Scientific Report of the Short-Term Scientific Mission (STSM)

Topic: Transform Faults Analogue Modelling: application to the NAF

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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)

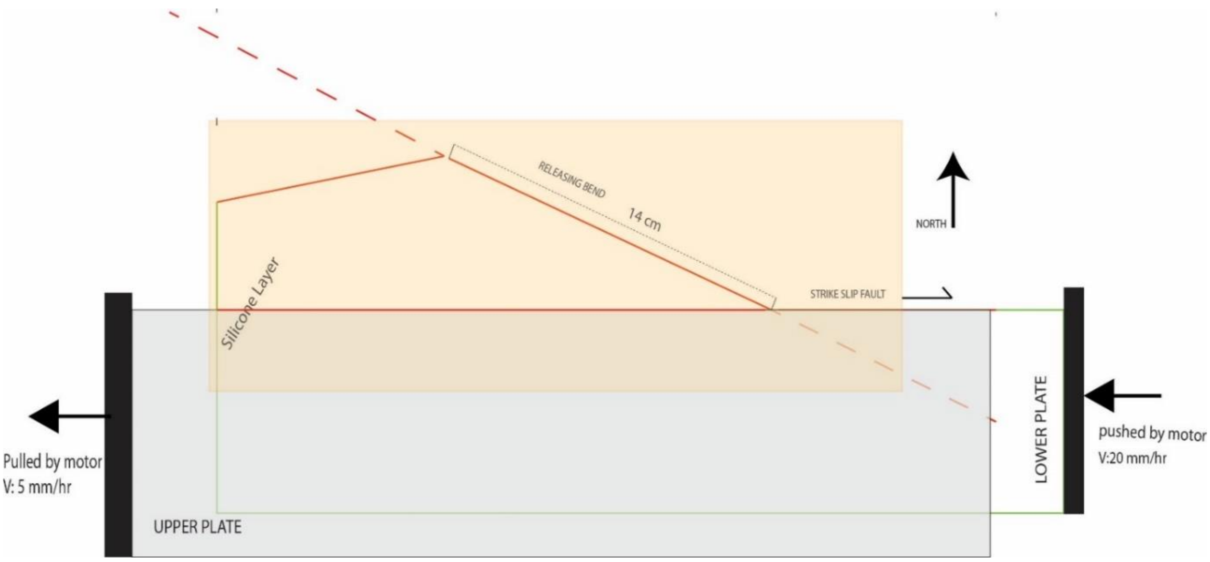

Figure 1 showing the one of example of experiment setup of models

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.

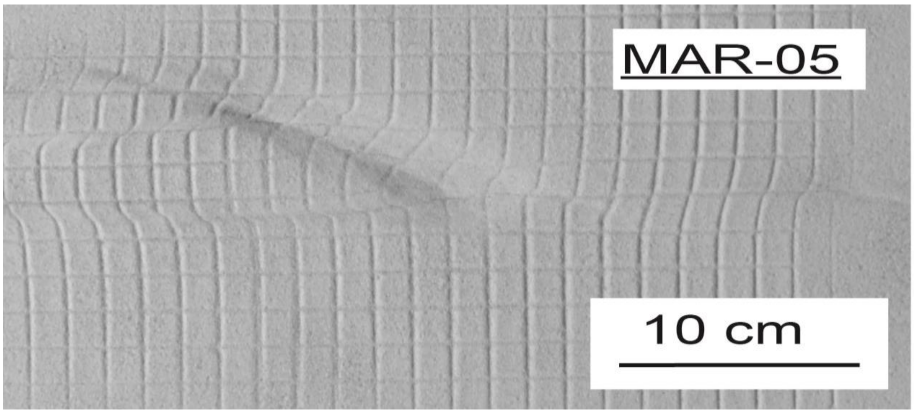

Figure 2 Top picture of the model 5 at the end of the deformation (7cm)

