Analogue modelling of the dynamic emplacement of cone sheets in volcanoes

1. Purpose of the visit

The Physics of Geological Processes analogue laboratory led by Dr. Galland at the University of Oslo offers the facilities and knowledge needed to model the volcanic processes that I study in the field. The experimental results so far achieved with the PGP apparatus underline that we need to better understand how cone sheets initiate, propagate and finally feed surface eruptions. Notably, it will be crucial to unravel the mechanical role of the deformable free surface on the formation of cone sheets. The purpose was therefore to conduct a series of experiments and establish a workflow using the PGP apparatus to analyze distinct aspects of the dynamic emplacement of cone sheets, with a particular focus on the associated surface deformation. Importantly, the experiments aimed at quantifying (i) the evolution of the magma pressure through time, (ii) the evolution of the surface deformation through time by using advanced photogrammetry software, (iii) the 3D shapes of the intrusions, and (iv) the physical effects of the model material properties. In addition to this, datasets from previous experiments will be manually computed at PGP because the hardware needed for computation is located there.

The experiments I carried out during my stay at PGP Oslo will form the basis for a fundamental conceptual advance in our understanding of the emplacement of cone-sheets, which will have direct applicability for interpreting field observations in eroded volcanic systems. Additionally, the direct link between the dynamics and geometry of the experimentally-produced cone sheets to the recorded surface deformation will allow us to develop a key for the interpretation of surface deformation in active volcanoes where cone sheets are emplaced and may feed eruptions.

2. Description of the work carried out during the visit

During the total of three weeks spent at PGP I carried out the following experimental work in collaboration with my host, Dr. Olivier Galland:

We performed a parametric study by running two series of experiments where the physical parameter of cohesion (C) was varied. This was done by using two different mixtures of silica flour and glass beads as an analogue to the brittle country rock. The cohesive property was expected to affect the way the material fractures thus influencing the propagation of the intrusion. The first series was conducted with a (medium cohesion) mixture of 50% silica flour and 50% glass bead while the second one used a (low-cohesion) mixture of 20% silica flour and 80% glass beads. During each series of experiments the depth of injection was varied to be able to sample both the dyke and the cone sheet regime. The remaining parameters of the experiment, such as magma viscosity, injection velocity and the inlet size were kept constant. The pressure was measured during the run of the experiment and will be further analyzed together with the dimensional data of the ground uplift. This study highlights the interplay of parameters that control the formation of cone sheets and their morphology and will lead to a quantitative understanding of the contribution of each parameter by means of a dimensional analysis.

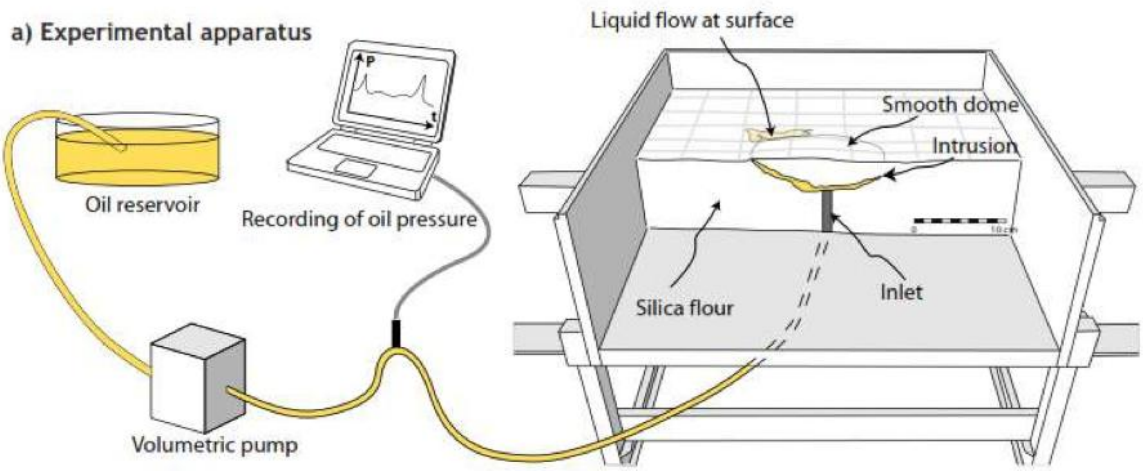

Figure 1. The experimental setup used by Dr. Galland. (Reproduced with permission from Galland, 2012).

Furthermore, we enhanced the methods used to quantify ground uplift associated with the intrusion during the experiment. Now instead of using the moiré projection technique, we implemented photogrammetry by using four calibrated high-resolution cameras synchronized to take images simultaneously. This made it possible to document the deformation at a higher sampling rate than before and at a much greater precision. By using the software MicMac, we were also able to create a 3D-model of the surface deformation at each time step. Moreover, we developed a workflow that allowed recording the 3D-shape of the intrusion after the experiment was finished and the intrusion was excavated. For this purpose, a textured background had to be created for the 3D-software MicMac to work with and so that the photographs included reference points for later georefencing. Ultimately, the calculated ground uplift and the shape of the intrusion can be linked using this procedure.

