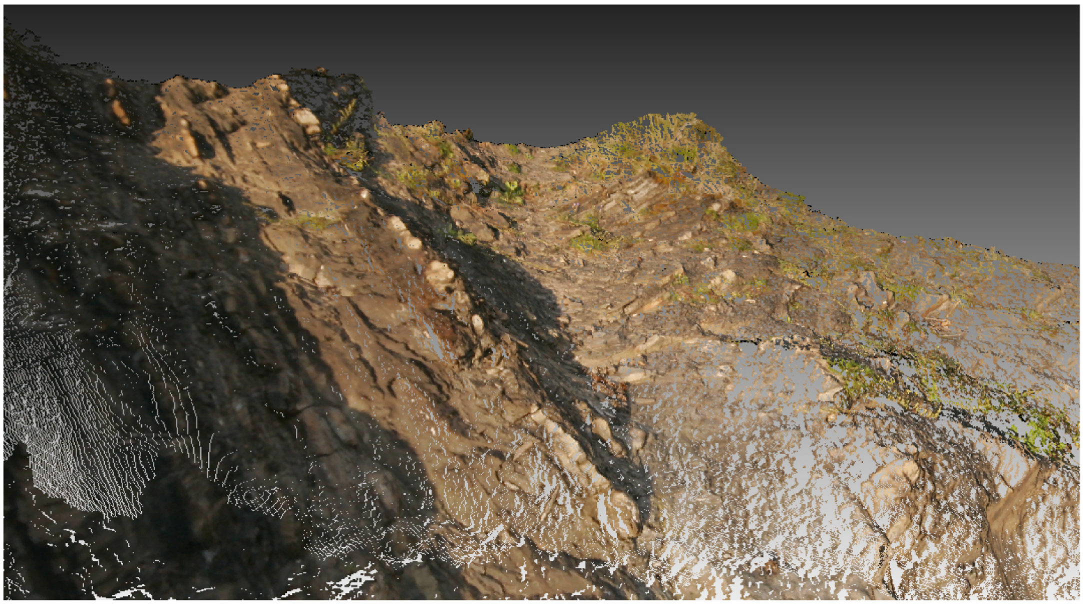
Rapport de Projet Pluridisciplinaire

2ème année du Cycle des Ingénieurs diplômés de l'ENSG

The use of SfM technologies in geosciences :

MicMac for geologists



Luc Girod

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Jury

Président du jury

Christine SALGÉ, directrice adjointe ENSG

Commanditaire :

Andreas Kääb,
Department of Geosciences
University of Oslo
PObox 1047 Blindern
N-0316 Oslo

Encadrement de stage :

Andreas Kääb, Universitetet i Oslo, maître de stage

Raphaële Heno, DPTS, ENSG, rapporteur principal

Responsable pédagogique du cycle Ingénieur: Serge BOTTON, DE/DPTS

Tuteur du stage pluridisciplinaire : Patricia Parisi, DSH

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For Odin, Vili and Vé
who killed Ymir and crafted the rocks for Midgard out of his bones

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I would like to thank everyone at the Geofag and PGP department at UiO for the opportunity they gave me this summer and their very friendly welcome.

A special thanks to Andreas Kääb, my supervisor, for his enthusiasms from the beginning and his undeniable helpfulness.

I would also like to thank Pierre-Marie “PiM” Lefeuvre and Olivier Galland who have both provided me with data sets, challenges, ideas and their experience in their fields.

Thanks also to my ENSG supervisor, Raphaële Heno, for her insightful advice.

But mostly, thanks to Marc Pierrot-Deseilligny, without whom MicMac would not exist.

Résumé

L'analyse et la compréhension des processus géophysiques qui ont eu lieu, ont lieu ou auront lieu sont des besoins critiques pour un bon nombre de problématiques liées, de la prospection pétrolière et gazière à la prévention de catastrophes naturelles en passant par la recherche sur l'évolution des espèces en regard du changement de leur environnement.

Ce rapport explore les possibilités offertes par les technologies de Structure-from-Motion dans les domaines de la géoscience, la géologie et la géophysique grâce à l'utilisation du logiciel gratuit en Open Source MicMac. Pour ce faire, il a été testé sur un certain nombre de projets différents tant au département de géologie qu'à celui de physique de l'université d'Oslo (Norvège).

