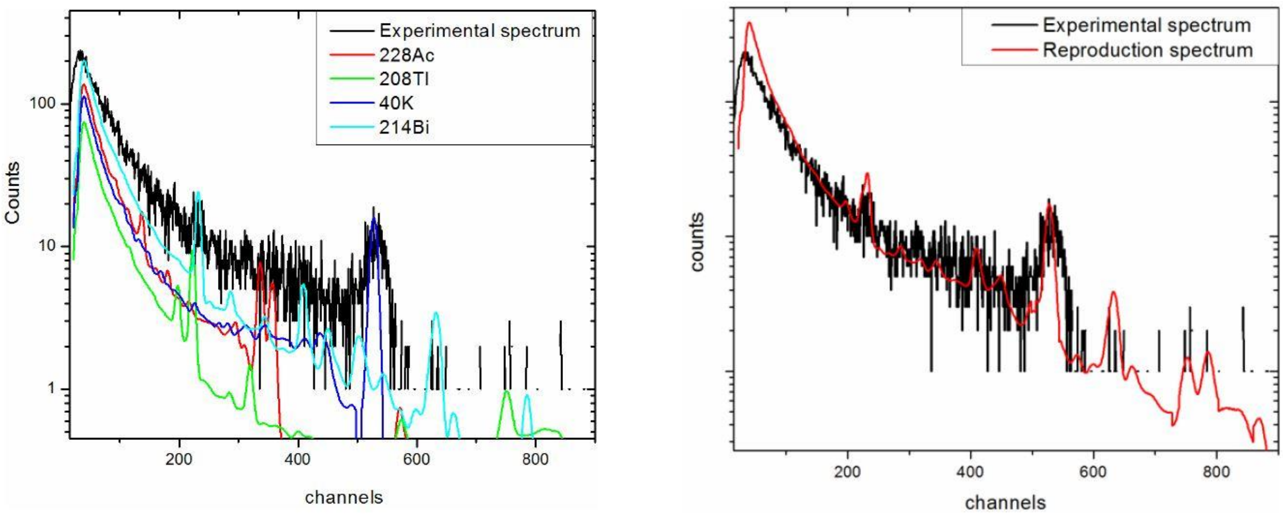

Figure 6. The reproduction of the spectrum obtained during the second trip by the FSA method

The use of the method resulted in the activity concentrations presented in the table 1. The uncertainty of the measurements range between 25-30% due to the poor statistics of using short acquisition time. In case of potassium 40K, the activity concentration corresponds to salinity values in the range of 20-21 which is close enough with the results obtained by the CTD. Further analysis of the separated spectra is expected to provide spatial distribution of the aforementioned radioisotopes in the vicinity of the area where the second trip was focused on.

Table 1. Activity concentration of radioisotopes involved in the FSA method

Radioisotope	Activity concentration (Bq/l)
^{214}Bi (radon daughter)	1.0
^{214}Pb (radon daughter)	0.9
^{228}Ac	0.1
^{208}Tl (thoron daughter)	0.2
^{40}K	7.0

Description of the main results obtained in light of the objectives of the FLOWS action

The data acquired during this STSM activities are in accordance with the main COST-FLOWS objective of “distinguish potential (bio) geochemical proxies that could be used in the future physico-chemical sensors to detect precursory seismic activity”. Specifically, introducing radio-tracers (radon, thoron, potassium) upon “fluid-emitting structures” as the pockmarks of Eckernforde Bay will support the efforts for “crucial insights to the connectivity of deeply buried crust, overlying sediments and water” which is a goal of the working group 3 of the project. The same working group encourages combined measurements of “temperature, gaseous hydrocarbons, and radioisotopes” using in-situ devices as well as the combination of in-situ measurements with laboratory ones. Moreover, common field work and interference among scientist of different disciplines realized strengthening the communication of novel technological and methodological aspects and promoting the integration of early-stage researchers in a frame of expert research group in the earthquakes precursors’ field.

Future collaboration with the host institution

During this STSM, the basis for future common operational actions between HCMR and GEOMAR was established concerning the identification and monitoring of submarine groundwater sources (or other fluids emanation). Combination of in situ radio-tracing techniques and seawater analysis methods may provide spatial profiling and/or temporal monitoring in areas with hydrogeological and geophysical interest.

Foreseen publications/articles resulting from the STSM

The analysis of a portion of the data (concerning the quantification of radon concentration) is still in progress. The quantification of radon concentration is based on recent published methods (Androulakaki et al., 2016; Tsabaris and Prospathopoulos, 2011). Both of them are automated and user-independent methods to analyse gamma-ray spectra even in the case of low concentrations and poor statistics. Both methods will be utilized to the analyses of the spectra obtained during this STSM. Also, it is the first time, the in situ gamma-ray spectrometry technique is followed in the investigation of the STSM area of study. Thus, the final results is expected to constitute the scientific base for upcoming publications in the form of article and/or conference presentations.

Confirmation by the host institution of the successful execution of the STSM

The successful STSM will help to further constrain joint activities in deep sea monitoring, as it is summarized in a recently submitted ITN proposal sent to the COST-FLOWS board.

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The crustal structure at the Gloria Fault and its relationship to fluid circulation and geological inheritance

Katrin Hannemann

During the short term scientific mission (STSM) within the framework of FLOWS, I visited the Instituto Dom Luiz (IDL) in Lisbon (Portugal) from 03. July until 08. July 2016. The main goals of the STSM were:

• joint meeting of researchers from different disciplines (e.g. geology, geophysics) with a research focus on the Eurasian-African plate boundary in the Atlantic (Gloria fault)

• exchange of results from seismology, structural geology, analogue experiments, numerical models and active seismics in the vicinity of the Gloria fault

• discussion of the obtained results with the aim to understand the overall structure, as well as the role of fluid migration and interaction processes at the Gloria fault (major transform fault)

• identification of possible drilling locations along the fault and identification of research questions for an IODP proposal

All goals were achieved during the STSM and all participants agreed on the benefits of a multi-disciplinary look at the structures related to the Gloria fault and their implications for fluid migration and interaction in relation to this major oceanic transform fault. I presented the results obtained with ocean bottom stations (OBS) North of the Gloria fault. The OBS were used for the localization of the local and regional seismicity. This gives insight into the fault activity within the Eurasian and African plate as well along the fault trace. The observations suggest an activation of parallel transform faults which form the plate boundary and are observed in the sea-floor bathymetry. East of the OBS array (at -18.4° E), the seismicity is located directly on the plate boundary given by Bird (2003) and shows a clear vertical fault line in depth profiles. West of the array, the seismicity is more diffuse and located North of the plate boundary given by Bird (2003). The researchers at IDL and Instituto Português do Mar e da Atmosfera (IPMA) were interested in the seismicity recorded by the OBS array as their own networks based on the Azores and in Portugal did not record it. Interestingly, the OBS array was not able to detect events with magnitude 5 close to the Azores. On the other hand, the researches at IPMA reported that events located around the former OBS array location are only detected on seismometer records in Portugal, but not at the Azores. This indicates that there seems to be some kind of barrier which prevents seismic waves to pass in either direction. The investigation of this apparent barrier might be a possible target for future research in this area.

An active seismic experiment across the Gloria fault presented by Luis Batista showed evidence for a layer of serpentinized mantle (Batista et al., submitted). This is in good agreement with my results of a receiver function study which give details for the crustal and mantle structures North of the Gloria fault (see Figure 1). Both data sets show in combination a transition of the serpentinized mantle observed close to the fault towards the rather undisturbed mantle in the Eurasian plate (Hannemann et al. 2016). This indicates a high influence of fluid interaction in the vicinity of the fault.

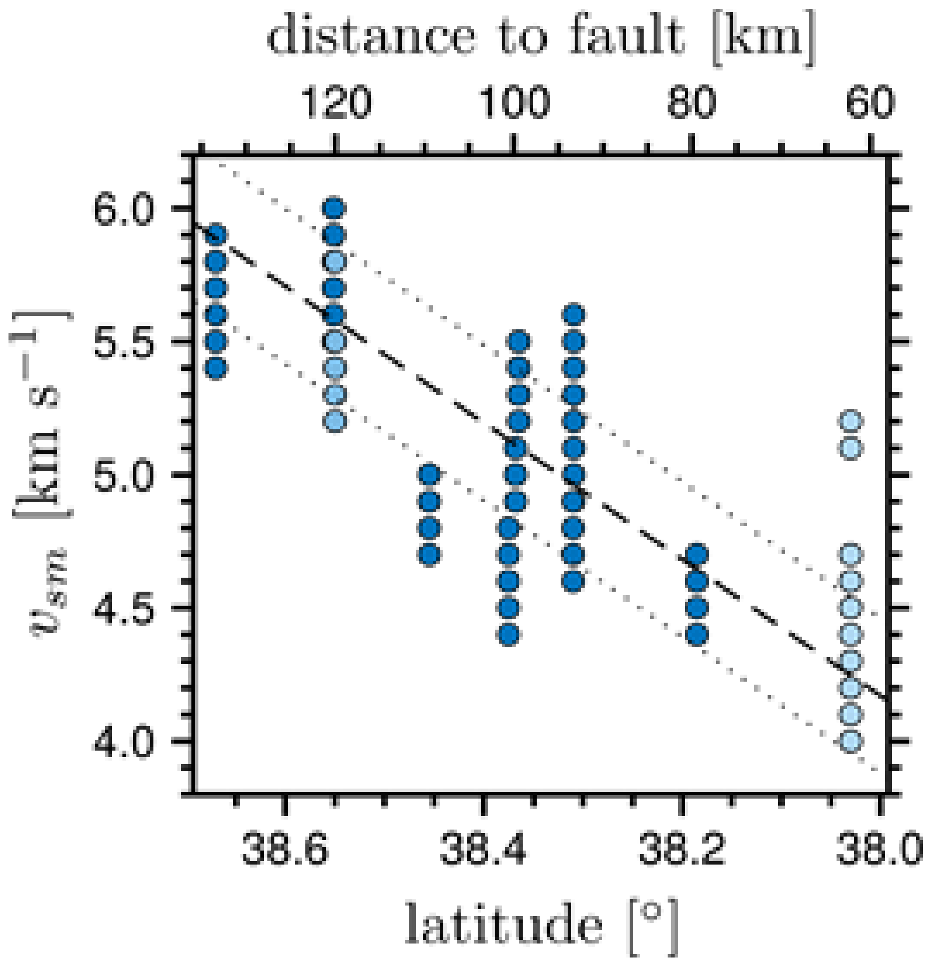

Figure 1: Mantle S wave velocities as obtained by the analysis of P wave polarization at the OBS array North of the Gloria Fault. The decrease in the velocity towards the fault can be interpreted as an increase in serpentinization in the mantle towards the fault (Hannemann et al. 2016, Fig. 15a).

The acquired data and results provide good insight on the segments of the Eurasian-African plate boundary (especially the Gloria Fault) which are more active. Furthermore, this information will be crucial for the selection of potential targets for higher-resolution surveys (e.g. seismic reflection and refraction, sampling, coring, imaging potential fluid-related processes and structures). The latter is also an important pre-requisite for the selection of possible drilling sites for an IODP proposal.

In conclusion, the STSM gave me a good opportunity to learn more about the crustal and mantle structures which I am investigating and to relate my observations with the tectonic structures North of the Gloria fault. Furthermore, I received new evidence to link my observations of decreasing shear wave velocities towards the Gloria fault to the penetration of fluids along fractures in the oceanic mantle. I also used this STSM to get in touch with the researchers at IDL and Instituto Português do Mar e da Atmosfera (IPMA) and to identify common research interest.

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Transform Faults Analogue Modelling: application to the NAF

Sibel Bulkan

Summary

During the STSM, between the 15th of September and 14th of December 2016, and under the guidance of Prof. Fabrizio Storti, 3D analogue experiments were performed at the "Elisabetta Costa" Analogue Modelling Laboratory of the University of Parma. The study aimed at investigating the relationship between the horizontal propagation and branching of the western part of the North Anatolian Fault (NAF).

The experiments were calibrated at the crustal scale. The lower crust ductile-brittle transition was simulated through viscous silicone. The silicone was placed on plexiglass sheets that were able to move according to the geometry that was intended to be reproduced. The brittle upper crust was simulated through pure sand placed on top of the silicone. Controlled strike-slip displacement and the pull-apart structures were reproduced by right-laterally pulling the plexiglass base using the two motors.

The results of the analogue experiments are compared with the west part of the NAF system.

Purpose of the STSM

One of the most remarkable features of the North Anatolian Fault –NAF- (Turkey) is the westward branching taking place in the area of the Sea of Marmara. The transition from a single to at least three main branches corresponds to slip rate variations as revealed by geodetic and paleoseismic measurements. Following the devastating earthquakes of 1999 studies focused on the northern branch of NAF and the Sea of Marmara. Contrasting geometry models - classic pull-apart, flower structure and transform-parallel strike slip basins - have been proposed based on different geophysical and geological data sets. The south branch, which is characterized by a lower slip rate than the northern branch. It has been less studied, yet the meaning of the slip deficit measured in the south branch is not well constrained. The purpose of the STSM in Parma University was:

1) Investigating the development of pull apart basins at releasing bend in strike slip fault by simulating the geometry of the NAF 2) Defining the regions of uplift and subsidence to see how the master-fault propagates during the deformation, helping to cover the gaps between geodetic and geologic slip information. 3) Comparing the results of these experiments with natural examples around the western part of NAF and with seismic observations - will have the ultimate aim to understand the geometric evolution of the branching and kinematic of west part of the NAF system.