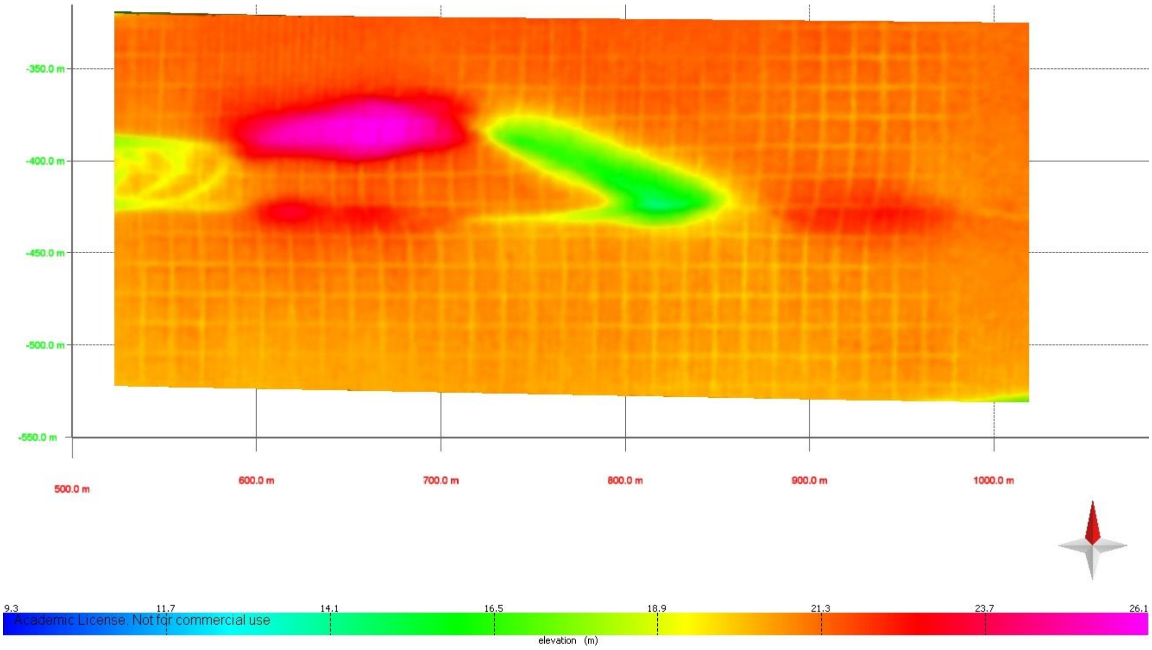

Figure 3 Top picture of the model 5 at the end of the deformation - shearing zone

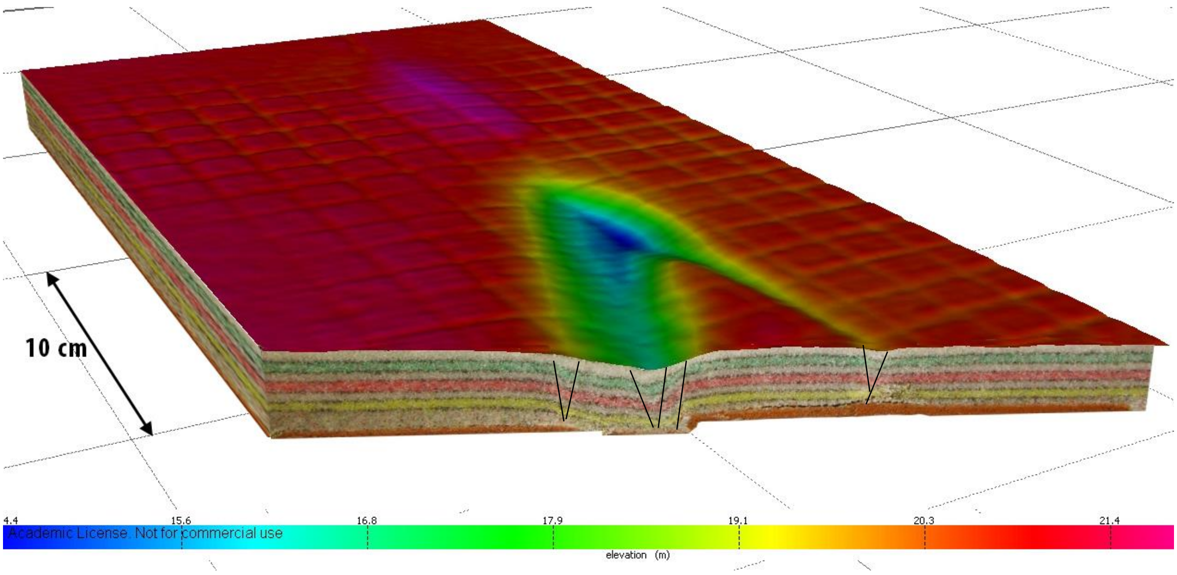

Figure 4 3D Visualisation and vertical profile of extensional pull apart basin Model 5 (MAR-05) after 7 cm of horizontal displacement

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.

References

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