Mots-Clés : Structure-from-Motion, MicMac, géologie, géophysique

Abstract

Analyzing and understanding the Earth and the geophysical process that have happened, are happening or will happen are critical needs for a large number of related issues, from oil and gas exploration to natural disaster prevention or even for the research on the evolution of species in regard of their changing environment.

This report explores the possibilities offered by the structure from motion technologies in the fields of geosciences, geology and geophysics through the use of the free and open source software MicMac. It was tested on a number of different projects at both the geosciences and physics department of the University of Oslo, Norway.

Keywords : Structure-from-Motion, MicMac, geology, geophysics

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Glossary and useful acronyms

SfM	Structure from Motion: a process used to find 3D structure from images.
MicMac	MicMac is a Linux based software using the principles of SfM and dense image matching. It is developed by Marc-Pierrot Deseilligny for the MATIS laboratory at IGN and is *Open Source* and free to use.
UiO	Universitetet i Oslo (University of Oslo)
PGP	Physics of Geological Processes Center at UiO
NVE	Norges Vassdrag-og Energidirektorat, the Norwegian Water and Energy Directorate
SIFT	Scale Invariant Feature Transform algorithm to detect feature points in images, giving them signature that can then be matched with points in other images.

INTRODUCTION

The concept of Structure from Motion (SfM) is a recently developed technology, made popular by Noah Snavely's Bundler in 2008. It consists of retrieving 3-dimensional information from a collection of images of the same scene, automatically and without the need of identifying tie-points manually or feeding the calibration of the camera(s) to the algorithms. The most common outputs of this technique are colored point clouds, digital elevation models (DEM) and orthoimages, therefore compiling in one tool a number of techniques. Since a simple camera and the software are the only compulsory tools for this technology, it stands out as very affordable.

In geology, the analysis of the shape and texture and the monitoring of deformation and movement are key tools. Former technologies that are used to get these information are very expensive (like Radar or LiDAR), not accurate enough or give an insufficient amount of points to compute a model (classical topography or GPS surveying). With SfM, geologists can easily obtain high quality products that can be analyzed in great precision.

The main purpose of my internship was to explore the possibilities and see to what extend the SfM technology could be of use in geoscience. It is therefore through a number of different projects that I have over-viewed the interest of geoscientists for this technique. I also intended to bring the MicMac tool to the research groups I was involved with through mentoring and step by step tutorials.

In this study, the software MicMac was chosen for its versatility, its ability to deliver very high density point clouds and easy-to-georeference products. However, other software (Bundler, ARC-3D...) provide more or less similar services.

I.METHODOLOGY

For each project I was involved with, three steps were followed : understanding the project's needs and requirements in terms of products and resolution, collecting the data and processing it.

A)Understanding the projects

The first step always is to understand and comprehend why and how MicMac can be of use to fulfill a specific need. Exploring the previous research, data and experiments on the subject gives a good overview of how the results or data sets to be analyzed might be improved with MicMac.

The different project leaders have different levels of familiarity with the tools available and the products which can be obtained through them. Seeing the data they are used to work with gives an edge when it comes to advertise other, newer (better) techniques.

This step results in a description of the products that will be made : orthoimages, depth maps, point clouds...and the desired resolution of them, since the size of the elements that are studied varies from a meter to under a millimeter.

B)Data collection

The second step is data collection. It consists of taking the images that will later be treated. Even if SfM techniques are meant to work with any image, the very dense correlation and precise products created by MicMac require the images to be taken in a specific way. Two main possibilities, that can be combined, are to be considered : a plane like approach, with one or more lines of images for roughly planar scene or objects, or a convergent viewpoints approach for more three-dimensional objects.

The acquisition techniques, as well as camera-setting advices are explained in the tutorial available in Annexe 3 : How to take Pictures for MicMac.

C)Data processing

This is the office work part of the job. Once the data is ready and available, parameters need to be defined and sometimes tested. This is where MicMac operates.

Processing data through the software is quite straightforward and work flows (see Annexe 1) simplify the work.