Description of the work carried out during the STSM

In this work, we carried out a set of 7 analogue models - each with different set of parameters. (Table 1) Plexiglass sheets were purposely cut to simulate the geometry of the NAF. Silicone was placed on the top of these to simulate the viscous lower crust, while the brittle upper crust sediments were simulated with pure dry sand (Table 2). Dextral relative fault motion was imposed with the computer-controlled motors as well using different velocities to reproduce different strain rates and pull apart formation at the releasing bend (Figure 1). The length scaling ratio was ~5x10-6 that is 0.05 cm in the experiment corresponds to ~1 km in nature (Table 1). Before the deformation, a 1x1 cm sand grid was applied on the surface of the models in order to monitor progressive displacement and rotations during the experiments (Figure 2)

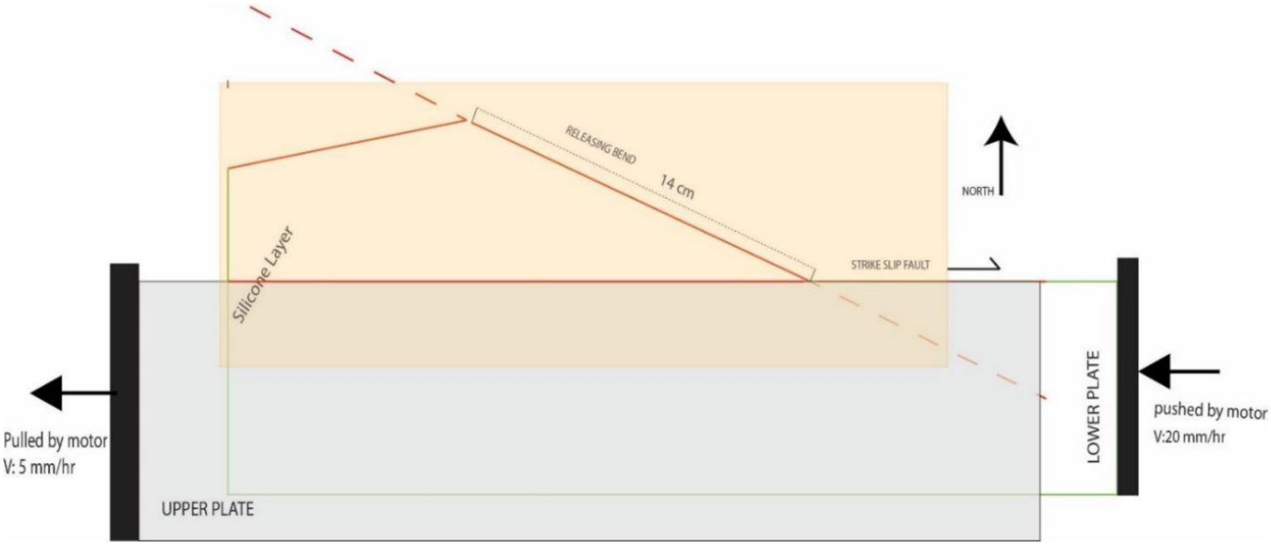

Figure 1: showing the one of example of experiment setup of models

The evaluation of all experiments was monitored by overhead time-lapse photography in every 2 to 5 minutes and structured light scanning, which provided
elevation data in every 5 mm displacement (Figure 3)

Model n.	Thickness (cm) silicone	Thickness (cm) dry sand	Velocity mm/hr	Displacement (cm) Lower Plate	Displacement (cm) Upper Plate
Mar-02	0.2	1.5	V_1:20	7	N/A
Mar-03	0.2	1.5	V_1: 20; V_2:6	7	1
Mar-04	0.2	1.5	V_1: 20; V_2:6	7	1
Mar-05	0.1	1.5	V_1: 20; V_2:6	7	1
Mar-06	0.1	1.5	V_1: 20; V_2:12	7	3.7

Table 1: Key parameters for models

Materials	Density (g/cm^3)	Mean grain size (μm)	Choesion at peak (Pa)	Angle of internal friction φ	Dynamic shear viscosity η (Pa s)
Sand[1]	1.670	224	102	33°	- - - -
Silicone + barite [2]	1.150	- - - -	- - - -	- - - -	1,4 x 10^4

Table 2: [1]Upper crust (from Klinkmüller et al., 2016) [2]Weak lower crust (from Cappelletti et al., 2013)

Serial cross sections were cut at the end of the deformation after wetting models with tap water and waiting 24 hours to ensure complete imbibition.
The top images of models taken during experimental runs were analysed at a scale with MATLAB based program, PIVlab software, a tool to determine displacement fields within and around individual shear structures on the sand particles.
Cross section photographs were uploaded to MOVE Software, to create 3D virtual models of the experimental results, thus helping their interpretation (Figure 4). Also, using MOVE software, we calculated the regions of uplift and subsidence to see how the fault growth could influence the geomorphology.

Preliminary results with the objectives of FLOWS Project

As a first step, using MOVE software, we extracted the positions of fault tips and folds every 5 mm of displacement on the master fault (Figure 3,4). Our next step in 3 months is analysing these positions in all of the experiments to find how the growth rate of faults. Secondly, with the 'displacement field analysis' we evaluated, the variation of the shear zone shapes and how the master-fault and newly-formed faults propagate into the sand.
Understanding of the interaction between the fluid activity and strike slip faults is, related with the FLOWS Project. Also, NAF is one of the key sites of FLOWS Project, particularly the west portion where the fault branches. The results obtained during the STSM work will provide insight to our current knowledge with the structure and activity of the west part of NAF in terms of a direct influence on fluid circulation, past and present, on fault rheology and potential seismic activity. We demonstrated that lower crustal flow may explain how the deformation is transferred to the upper crust, and stress partitioned among the strike slip faults and pull-apart basin systems. Stress field evolution seems to play an interesting role to help strain localization.
With the scope of STSM, 7 different models have been achieved only in 3 months. In addition, during the STSM period with Parma University in Italy, I was supervised by Prof. Fabrizio Storti and Dr. Cristian Cavozzi (technical head of the lab) and I have learnt how to design, deform and analyse analogue models. Also, I had to chance to practice of using software

"MOVE" which allowed to analysis of results by producing the topography maps, cross-sections and, eventually, 3D renderings.

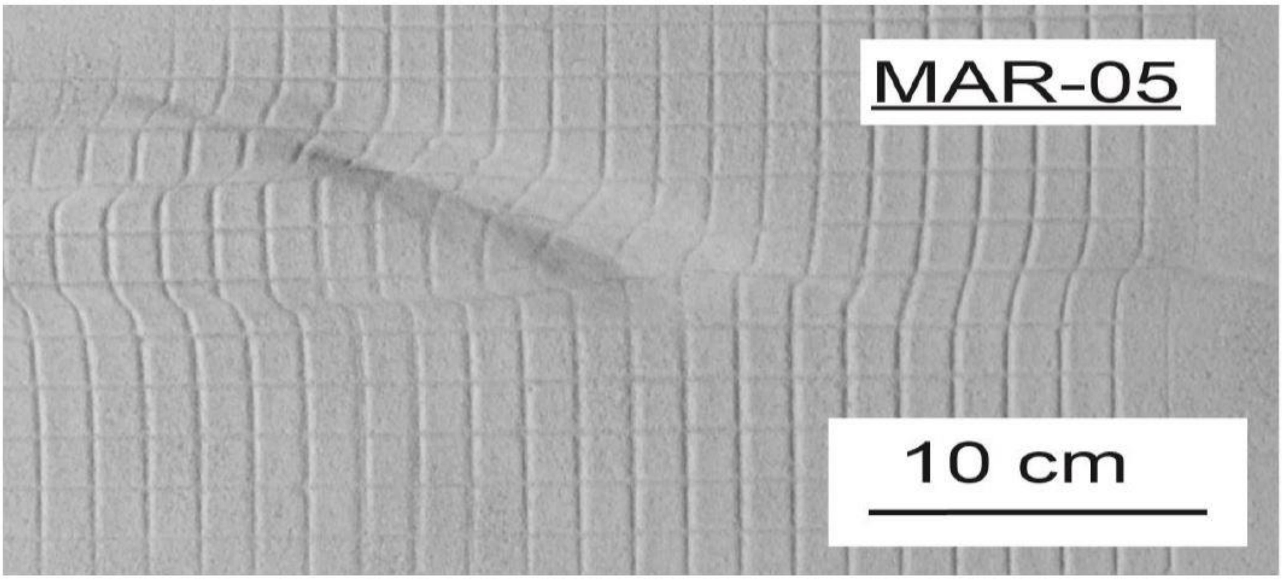

Figure 2 Top picture of the model 5 at the end of the deformation (7cm)

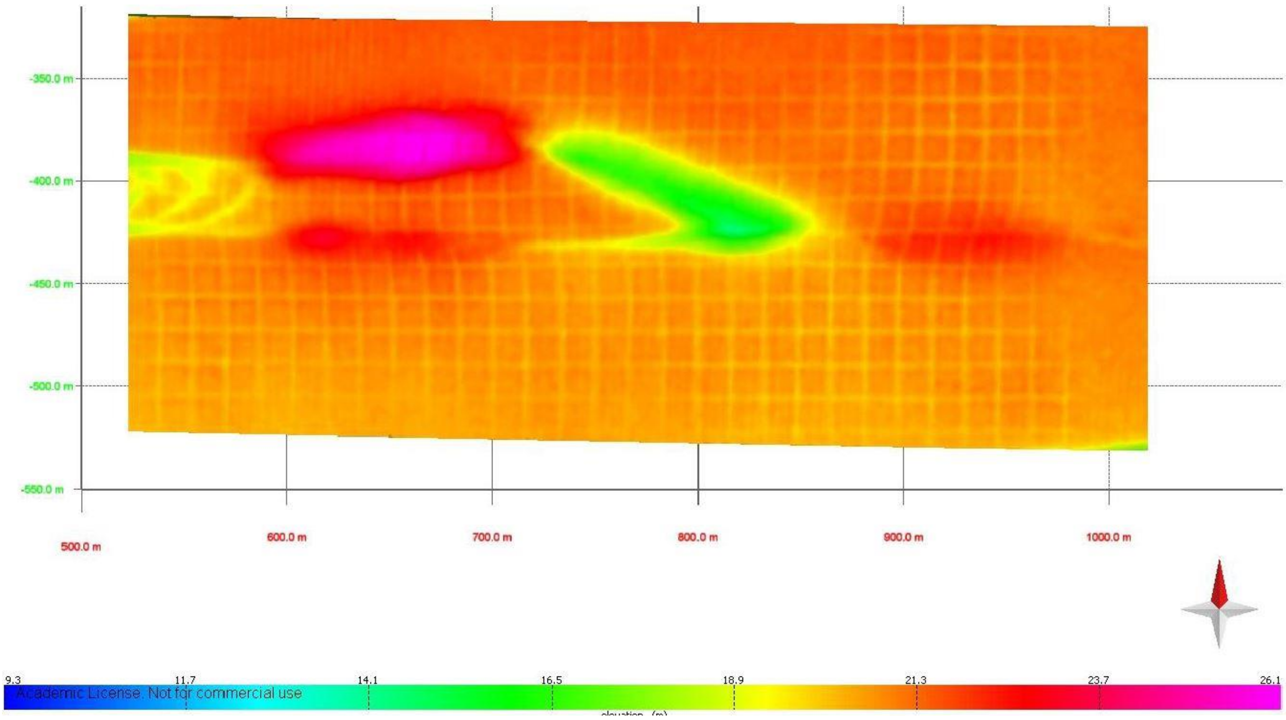

Figure 3 Top picture of the model 5 at the end of the deformation - shearing zone