Each experiment is very time-consuming and takes about four hours to set up, while it takes about 30 seconds to run the experiment. After 30 minutes to one hour cooling time, the excavation of the intrusion may take up to 30 minutes, followed by about five hours of systematic recording of the intrusion geometry and one hour cleaning.

Postprocessing of most of the data will happen after the exchange at Uppsala University. However, we manually calculated uplift data and developed a MatLab code to convert the pressure measurements, noise correct the surface uplift data and plot the uplift data as a function of time.

<u>The work was carried out according to this schedule:</u>

<u>week 1:</u> Introduction to the experimental facility and setup, dimensional analysis of the models, establishment of the experimental strategy (parametric study), development of MatLab code. experimental runs according to the parametric study and manual computation of data sets.

week 2: Experimental runs according to the parametric study and manual computation of data sets.

week 3: Experimental runs according to the parametric study and manual computation of data sets. Processing datasets with help of MatLab code. Start developing new code to analyze the experiments done with the new photogrammetry method with image correlation and image analysis which will result in the deformation represented as vectors. Retrieving and analysing surface deformation & pressure data for further processing

3. Description of the main results obtained

First results of pressure, uplifted surface area and volume during an experiment were obtained by manual computation and MatLab calculation (Fig. 2).

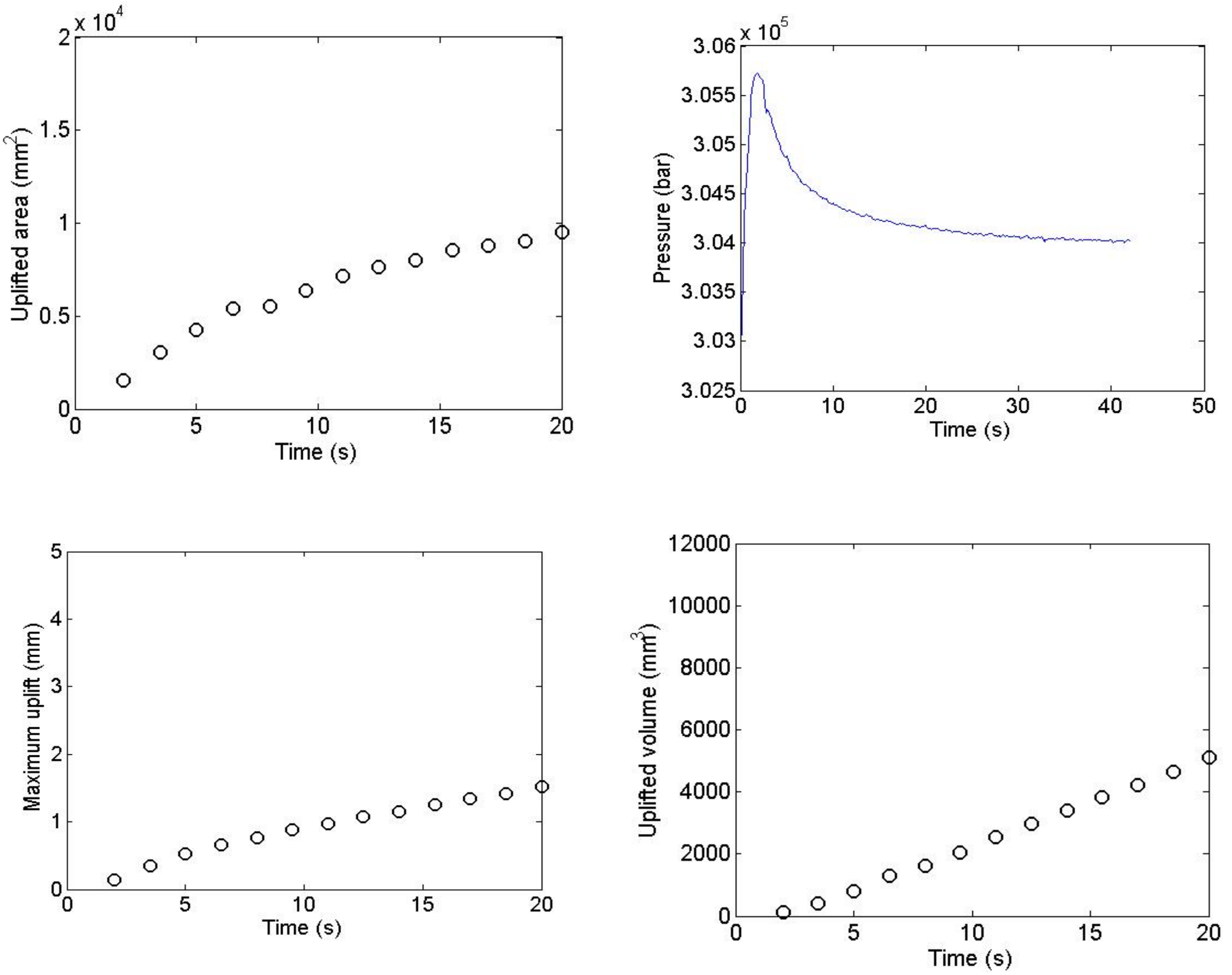

Figure 2. The development of uplifted surface area, pressure, maximum vertical uplift, and uplifted volume as a function of time in an experiment where a cone sheet was formed.