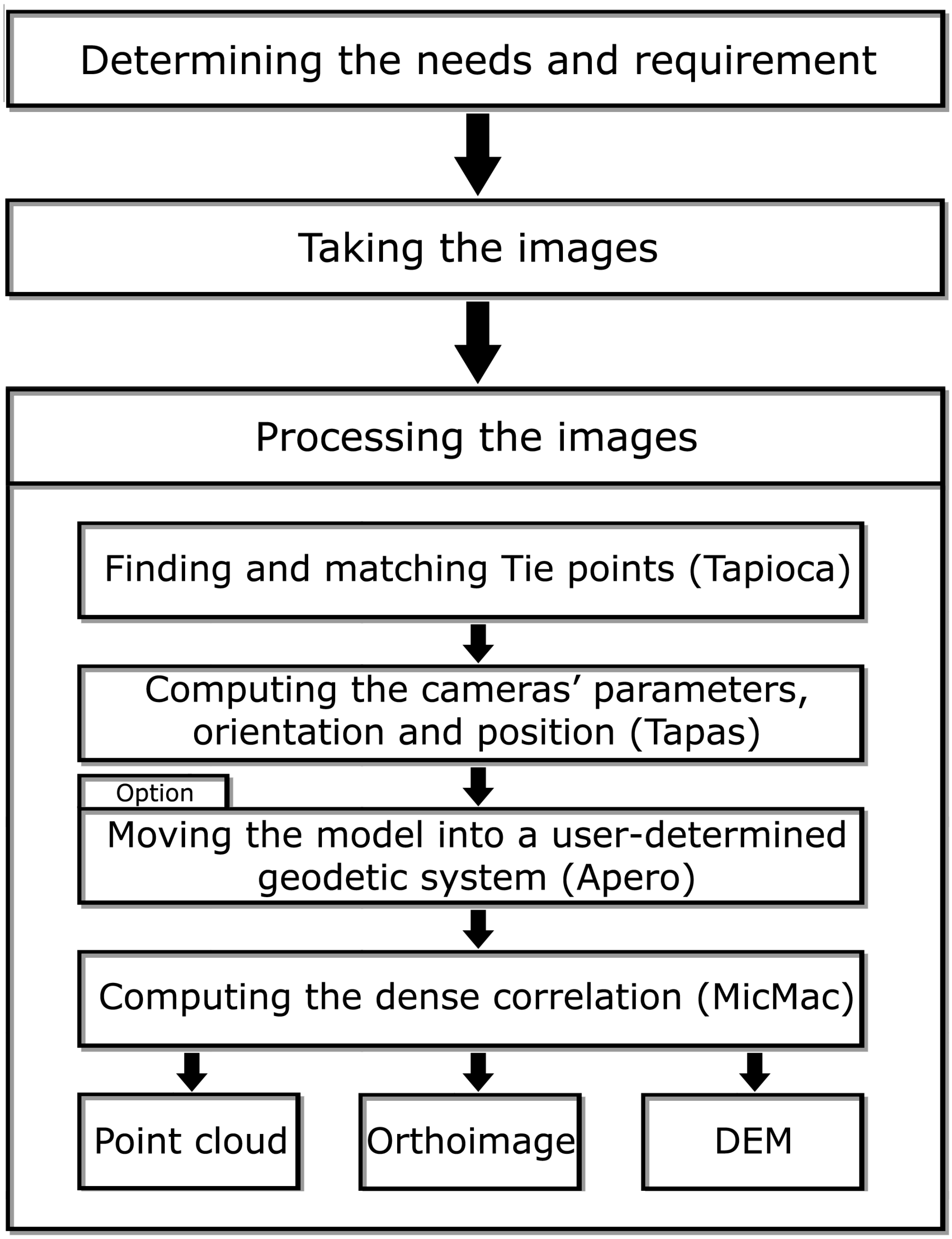
These work flows are the result of an elementary analysis of the most common needs and possibilities offered by MicMac:

- The model might be georeferenced in an absolute geodetic reference or scaled with a local reference, which is the same process for MicMac, or it might stay in the Apero (one of the step in the MicMac process) self-defined empirical system.
- The geometry could be image based with central images on which the correlation masks are defined and their peripheral counterparts that make the 3D possible or they could be ground based, with an elementary mosaic of the images on which the correlation mask is done.

This gives a total of four different elementary work flows that can evidently be altered if specific needs were to arise. The example that comes to mind is the possibility of combining ground and image geometry based point clouds to get more details on some areas, or to cover hidden areas.