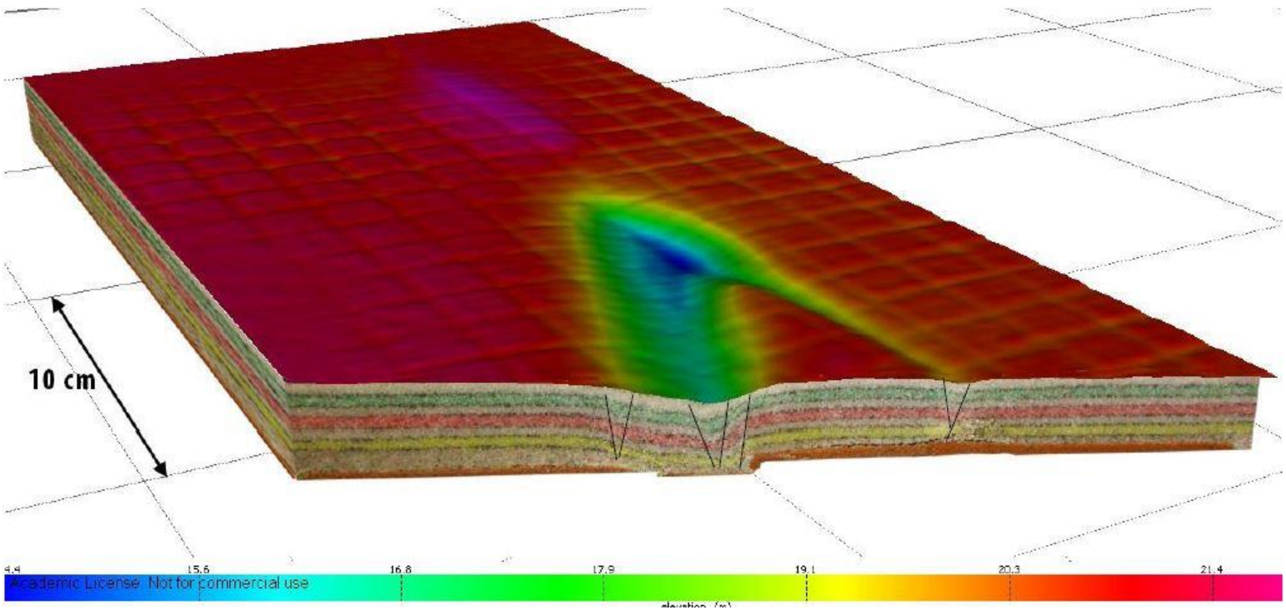

Figure 4 3D Visualisation and vertical profile of extensional pull apart basin Model 5 (MAR-05) after 7 cm of horizontal displacement

Future collaborations including publications

This research is the primary topic of paper in preparation. The main focus of the paper is: the analogue modelling methodology applied to strike-slip faults (still not fully developed in literature), the interpretation of our analogue models, the localization of deformation in the extensional pull-apart basin with the example of the west part of NAF. We also plan to present this research at international conferences: both EGU and AGU. Recently, we have submitted an abstract for the poster presentation to EGU 2017 conference.

Collaboration between the Fabrizio Storti, Cristian Cavozzi and us will continue in the following years. After analysing all results, we may arrange for the second attempt in analogue modelling for the Sea of Marmara.

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Noble and hydrocarbon gas insights into deep fluid migration in Gulf of Cadiz (manuscript) & Heat and Fluid flow modelling school

Marianne Nuzzo

Objective

Work plan for the STSM at Geomar Helmholtz Center for Ocean Research Kiel: Noble and hydrocarbon gas insights into deep fluid migration in Gulf of Cadiz (manuscript) & Heat and Fluid flow modelling.

I am submitting a proposal for a STSM to travel to Kiel (Germany) to work at Geomar with Ewa Burwicz-Galerne from Geomar (Kiel), Heiner Villinger (Bremen University) and Christian Hensen (Geomar). The work plan includes joint work on modelling of heat flow (Heiner Villinger), fluid flow (Ewa Burwicz-Galerne) and thermal degradation of organic matter as a preparation step toward the construction of modelling teaching material. The teaching material is destined primarily to the training school that I am organising in North Devon as part of the Flows project, but not only as it will be used in different circumstances. Secondly, the purpose of my visit to Kiel is the finalisation of a paper of which I am first author and Christian Hensen a co-author on the hydrocarbon and noble gas geochemistry of mud volcano fluids in the Gulf of Cadiz (SW Iberia), one of the areas of investigation of the FLOWS project. It will also involve planning further collaborative work to publish data acquired as part of research cruises in the Gulf of Cadiz.

Active mud-methane discharge evidenced by authigenic methane-derived carbonates in mud volcanoes from the Alboran Sea

Carmina López Rodríquez

Purpose of the STSM

In sedimentary basins, overpressure development and pressure release result in submarine fluid and gas discharges into the ocean, which can occur slowly or abruptly and in cases, can reach the atmosphere. Understanding fluid escape processes and submarine mud volcanism in ocean basins is a key research topic for marine exploration and basin analysis. Its scientific interest concerns in particular the linkages between mud diapirism/volcanism and the presence of deep oil and gas reservoirs. The occurrence of mud volcanoes (MVs) indicates hydrocarbon- rich fluid migration and provides a key to unraveling the hydrocarbon potential at depth (*Ivanov, et al., 1998; Kholodov, 2002; Dählmann and de Lange, 2003; Haese et al., 2006; Hensen et al., 2007; Scholz et al., 2009; Magalhães et al., 2012, Hensen et al., 2015)*.

Recent studies have identified active discharge of methane-rich fluids based on geochemical profiles of pore waters (e.g., *Haese et al., 2006; Hensen et al., 2007; Scholz et al., 2009)*. However, these investigations focused on liquid and gas phases without analyzing and integrating data from sediments and rocks that are expelled to the subsurface. Rocks and sediments are intimately linked with gases and fluids, and they are excellent indicators of source strata and oil potential of deep parent bed layers where MVs root. We pursue in assessing the impact of mud volcanism within the West Mediterranean based on cutting-edge multidisciplinary approaches in marine research using sensitive geochemical, mineral and sediment techniques. The scope this FLOWS STSM is to recognize single eruptive events to give more accuracy and quality in the quantification of discharge rates of hydrocarbons (mainly methane)-rich fluids and to understand mechanisms controlling migration and generation of fluids to lately understand the chemical fluxes besides patterns of MV-activity. Data will contribute to a thorough understanding of the behavior of recent eruptions, to obtain specific details about the hydrocarbon potential of deep reservoirs and deep fluid fluxes, which may contribute for further monitoring of submarine geologic hazards linked to mud volcanism and mud diapirism.

Description of the work performed during the STSM

During the 30 days of my stay at the Department of Earth Sciences (DES) at Utrecht University (Utrecht, the Netherlands), I have performed the preparation, analysis and interpretation of a variable set of data, including major and trace elements, total organic carbon, total nitrogen, bulk and clay mineral assemblages of solid phases of mud breccia matrices from the active Carmen mud volcano (Alboran Sea).

To achieve the main target I sub-sampled the piston core GP09PC from Carmen mud volcano. Prior to perform the geochemical and mineralogical analysis, all discrete samples of mud breccia matrices were previously dried in an oven at 40 °C and later ground and homogenized in an agate mortar.

For Coupled plasma atomic emission spectroscopy (ICP-OES) was performed for major element determinations (Al, Ca, Mg, K, Fe, Mn, Na, P, S). Analyses were done by spectrometry via a Perkin Elmer Optima 8300 (Dual vision) and autosamples Perkin Elmer S10. Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) was performed for trace element and rare earth element (REE) determinations and on the same samples as for ICP-OES. Measurements were done by spectrometry via a Perkin Elmer Scienx-Elan 5000 spectrometer. For total organic carbon (TOC) 1000 mg of each sample was decalcified using 1 M HCl. The decalcified samples were again dried at 40 °C and finely ground using an agate mortar. Decalcified samples were afterwards put into specific silver cups and carefully weighted in a high precision microbalance. For TOC and TN contents samples were weighted between 5-20μg. After weighing, TOC and TN were determined on a Fisons Instruments NCS NA 1500 analyzer using dry combustion at 1030°C. The isotope data were reported in the conventional delta notation with respect to VPDB. Precision (::0.1o) and accuracy were established using international (Graphite quartzite standard NAXOS (GQ)), and in-house standards (Ammonium Sulphate (ASS), Acetanilide, and Atropine).

Bulk and clay mineral composition was determined by X-ray diffraction (XRD). Separation of the <2 μm fraction and preparation of samples for XRD analyses were performed by sequential decalcification and centrifugation. X-ray diffractograms were obtained using a PANalytical X'Pert PRO diffractometer equipped with an X'Celerator solid-state linear detector, using a step increment of 0.01° 28 and a counting time of 1 s/step, with Cu-Ka radiation (45 kV, 40 mA) and an automatic slit. Scans were run from 3-50° for untreated clay preparation as well as for glycolated samples.

Description of the main results obtained

Inorganic and organic geochemical determinations on expelled mud volcano materials from Carmen mud volcano serve as proxies elucidating past activity so as to reconstruct ancient pulses of methane seepage and paleo-sulfate-methane transition zones and at the time provide relevant information about the nature of source units feeding MVs, whereas bulk and clay mineral data provide information about mineral transformation, diagenesis and fluid sources.

During this FLOWS STSM sample preparation and a wide range of analyses have been successfully performed. Preliminary results have shown that mud breccia samples from piston core GP09PC have similar geochemical characteristics compared to mud breccia samples from core GP05PC, which was investigated during the previous STSM. In the case of GP09PC, depth trends have revealed enriched fronts in redox-sensitive elements (e.g., Mo, V, Ni). Also the carbonate ($CaCO_3$) content of mud breccia matrix

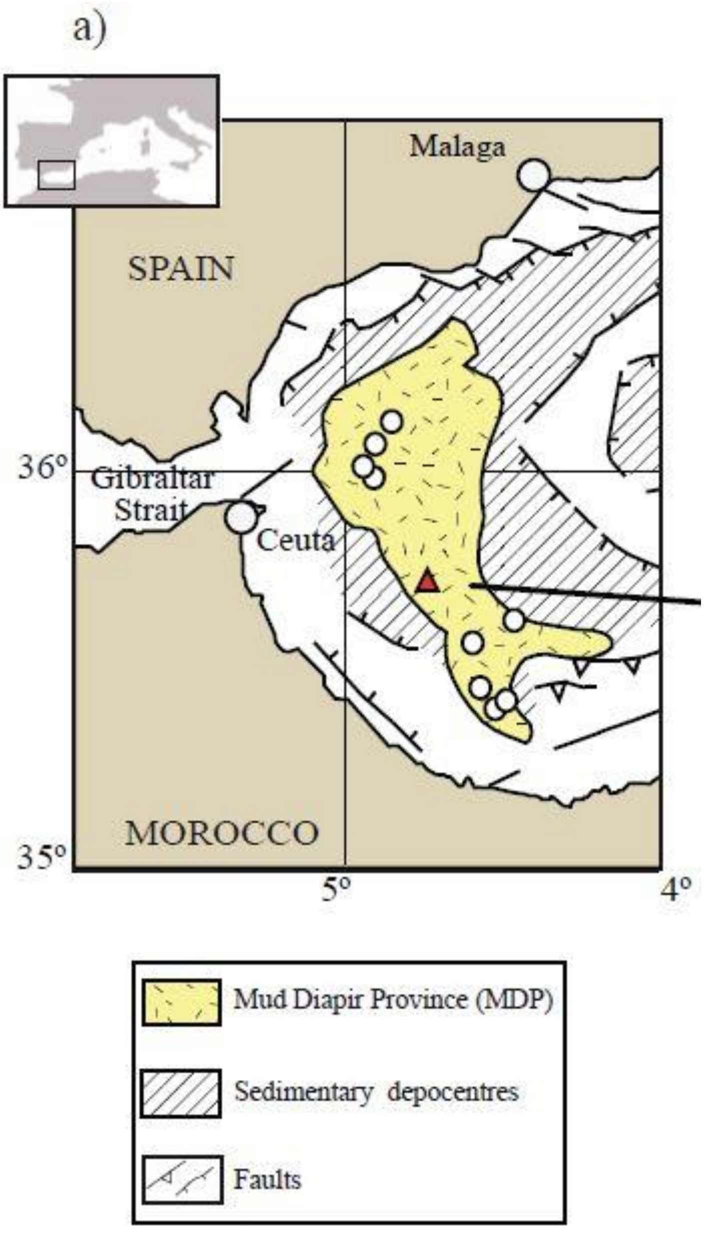
from GP09PC show similar values compared with other mud volcanoes. Sr/Ca vs Mg/Ca signatures reveal most likely Mg-calcite (after *Bayon et al., 2007*), being thus in line with other mud breccia matrices investigated in neighbors gravity and piston cores at Carmen MV. Total organic carbon (TOC) content in the investigated mud breccia matrix samples has reported some interesting peaks in depth. Similarly, nitrogen and sulfur content also exhibit comparable trends. All these findings provide key information about the geochemical signatures of the solid phases of the extruded materials from Carmen MV. Preliminary results obtained during this FLOWS STSM are also being compared with previous sediment data from piston GP05PC, also obtained during a FLOWS STSM in 2016, as well as with complementary data of porewaters (*López-Rodríguez et al., 2017*), in order to find paleo-SMTZ within the mud breccias and make an assessment of rates of fluxes methane in the past.
New datasets together with previous geochemical data from mud breccias from piston GP05PC, and the combination of porewaters data, we will be able to estimate the activity and dynamics of the Carmen mud volcano. This study will permit to date methane-rich mud discharge events, to evaluate their impact in the seafloor and will help to predict potential mud eruptions in the future.