A second key result is the establishment of a workflow regarding the newly implemented method using photogrammetry. A clear method of placing the cameras and how to obtain and process the images was developed, resulting in even more precise data than that of previous experiments. Figure 3 below illustrates the camera setup used for capturing ground deformation.

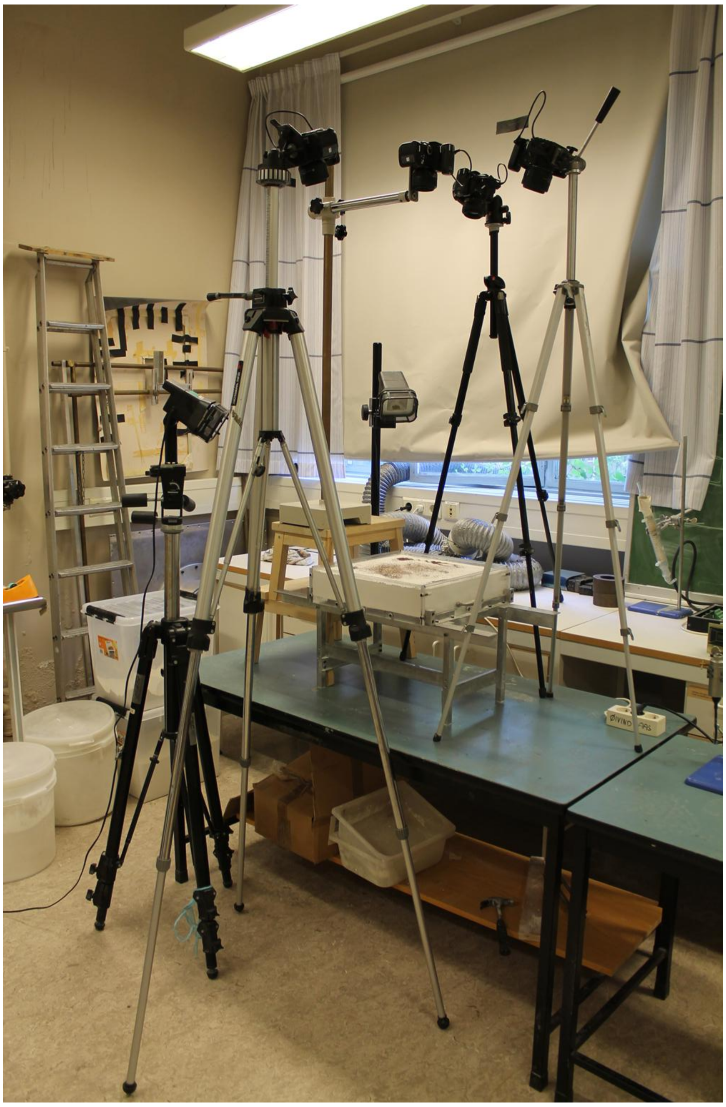

Figure 3. The photogrammetric camera setup developed to document the surface uplift.

A third important achievement of my visit was the further development of the photogrammetry method (Figure 4) to produce low-noise high-resolution 3D models of both the ground uplift but also of the intrusion geometry and compile these two without offset (Figure 5).

A B

Figure 4 A. Taking photos of the excavated intrusion played a major part in the resulting quality of the intrusion. It can require over 100 images to create a single model. **B.** An example of a dyke produced during an experiment. The excavation of the intrusion had to be performed extremely carefully as the intrusions are fragile. It was also established that the computer software required texture in the images to make the georeferencing work properly. Therefore the boards with drawings were fastened to the box.

Figure 5. Different views of a low-resolution example of a 3D-model of a dyke with features resembling a cone sheet.

4. Future collaboration with host institution

My exchange visit at the analogue laboratory at PGP Oslo has not only produced extremely promising scientific results that will lead to several publications (see section 5), it has also strengthened the collaboration between Dr. Olivier Galland and myself. The visit has given us the chance to plan common projects in the next years. This way, we will establish a strong link between PGP Oslo and the volcanology research group at Uppsala University, which is a significant step forward for an international network of volcano research in the Nordic countries.

As a next step in our collaboration, Dr. Galland and I are organizing a session on volcano modeling at the EGU General Assembly 2014. We have also planned to jointly supervise MSc and PhD projects in the near future.

5. Projected publications / articles resulting or to result from the grant

The quantitative dataset produced during the visit will likely lead to at least two publications in international scientific journals, one on the pressure development and surface deformation during intrusion and one on the geometry of the experimental intrusions in comparison to examples in nature.

References

Galland O. (2012) Experimental modelling of ground deformation associated with shallow magma intrusions. Earth and Planetary Science Letters, 317-318, 145-156.