The main outputs of MicMac are .PLY point clouds (with Nuage2Ply), orthoimages (with Porto), shaded images (with GrShade) and depth map (automatically generated by MicMac), but one might also be interested in the camera's positions through AperiCloud...

Figure 1: Overall work flow schematics



Luc Girod,2012

II.USING SFM IN DIFFERENT PROJECTS

In order to get an overview of the needs of geologists for a tool like MicMac, a number of projects where the technique seems applicable can be used to get data sets. The analysis of the MicMac outputs by the scientists in charge of the projects provides a good insight on how efficient the process is for their research.

During the internship, four different projects were used as data sets providers. These projects were carried on at the Geosciences Department or at the Physics of Geological Processes Center (PGP) of the University of Oslo. The researchers in charge of these projects showed an interest in the SfM technology and wanted to try it out on their subjects to see how they could use it and have an idea of both the type of results to expect and the quality of those results.

A)Small scale phenomenons : sorted circles in Svalbard

1.Introduction

The first project studied during the internship was centered on the geological phenomenon referred as Sorted Circles. It consists of small -about two meters wide- naturally occurring geometric shapes made of small stones, covering large flat areas of permafrost. The way they appear and evolve is not yet perfectly understood and producing accurate 3D models and orthoimages of the same circles at different moments in time might help understanding their evolution.

The circles studied are in the North-West of Svalbard (78.95°N 11.5°E), in an area called Kvadehuksletta**.** This very flat area is covered by these circles and is the prime location for their studies.

Previous results were only made with pair of images, and even if they showed a globally true model, it was nowhere close to be good enough to be analyzed and compared with other models.

2.Data description

To be able to analyze the movement that occurs in a circle, sets of pictures were taken in 2007 (63 images) and 2010 (104 images) , it is planned to take another set in 2013. The area were the circles are is so remote that an expedition there only for the pictures is never considered and must be part of a bigger surveying project.

The images were taken from a ladder, therefore resulting in a slightly non vertical point of view (40° off). The geometrical configuration is still close enough to a plane like geometry with two flight lines.

If the number of images is clearly too high given the size of the covered area (40m²), it is because at each point of view, images were taken looking sideways. But given the long baselines, extracting the central image of each point of view would result in an insufficient cross coverage.

Figure 2: Sorted Circle in Svalbard (4 to 5 meters wide)

Andreas Kääb, 2010

For each set of images, 10 ground control points acquired by GPS were given in order to georeference the outputs of MicMac through a Dico-appuis.xml/Mesure-appuis.xml Apero procedure. The points were numbered orange metal stakes pined in the ground. Since the presence of the sorted patterns is explained by a very moving soil, the stakes can't be expected to be at the same place after three years. Therefore, the GPS coordinates of the points are different from a set to another. If the plane coordinates were consistent with the predictable movement, the altitudes were not. It turned out that the ~5cm difference was the result of a similar difference in the RTK base coordinates. The altitudes were corrected with the average of the difference.

3. Data processing

This was the first project of my internship and was therefore the one which causes the biggest methodological problems, since a suitable work flow had to be defined. I also had to get used to MicMac again since I hadn't been using it for nearly a year. This getting used to was however pretty quick in the end.

The two sets were treated through the same work flow (see Annexe 1), giving for each set a georeferenced orthoimage and a point cloud as outputs.

The number of images resulted in very long computing time, and the result was only available overnight. Some images proved to be the source of random problems and clearly wrong results and had to be evicted from the image set manually.