Ongoing work and collaboration with the host institution

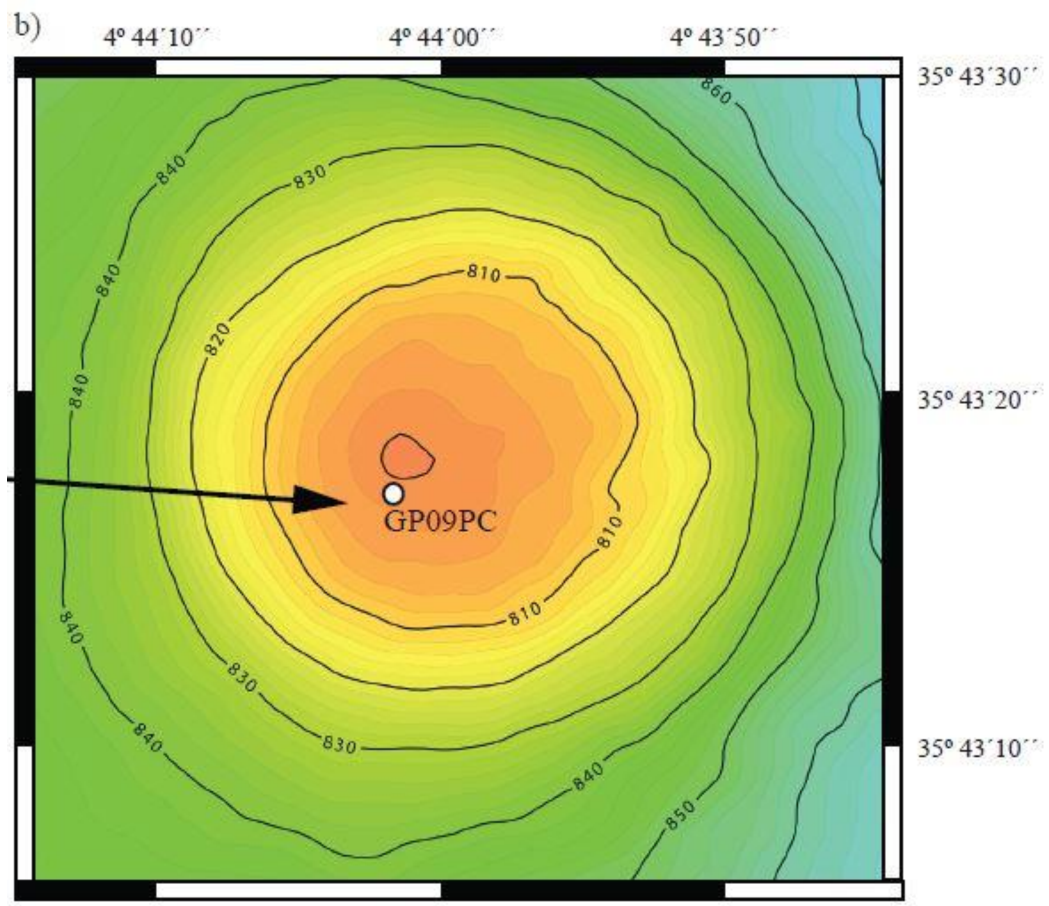
The Department of Earth Sciences is one of the most important research unit in Europe dedicated to the study of earth sciences and geochemistry and an excellent institution to carry on multidisciplinary research. The Department combines field data with experimental, modeling and theoretical approaches to elucidate biogeochemical cycles and mineral transformations along the aquatic realms and the associated shore-based Geo-Lab is the main laboratory facility of the Faculty of Geosciences which has a wide range of lab facilities available for measuring bulk rock geochemistry, bulk rock stable isotopes (H, C, N, S), in situ stable and radiogenic isotopes (U,Pb-dating), in situ major and trace elements and crystallography. The development of this research project has been an excellent opportunity to be trained in preparatory methods for specific geochemical analyses as well as to be formed in discusses and interprets geochemical data. It has permitted to continue the closely work under the supervision of Prof. Gert De Lange, ensuring the well development and completion of this research. This short-term scientific mission has enormously contributed in the ongoing collaboration between the host institution and our scientific group in Spain, favoring new discussions and geochemical issues which will be the target of further short-term scientific missions and potential Postdoc projects.

Scientific contributions and publications resulting from the STSM

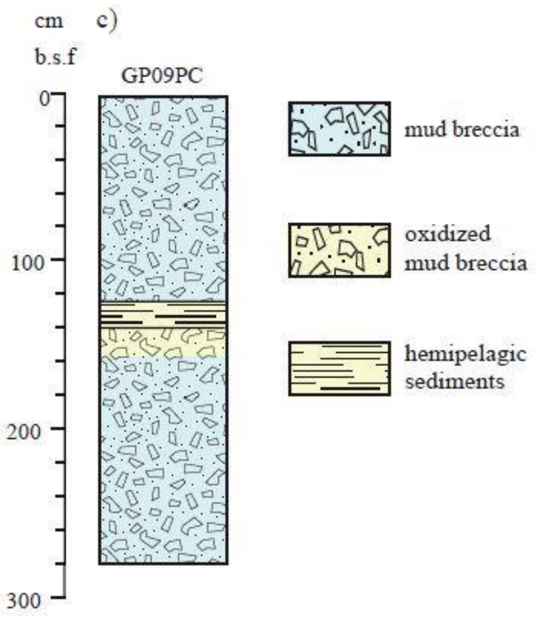
All data that have been obtained during this short-term scientific mission are being processed and corrected. We have planned to increase to improve the geochemical record with additional samples from the investigated piston core GP09PC and thus work on a high-resolution dataset. We expect to find other interesting fluctuations along the mud breccias which will help to locate ancient SMTZ, leading to provide relevant information about the Carmen mud volcano dynamics and eruption timing. Once results will be interpreted and discussed they will be integrated as part of a scientific manuscript which will be submitted in highly internationally-reputed journal in Earth Science (e.g., Geochimica e Cosmochimica Acta, Chemical Geology or Earth and Planetary Science Letters) and presented in international geological congresses (e.g., European Geosciences Union General Assembly, Goldschmidt Conference).

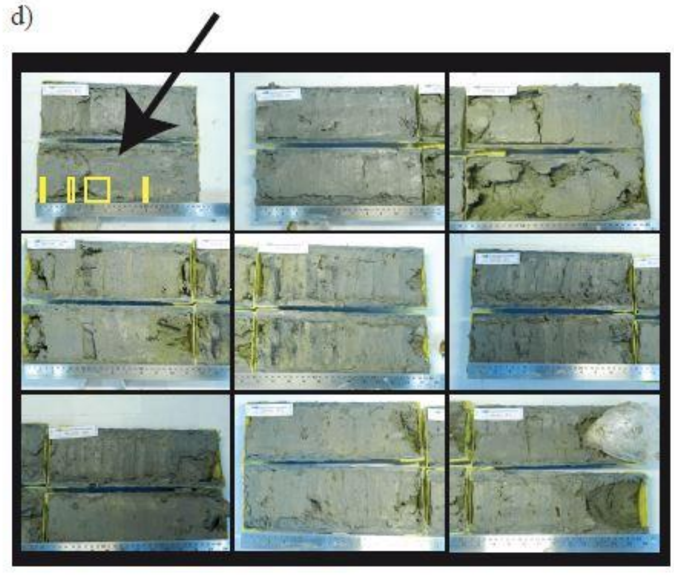


a) Sketch of the West Alboran Basin (WAB) showing the location of the Mud Diapir Province (MDP). White dots are other reported MVs, whereas red triangle correspond to Carmen MV.



b) Multibeam image of the crater of Carmen MV. White dot belong to the studied core GP05PC, GP09PC (from Lopez-Rodriguez et al., 2017)





c) schematic core log showing the main sediment facies from the studied core GP09PC. d) Sediment sections from core GP09PC. Arrow and yellow rectangles show preliminar sub-sampled areas.

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Effects of seismicity on the active Lusi eruption site

Mohammad Javad Fallahi

In the framework of the ERC LUSI LAB project lead by Dr. Adriano Mazzini at the CEED - University of Oslo, Norway - I visited the group of Crustal Deformation and Fluid Flow lead by Prof. Matteo Lupi at the University of Geneva, Switzerland from the 6 th to the 22nd of November 2017. Lusi is a sediment hosted hydrothermal system located in East Java active since 2006. I used a network composed of 31 seismic stations deployed in this region to monitor the seismic activity occurring around Lusi. The network encompasses the volcanic arc, the back arc basin where Lusi resides and the strike slip fault system connecting the two. Additionally, I also used seismic data from the Aegean Sea to study the seismic activity promoted by a M6.9 strike slip event occurred in May 2014 on the westernmost branch of the North Anatolian Fault. The scope of my short-term mission was to exploit the datasets and tackle the following scientific questions (SQ):

1. Is it possible to locate anomalous sources of noise in East Java. We used gridsearch methods to investigate whether it is possible to localize geological events with regional seismic networks.

2. Is it possible to identify seismic precursors by monitoring seismic parameters before and after the M6.9 earthquake occurred at the western end of the North Anatolian fault in May 2014?

The results of these studies are briefly outlined below:

SQ1. We used records from 31 seismic stations deployed around Lusi and its neighboring volcanic arc as well as additional seismic stations from BMKG network in Java (Fig. 1). Fig. 2a shows spectrograms of the vertical-component continuous seismic records at stations SP01, SP05, BLJI and GMJI. From November 2015 to March 2016, seismic noise and spectral analysis of continuous seismic records at Lusi network and BMKG network stations in East Java suggest the presence of a localized source around Tengger Caldera. An eruption began in November 2015 at the Bromo cone of Tengger Caldera and continued for about a year. At the same time Lusi eruption reached a peak in flow rate. The RMS amplitude and spectral analysis reveals the existence of monochromatic low frequency seismic signals (~0.3-0.7 Hz) that begin from November 2015 and continued for about four months. These signals decline gradually with distance from Tengger Caldera in East Java.

Continuous vertical-component seismic noise records of Lusi seismic network and three stations (KRK, BLJI and GMJI) from BMKG network were used to compute daily crosscorrelations (CCs) of ambient noise between all station pairs. It has been shown that by crosscorrelating noise traces recorded at two locations on the surface, we can construct the wavefield that would be recorded at one of the locations if there was a source at the other location.

Fig. 1. Map of seismic stations from Lusi network and BMKG network in East Java.

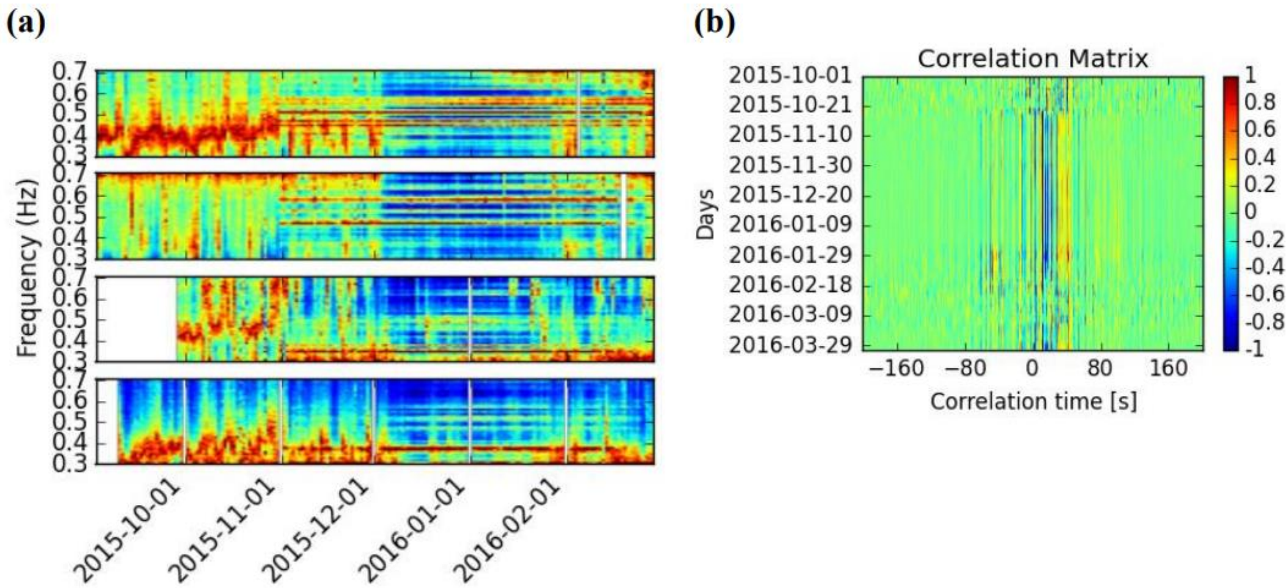

Fig. 2. (a) Spectrogram of the vertical-component continuous seismic record at SP01, SP05, BLJI and GMJI. (b) Daily cross-correlation functions for station pair SP01-SP05 from Lusi Network.

Fig. 2b shows example of daily cross-correlation functions for station pair SP01-SP05 in frequency band of 0.3-0.7 Hz. The observed monochromatic signals in spectrograms are clear on CCs during the same period. Daily CCs were stacked for the period from November 2015 to March 2016 and the obtained waveforms were used to locate the main source of the noise during these days.

We used two approaches to locate the noise source. In the first approach, we measured the travel times of the maxima of the envelope from the stacked waveforms between all pairs of stations. The travel times and source-station distances were used to define the following misfit function:

$$\sum_i \left| \frac{dist(B_i, r_s) - dist(A_i, r_s)}{V} - \Delta T_i \right|$$

where rs is source position, dist(Ai/Bi, rs) is the station(Ai/Bi)-source(rs) distance, ΔTi is the measured travel time, V is the group velocity and i denotes pairs of stations (Ai and Bi). A grid search has been used to minimize the misfit function in order to find the optimal location of the source (See Mordret et al., 2013 for details of the approach). In the second approach, a 2D grid of amplitudes has been defined for each pair of stations. For each pair, the travel times of the waves that originate from each grid node (assumed source position) were measured by [dist(Bi, rs) - dist(Ai, rs)]/V and their corresponding amplitudes from stacked waveform were attributed to the grid nodes. The advantage of this method is to consider all the amplitudes in the stacked waveform rather than just the maximum amplitude. Element-wise addition of grid amplitudes (defined for each pair of stations) gives the optimal source position. Results of both approaches are presented in Figs 3a and 3b showing that the noise at frequencies between 0.3 and 0.7Hz could be originated from Tengger Caldera. Spectral analysis of seismic stations around Tengger Caldera shows that low frequency signals were identified a couple of days before the reported eruption at the Bromo cone of Tengger Caldera in November 2015 and last until March 2016.

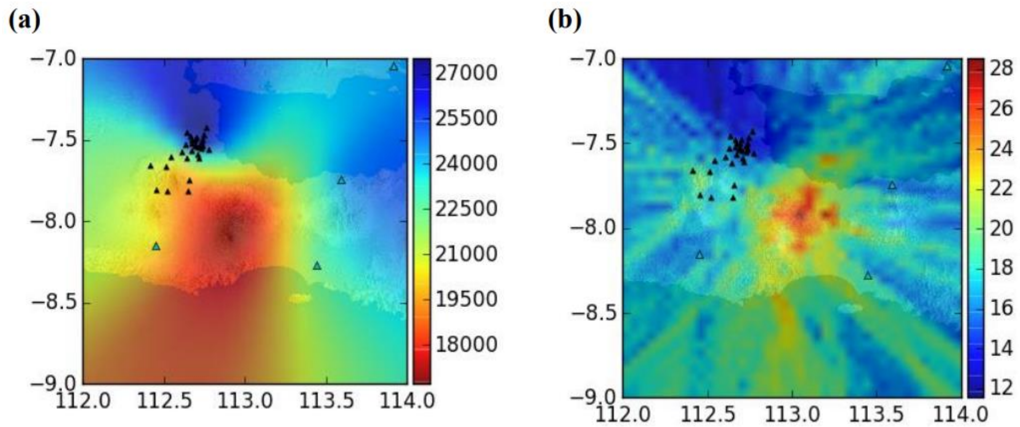

Fig. 3. Results of the locating main noise source for the frequency band 0.3-0.7Hz (a) with maximum amplitude grid search and (b) full waveform amplitude grid search. The colorbar changes from high probability location (red) to low probability (blue). Black triangles show the Lusi network and cyan triangles show the BMKG network stations.

Moreover, from spectrograms of continuous seismic records we observed that high frequency (1-4 Hz) content becomes dominant at stations around Lusi. This brought up an interesting idea of deriving an average 1D velocity model and a high-resolution 3D shear wave velocity model for shallow depths around Lusi. Therefore, during this trip we decided to test the possibility of setting up a near-surface study around Lusi from ambient noise surface wave tomography. We first extracted ambient noise data from continuous recordings of seismic stations around Lusi. CCs on vertical components were calculated at high frequencies between 1 and 4Hz. Fig. 4 shows the daily CCs for pairs of SP05-SP19 and SP09-SP13. Surface waves propagating between the two stations can be clearly seen in this Figure.

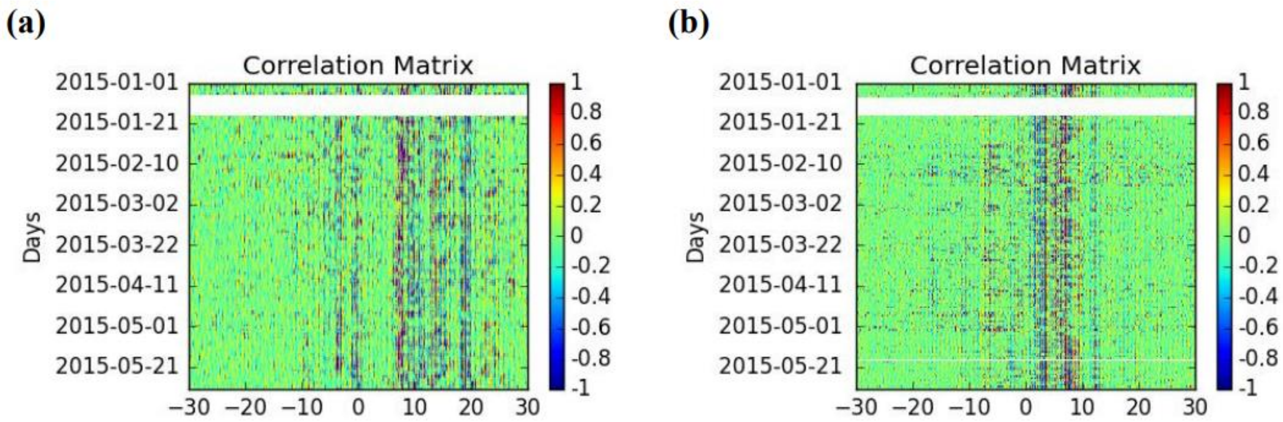

Fig. 4. CCs in the frequency range of 1-4 HZ for (a) SP05-SP19 and (b) SP09-SP13.Color scales indicate the amplitude of the phases.

These preliminary results are positive and promising for future work. This study is currently in progress and for the next step we will invert the surface wave group velocities into 2D velocity maps between 0.25 and 1s. Finally, we will invert 2D velocity maps into 1D flatlayered velocity models to construct a 3D shear-velocity model down to 1 km below Lusi. SQ2. To monitor possible changes in scattering properties of the medium before the earthquake we applied interferometry methods using continuous seismic noise records at the closest stations to the epicenter. Additionally, spectrograms of seismic records at four ocean bottom seismometers (OBS) in the central part of the Sea of Marmara were analyzed to investigate the dynamic triggering of an active mud volcano located close to the North Anatolian fault. Fig. 5b shows the daily CCs for ALN-GELI pair from January 2014 to December 2016. Seasonal changes of ambient noise are observed visually (Fig. 5b) and by applying interferometry methods but it reveals stable seismic velocities and coherency without a clear precursor to the earthquake. Moreover, spectrograms of seismic records at four ocean bottom seismometers (OBS) in the central part of the Sea of Marmara analyzed to investigate the dynamic triggering of an active mud volcano located close to the North Anatolian fault trace. We find no clear temporal changes associated with the earthquake. The fact that no velocity/coherency variation is observed by employing coda waves, suggests that the source area may be too small for the interstation distance to be detected by investigating the time shifts of multiply scattered coda waves.

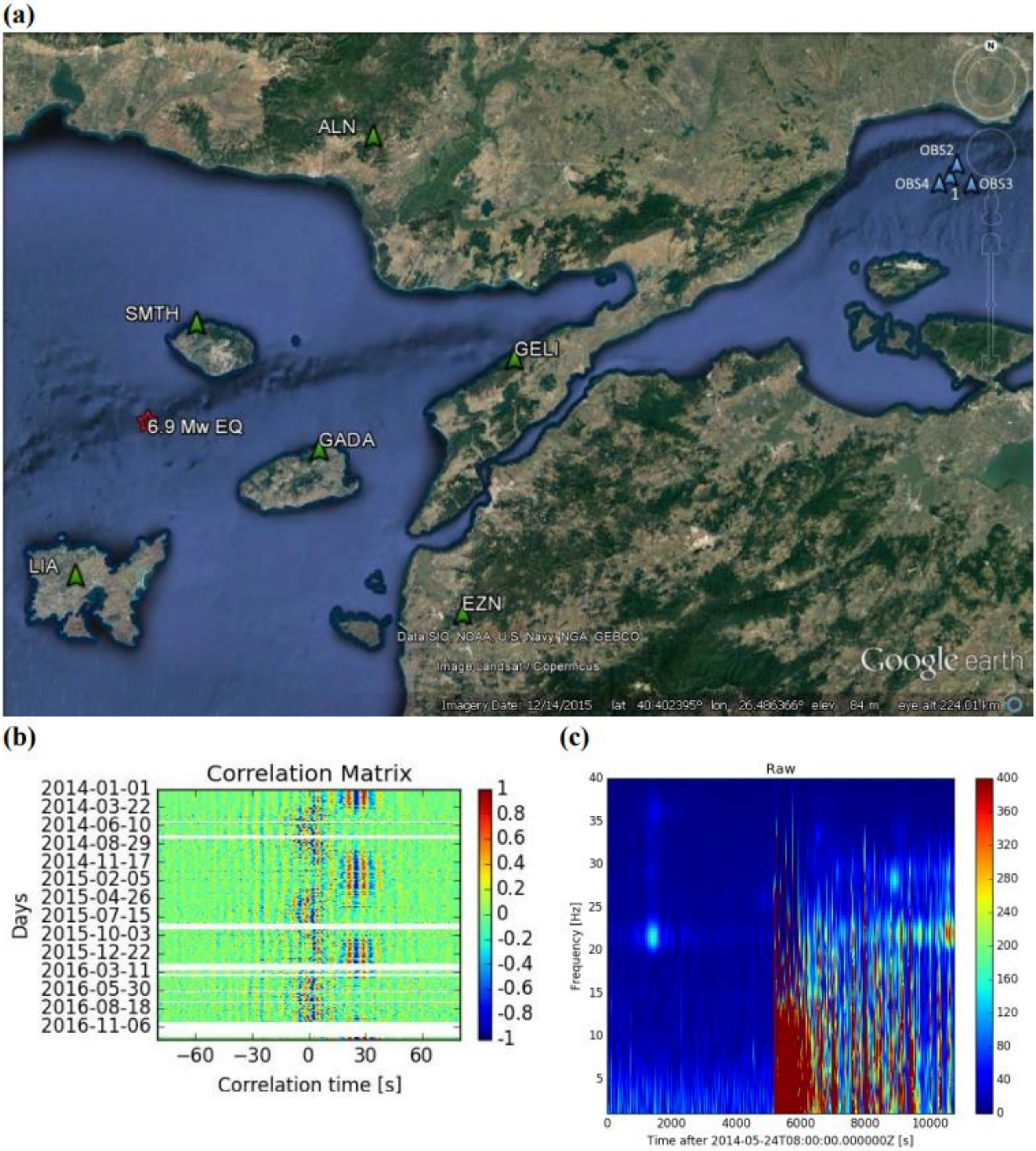

Fig. 5. (a) Map of seismic stations close to the M6.9 earthquake and OBS locations on the sea (Marmara) floor. (b) CCs for ALN-GELI in the frequency range of 0.1-2 HZ and in the period from January 2014 to December 2016. Color scales indicate the amplitude of the phases. (c) Spectrogram of the seismic record at OBS1, ~5000s before and after the earthquake.

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Shear Strain Localization during Evaluation of NAF

Sibel Bulkan

Purpose of the STSM

The main objective of the STSM conducted at CEREGE (Marseille, France) under the supervision of Pierre Henry was two folds:

- discuss the strain accumulation between the major segments of the northern branch of the North Anatolian Fault (NAF);
- consider the tectonic setting of the NAF and the Marmara Sea in the frame of lithosphere dynamics.

In particular we were interested in the comparison of offshore data on fault activity acquired from the Sea of Marmara, investigated by Pierre Henry on board "Pour quoi Pas?" during the MARSITE cruise, and geodetic data. This comparison was important because it offered a complete overview of the modern NAF system, a key dataset to unravel the geometric evolution and kinematic of the west part of the NAF system, over the last few Ma years of the fault system's evolution. A further step was the association of this dataset with the results of analogue modelling performed last year during my STSM in Parma. In this, we were aiming to test the localization of strain allowing us to investigate how the deformation is distributed in each section of western part of the NAF and why it is more active in the Sea of Marmara. This short term scientific mission was an important contribution toward my ongoing thesis, but also a key step to finalize a manuscript draft and to collect information on available data for future work.

Description of work carried out during the STSM

During the month spent at CEREGE, we analyzed and interpreted independent measurements from different data sets. The data sets were obtained from 3D deformation in sandbox experiments. In these experiments, performed during the first STSM in Parma University, Italy, we reproduced releasing bend and restraining bend geometry analogous to the western part of the NAF. The analogue models were scanned by light laser every 5mm deformation and sequential photographs were taken from the top of the model every 5 minutes. These scans served to monitor progressive displacement and rotations during the physical experiments. Further Particle Image Velocimetry (PIV) analysis provided us with incremental particle displacements and velocity fields throughout the experiments. From these data, we calculated the simple shear rates and areal rate of changes along the strike-slip fault system in the pull-apart basin. The scan data were processed with MATLAB to create gridded elevation models for every 5-mm deformation. The rate of topography change was calculated by subtracting each elevation model iteration. Comparisons with subsidence rates, uplift rates and sedimentation rates in the Sea of Marmara were also performed. We calculated the strain tensors from the gradients of the velocity components. Incremental simple shear rate is approximated as the strain component parallel to the velocity discontinuity applied at the base of the model (Exy). Incremental areal strain is the sum of the diagonal components (Exx+Eyy). These were used to obtain inferences on the strain accumulation and shear transition between the major segments of the northern branch of the NAF. We related the incremental topography rate of changes with the incremental strain patterns to show how much stretching of compression is taking place in each segment of fault. Shear strain map showed how much shearing deformation is taking place. The areal strain maps showed the rate of which area have the extension and compression. The areal strain can be less than the simple shear rates and it is showing less clear patterns with some noise on the data. However, we demonstrated that the results of strain patterns correlated well with the results of the rate of topography changes.

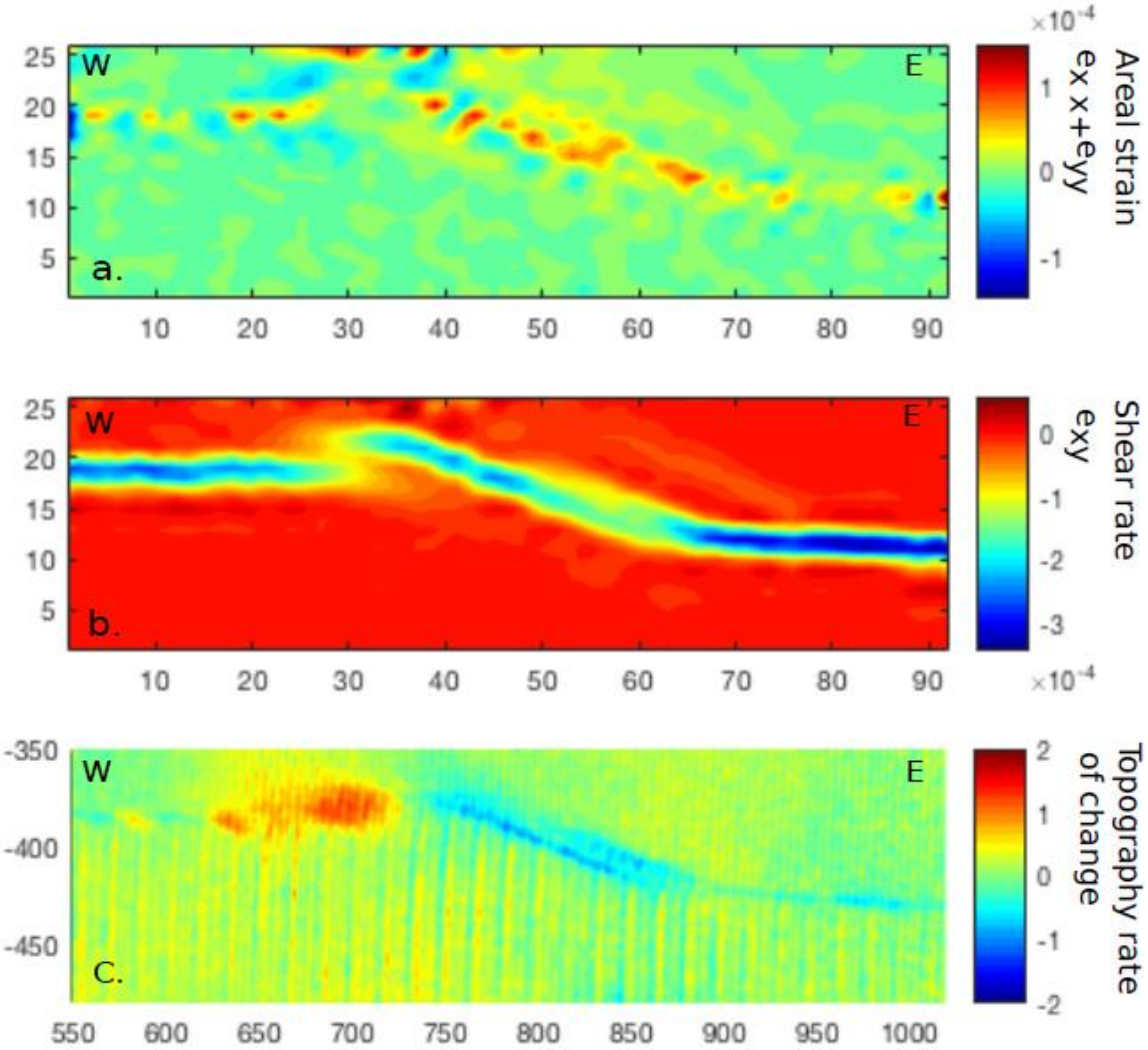

Figure 1: Comparison the strain patterns with the rate of topographic change before the transition of from a single to a two-branches fault, @ 20 mm displacements of fault. A Areal strain distribution along the fault zone: red fields represent extension, the areas in blue are compressional. The extension is localized on topographic highs, while compression is concentrated on the side of the hill. There is extension also where the graben is developing and a secondary extension zone initiates NE of the releasing bend. b) Shear rate distribution along the fault zone correspondent to 1a. c) Differential topography. Uplifted areas in red, blue areas represent subsidence. The uplift is concentrated in the western part of the fault.

Description of the main results obtained

The results obtained during this STSM are within the scope of FLOWS. In particular we concentrated on the west portion of the North Anatolian Fault in the Sea of Marmara, a transform type plate boundary, a key site of working group 4. We extracted the position on the master fault of fault tips and folds integrated over time, analyzing these positions in the experiment to find how the fault evolved. We showed how the master fault and newly formed faults changed geometry during its evolution. These results will advance our current knowledge of the structure and activity of the west part of the NAF.

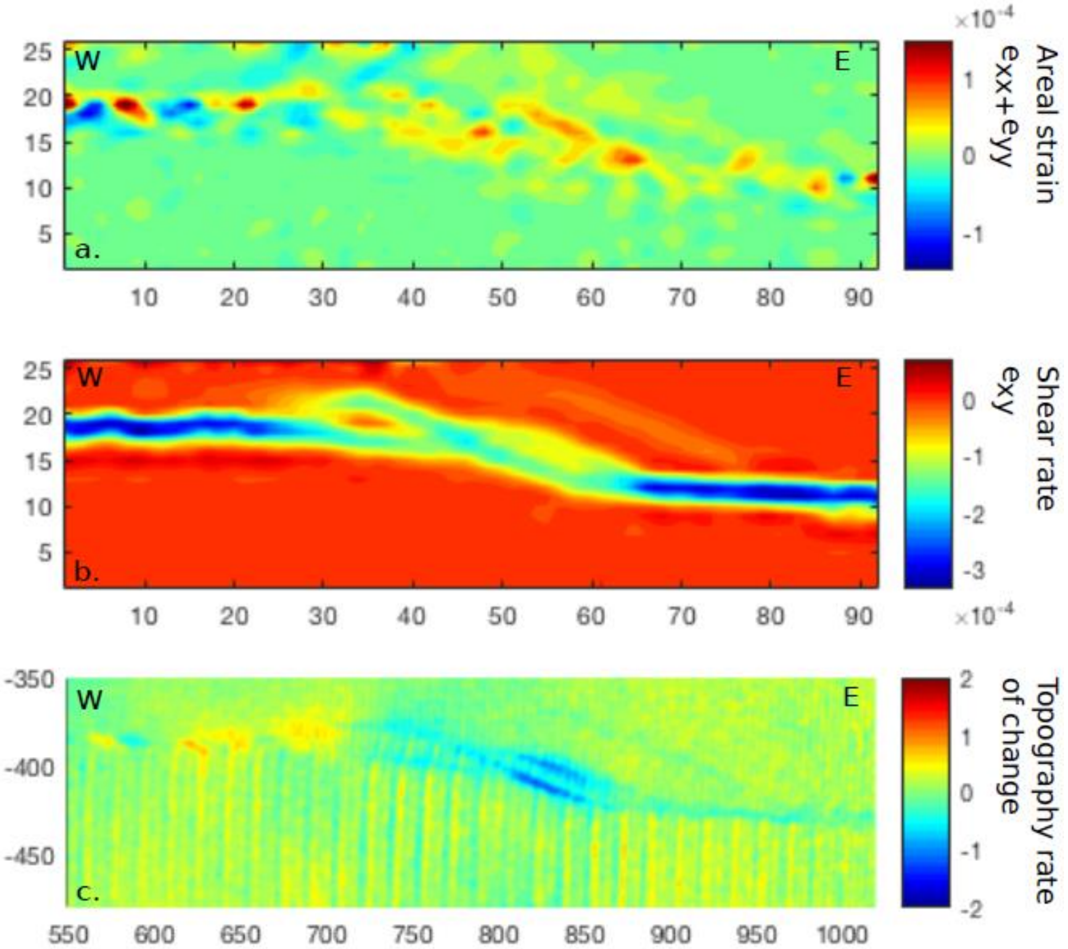

Figure 2: Comparison the strain patterns with the rate of topographic change during the transition of from a single to a two-branches fault, @ 30 mm displacements of faults. a) Areal strain distribution along the fault zone: red fields represent extension, the areas in blue are compressional. Here the areal strain is more distributed than in figure 1a. Although there is some noise, the extension is concentrated where the graben is developing. Two shear zones became active. b) Shear rate distribution along the fault zone correspondent to 2a. The transition zone is here clearly formed already. c) Differential topography. Uplifted areas in red, blue areas represent subsidence. Two faults have become active, they border the graben zone and are causing subsidence. The strain and the topographical configuration changed when compared to figure 1c, in particular the ongoing uplift was deactivated by the extensional field.

In the analogue models, the patterns indicated that a transition from single fault to two branches occurred for a total displacement of 30 mm (Fig.2) and it is associated with a reduction of uplift rates and compressive strain above the restraining bend. We considered and presented the fault evolution in three stages; 1. before the single fault to two branches transition (Fig.1), 2. during the transition (Fig.2), and 3. after the transition (Fig.3). Also, our results revealed that a depocenter migration has occurred during the evolution of the fault (Fig.3c).

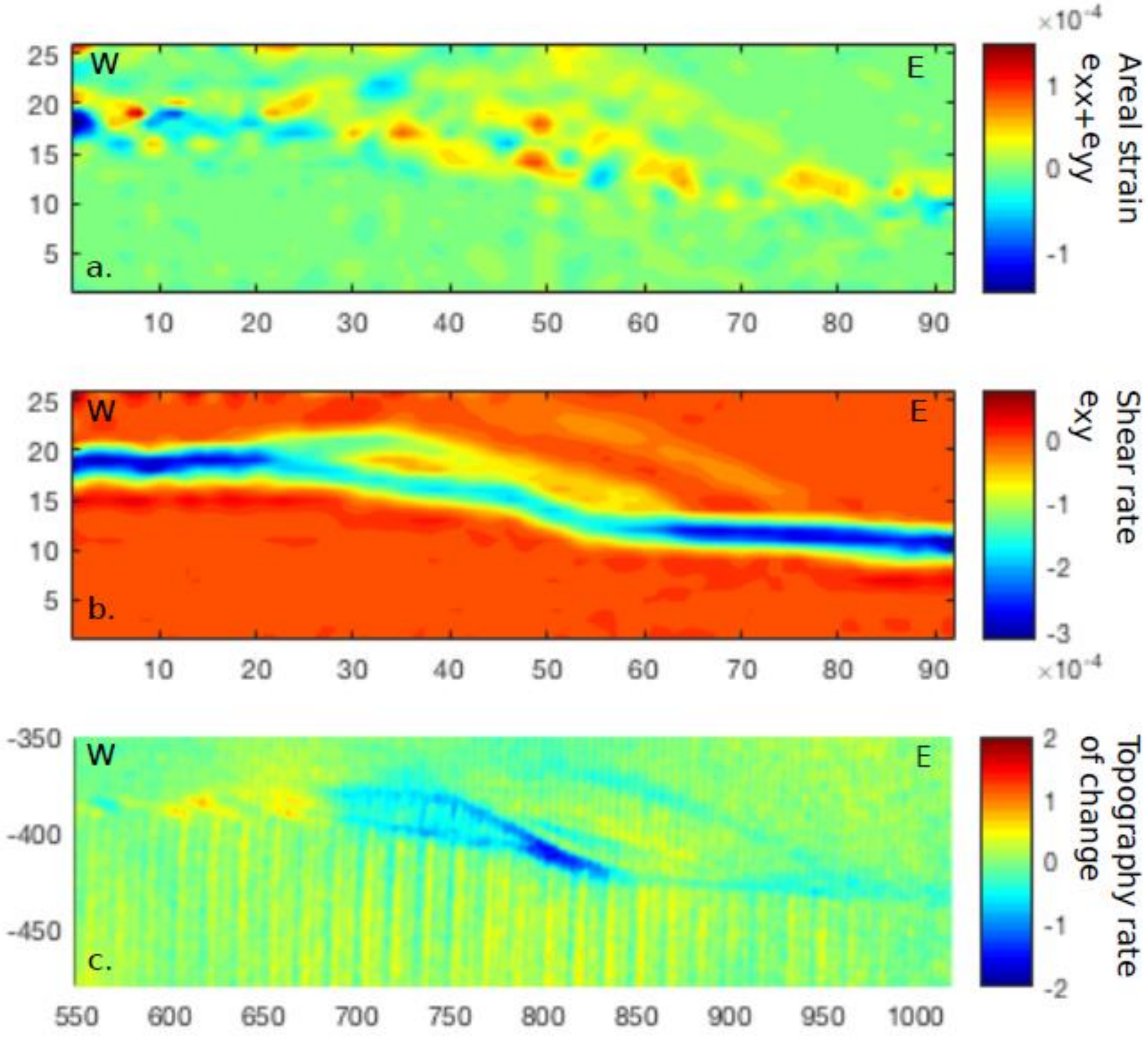

***Figure 3**: Comparison the strain patterns with the rate of topographic change after the transition of from a single to a two-branches fault, @ 50 mm displacements of faults. a) Areal strain distribution along the fault zone: red fields represent extension, the areas in blue are compressional. The compressional field was deactivated and the extensional fields became more distributed than shearing. b) Shear rate distribution along the fault zone correspondent to 3a. c) Differential topography. Uplifted areas in red, blue areas represent subsidence. The development of the two-branches fault results in: the basin becoming asymmetric, the depocenter becoming localized at the fault intersections, ongoing subsidence in the minor extension zone NE of the releasing bend.*

This STSM helped to analyze, interpret and discuss the data obtained from analogue experiments, conducted during the first STSM in Parma University, Italy. It was also important for my training in terms of data processing in MATLAB and planning of future works.

Future collaborations

Our study in CEREGE will be a primary topic of a manuscript under preparation. The manuscript describes the strain localization along the west part of the NAF by the analogue modelling. Collaboration between Pierre Henry and us will continue in the following year. We have planned to support the result with the real subsidence data from Marmara, calculated by C. Grall, one of Pierre's students - she submitted a paper for publication. Also, we established that depocenter migration within the basin can be comparable with the data sets in Sea of Marmara - already published by Rangin et al. (2004) Sorlien et al. (2012), and Kurt et al. (2013). Our schedule is to finalize the paper just after the STSM. On a different point, we went back to the design of the analogue models where the crustal scale geometry mimics that of the western part of the NAF. Because of some limitations on the analogue modelling, we simplified the geometry of the fault to take best performance from the lateral movement of the fault. When we fit the map of study area with our model, it doesn't match at some points. We established if we convert the projection system from WGS-84 to the oblique-Mercator projection, it will allow us to rotate the geometry of fault (McKenzie et al., 1970) and will give best fit with Sea of Marmara.

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Use of geophysical techniques and 3D modelling to investigate mud volcanoes and extinguished pyroclastic cones

Sebastiano D'Amico

Abstract

This report describes the main results of the Short Term Scientific Mission (STSM) carried out in collaboration with University of Catania (Department of Geology). The main goal of the STSM was to investigate: mud volcanoes site in the vicinity of Mt. Etna. Data were also acquired and the integrated with previous ones. Finally a 3D surface model has been derived and will be in the near future integrated with the 3D reconstruction model of the subsurface inferred from the study. Geophysical date from "salse di Nirano" were analized and preliminary results obtained A 3D modelling of the Mt Vetore (Etna) was constructed. Finite Element simulations were carried out to match the experimental data. Results are going to be submiited to Geophysical Journal international

Purpose of the STSM

The main goal of the proposed Short Term Scientific Mission (STSM) was to investigate mud volcanoes site in the vicinity of Mt. Etna. In particular, a microtremor survey aiming to obtain information on the Salinelle area (Paterno') subsoil structure was performed and new data were collected. The STSM served also to better plan some further campaigns during which several different kind of data (e.g. ERT, geochemical survey, and drone survey) will be collected. Similarly, we analyzed data related to the mud volcano "salse di Nirano" in Northern Italy. During this Short Term Scientific Mission geophysical data were also acquired on extinguished pyroclastic cones located on Mt. Etna (Mt. Vetore). The ambient vibrations survey helped to collect high quality data and derive useful information about the subsurface structure of Mt.Vetore pyroclastic cone. In both cases a 3D digital model was constructed.

Description of the work carried out during the STSM and main results

The Salinelle area (Figure 1) is characterized by emissions of muddy and salty water which create specific pseudo-volcanic edifices. The method has been successfully applied in the case of Lusi hydrothermal system (Panzera et al. 2018a). The main goal was to identify important stratigraphic discontinuities aiming and try to locate the reservoir location below the mud-structures and combine results with ones inferred through geochemical data. New data were acquired using portable seismometers as well as array of vertical geophones (Figure 1). An example, of processed data is given in Figure 2. We combined data from previous survey aiming to better reconstruct the subsoil structure and to understand, combining also geochemical data, the fluid migration from depth to the surface. During the

STSM a detailed 3D model of the area was constructed (Figure 3) and in the near future a 3D model of the subsurface will be added in order to have an outline of a comprehensive model of the area. We analyzed also data previously collected in the “Salse di Nirano” area (northern Italy (Figure 4). In this study we applied the HVSR method, which is a common tool used for site effect investigations to assess fundamental frequency of sediments. It is based on the ratio of the horizontal to vertical components of ground motion and it generally exhibits a peak corresponding to the fundamental frequency of the site. Although experimental data peaks usually fit quite well the resonance frequency of the theoretical curves, they are less reliable as regards to their amplitude. Nevertheless, the HVSR curve contains valuable information about the underlying structure. These peaks could be interpreted as related to the velocity contrast at depth between alternating shale and sand overlaying a velocity anomaly.

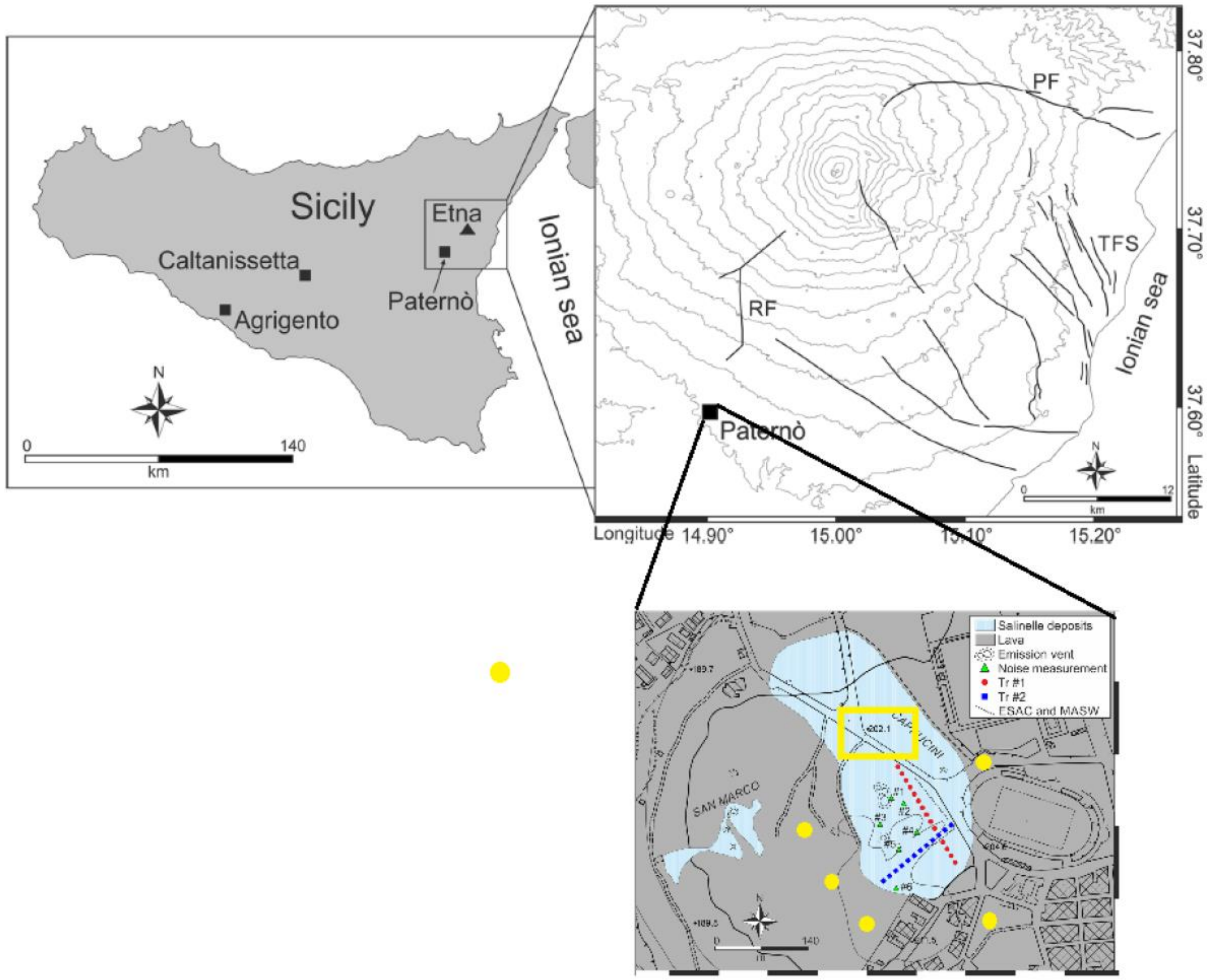

Figure 1: Geographic location of the study area (left panel) and main structural features of Mt. Etna (right panel; RFS Ragalna fault system, TFS Timpe fault system, PF Pernicana fault). Lower panel shows simplified geologic map of the Salinelle area as well as the location of the taken measurements. In yellow are indicated the location of the new acquired data.

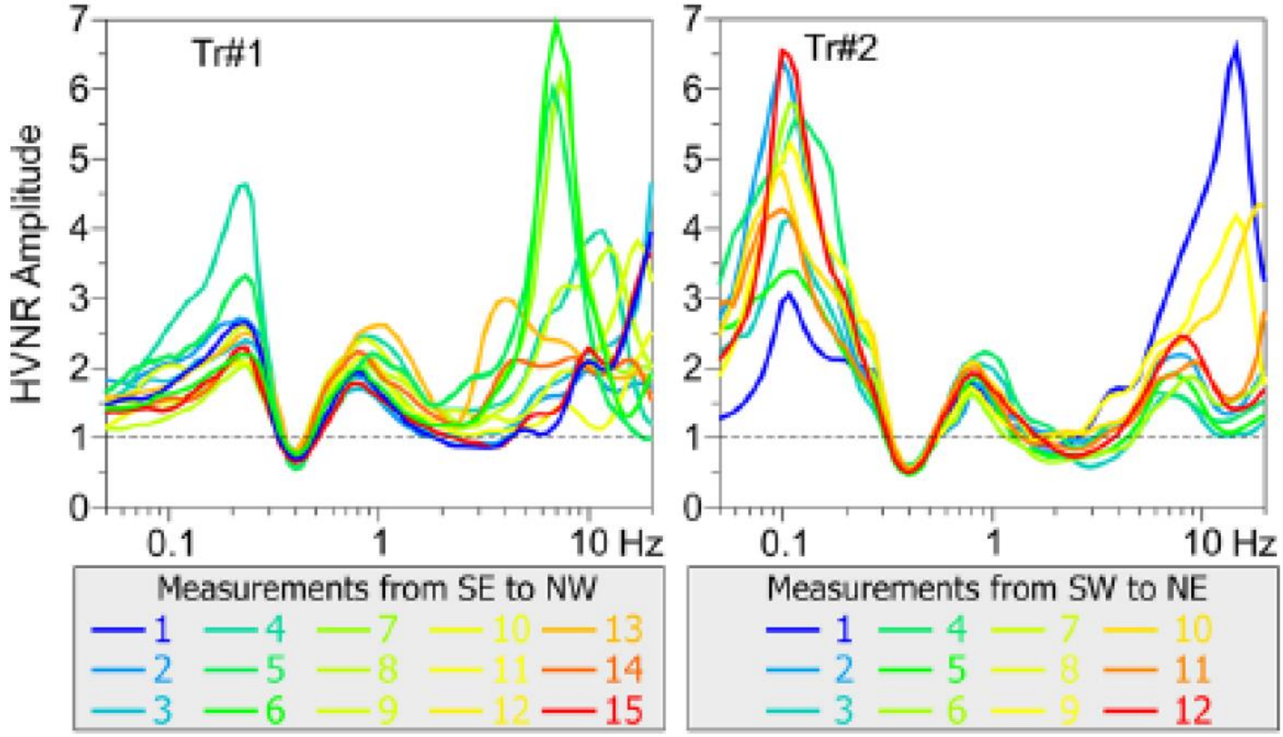

Figure 2: HVNRs computed at each site along the Tr#1 and Tr#2 profiles (modified from Panzera et al. 2016).

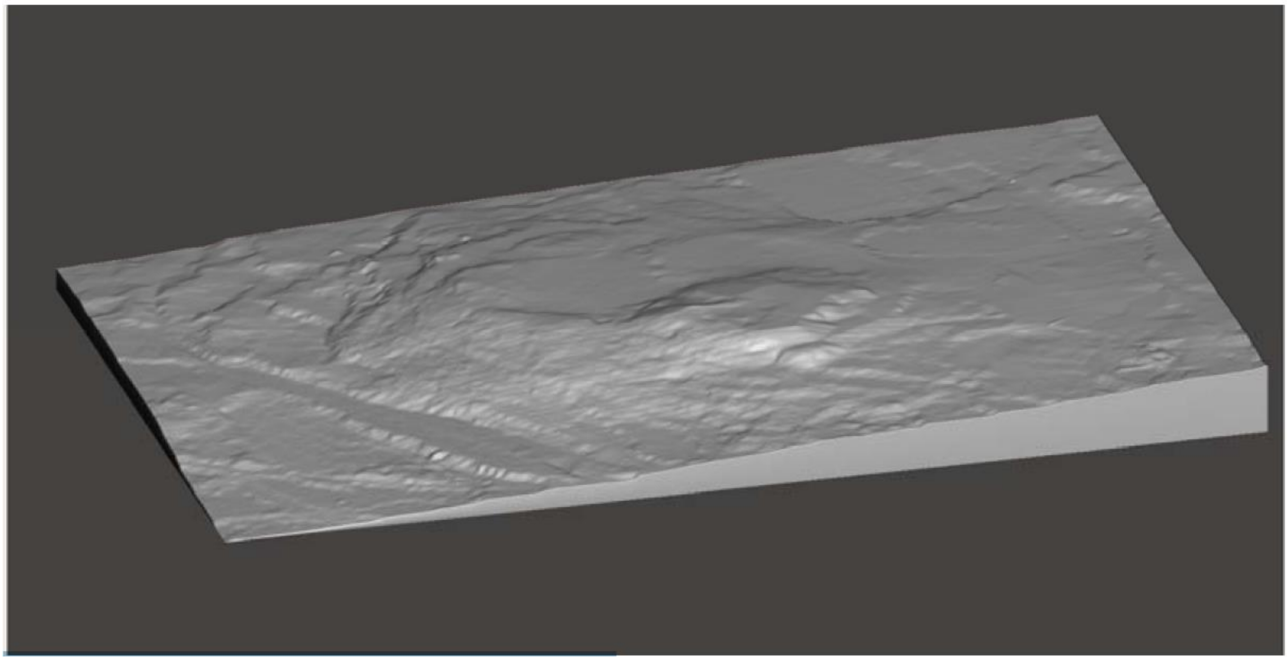

Figure 3: 3D elevation model of the Salinelle area.

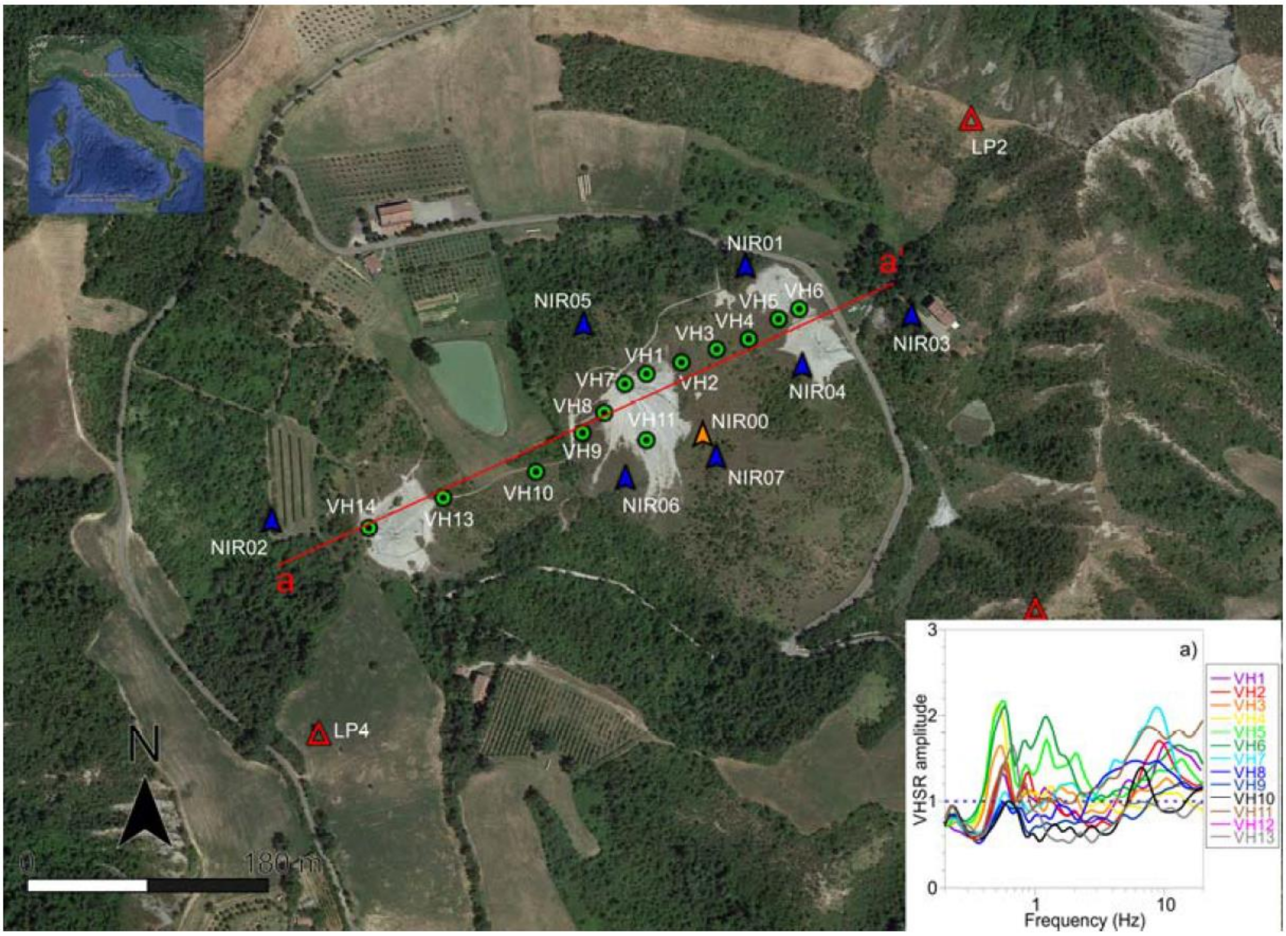

Figure 4: Salse di Nirano study area reporting the acquisition point data. Inset shows preliminary results.

During the STSM data acquired on Mt Vetore (Etna, Sicily) were analyzed. Mt. Vetore is a pyroclastic cone (Corazzato and Tibaldi, 2016) located on the flank of Etna (Figure 5). Parasitic volcanic cones is an important marker especially in volcanoes characterized by lateral activity. Their distribution and orientation is an important marker to obtain information on the maximum horizontal compressional stress that act on a volcano. A geophysical survey on Mt. Vetore pyroclastic cone was performed to obtain important information on its structural setting and to support the usual morphometric analysis. Results highlighted an evident peak at 1.0 Hz inside the cone, which is attenuated away from it. Random decrement method was applied to this peak to compute damping and then to exclude a link with anthropogenic sources. Moreover, time-frequency polarization analysis revealed that ambient vibrations are strongly polarized in a narrow frequency band centred at frequency of 1.0 Hz, with a preferred oscillation azimuth almost 70°-90° N. Array measurement of ambient vibrations was also used to obtain shear wave velocity profile and then to retrieve the main interfaces with high seismic impedance. The results suggest a cone structure having a feeder pipe consisting of about 50 m of fragmented rocks surrounded by piroclastics laying on a high velocity substrate. Finally, a 3D model of Mt Vetore was built employing the Finite Element method to reproduce the first experimental modal frequency of the cone. The numerical results reproduced quite well the first experimental frequency as well as the oscillation direction observed during the geophysical survey.

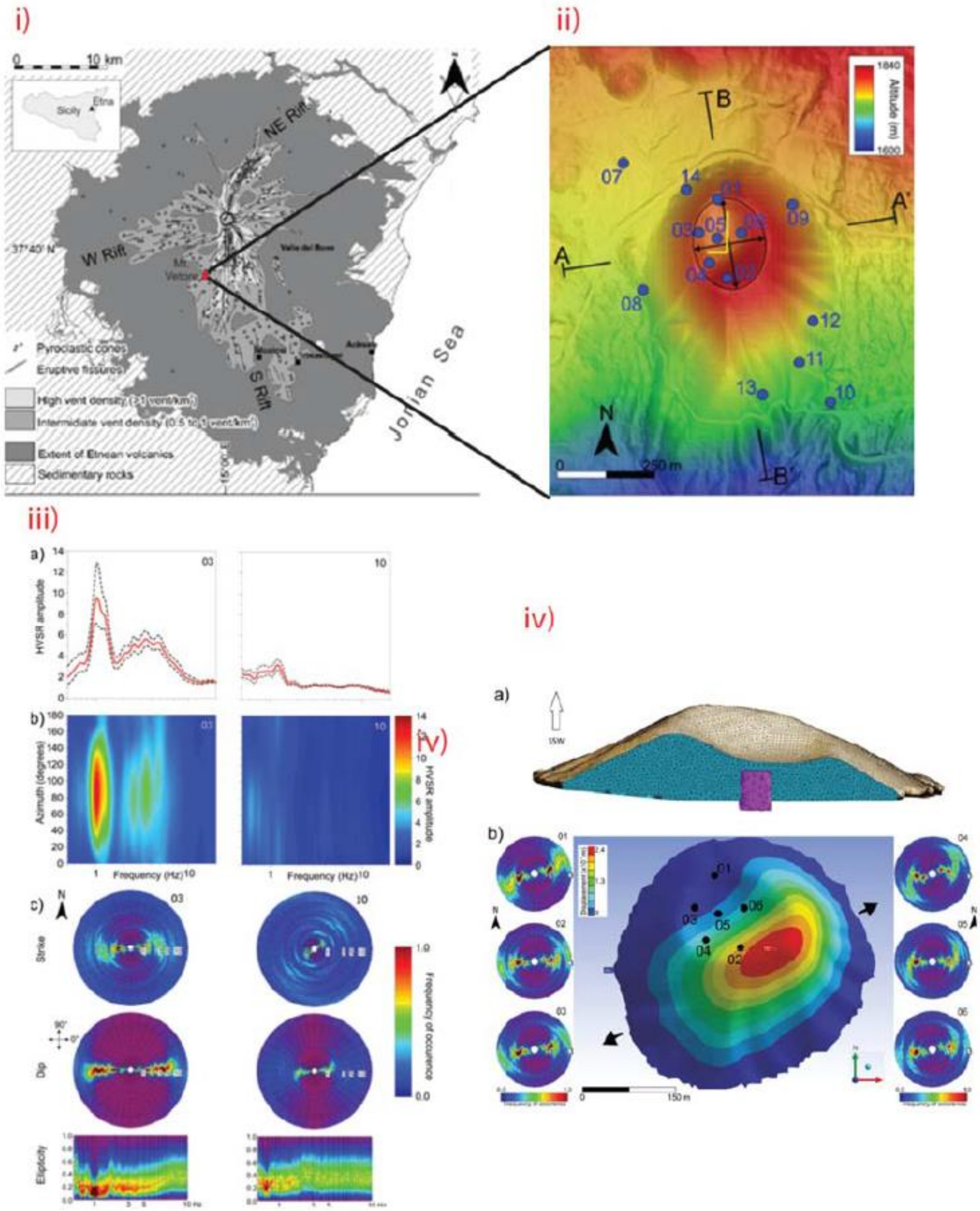

Figure 5: i) study area; ii) Altitude map of Mt. Vetore; iii) a) Examples of HVSRs obtained at the investigated sites and corresponding contours plots (b) TF analysis results for the selected sites (c). iv) a) Sections of FE model of Mt. Vetore in purple the dike and in light blue the pyroclastic material. b) Pyroclastic cone displacement for the first experimental modal frequency, in which black arrows show the oscillation direction (continuous animation of this is available as animations S1 and S2 of the auxiliary material). Black point indicate the experimental ambient vibrations measurement sites inside the cone, for which are reported polar plots of the polarization strike. The contour scale represents the relative occurrence frequency of each value and the distance to the center represents the signal frequency in Hz (modified from Panzera et al. 2018b).

Future collaboration with the host institution

The two Institutions involved in this STMS intend to submit a common research proposal. In particular, the authors are considering the calls explicitly designed and directed to facilitate Italian-Maltese scientific collaborations. On this framework we are going to propose a project that deals with innovation technologies and multidisciplinary survey to study the subsurface. Independently from this, we hope to have many future occasions to perform integrated studies and improve the ongoing collaborations.

Foreseen publications/articles resulting from the STSM

At the moment, the next occasions for publishing part of the data are the next ESC were two abstracts were submitted. One related to the Salinelle area and the other related to the result on Salse di Nirano. Results about Mt Vetore have been submitted as a peer-review journal.

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