Figure 3: Orthoimage of the 2007 data set

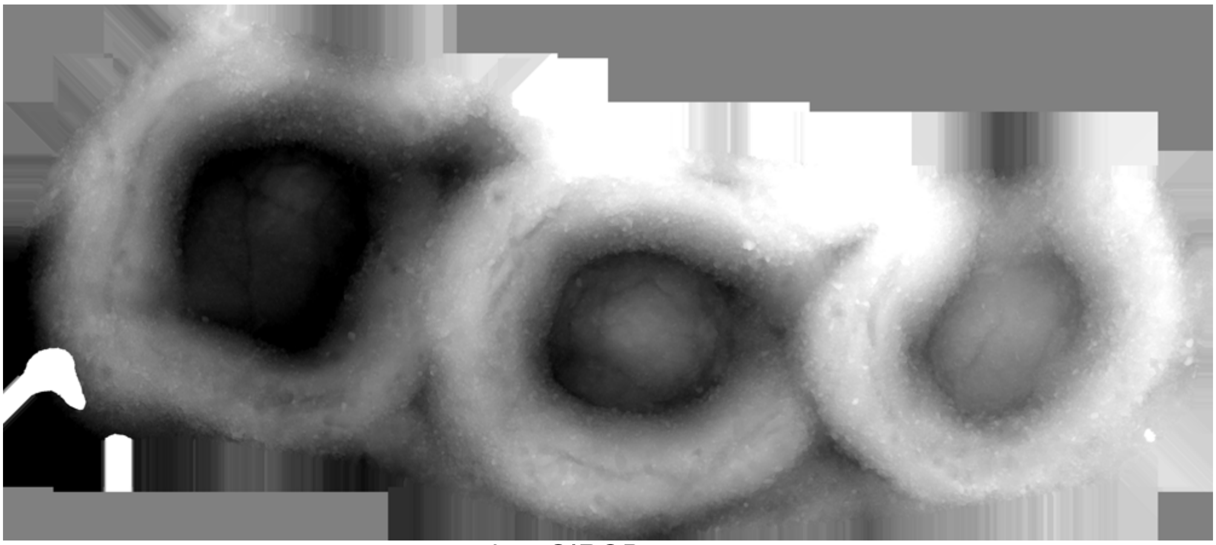
4.Comments on the outputs

a)Quality and quantification

The 2007 data sets delivered a 24.744.929 points cloud and a orthoimage with a 1.3mm resolution while the 2010 data sets delivered a 33.179.159 points cloud and a orthoimage with a 1.1mm resolution. This is a significant improvement on the former products obtained with these images. With a quadratic error after the “Apero” step under 0.4 and the almost absence of noise in the point cloud, the quality is very satisfactory.

Since the two sets are properly georeferenced, the two clouds can be loaded -given that the computer can handle a 50 millions+ point could- at the same time and compared easily and visually. The two orthoimages can be scaled to be also superimposed and therefore easily compared.

Figure 4: DEM of the 2007 data set



Luc GIROD, 2012

The post-MicMac analysis will consist on using feature tracking software on the orthoimages and using the DEM to get the third dimension coordinates of the tracked points. Therefore, a displacement vector field might be computed.

b)Feedback from Andreas Kääb

I am a researcher and professor in remote sensing at the Department of Geosciences of the University of Oslo. My group focuses on the observation of cold regions : glaciers, permafrost and related natural hazards in the Arctic, Antarctica and high mountain regions worldwide. The scale of processes we work on ranges from entire mountain ranges (hundreds to thousands of kilometers) to small details (several meters and decimeters). While we apply space methods for the first category of scale, we rely on terrestrial methods for the latter one, often using ground-based photography. In most of our studies we are interested in dynamical processes, so that we usually work with repeat acquisitions from which we detect and quantify three-dimensional surface changes, for instance vertical elevation changes and horizontal displacements.

The necessary imagery is usually taken in rough field conditions, i.e. under “difficult” conditions in terms weather, geometrical constraints, temporal constraints, or availability of ground control points. The standard photogrammetric approaches used so far have often presented problems. The SfM/Micmac projects that Luc Girod conducted and demonstrated to our group have shown a huge potential to massively facilitate our projects and open for new applications in the field of dynamic local-scale Earth surface processes. Applications include:

- Soil sorting and convection due to freeze-thaw cycles (changes in repeat DEMs and multi-temporal matching of lateral displacements, as seen in this project)

- Laboratory tests on deformation of frozen ground under different mixture properties (changes in repeat DEMs and multi-temporal matching of lateral displacements; existing project, suitable imagery not yet taken)

- Rock wall weathering and coastal erosion under different topographic, geologic and climatic conditions (repeat DEMs, project foreseen, perhaps re-computation of existing imagery)

This list is far from exhaustive and more applications are to come for sure after gaining more experience with SfM and Micmac.

Andreas Kääb, August 2012

B)Projects at the Physics of Geological Processes Center

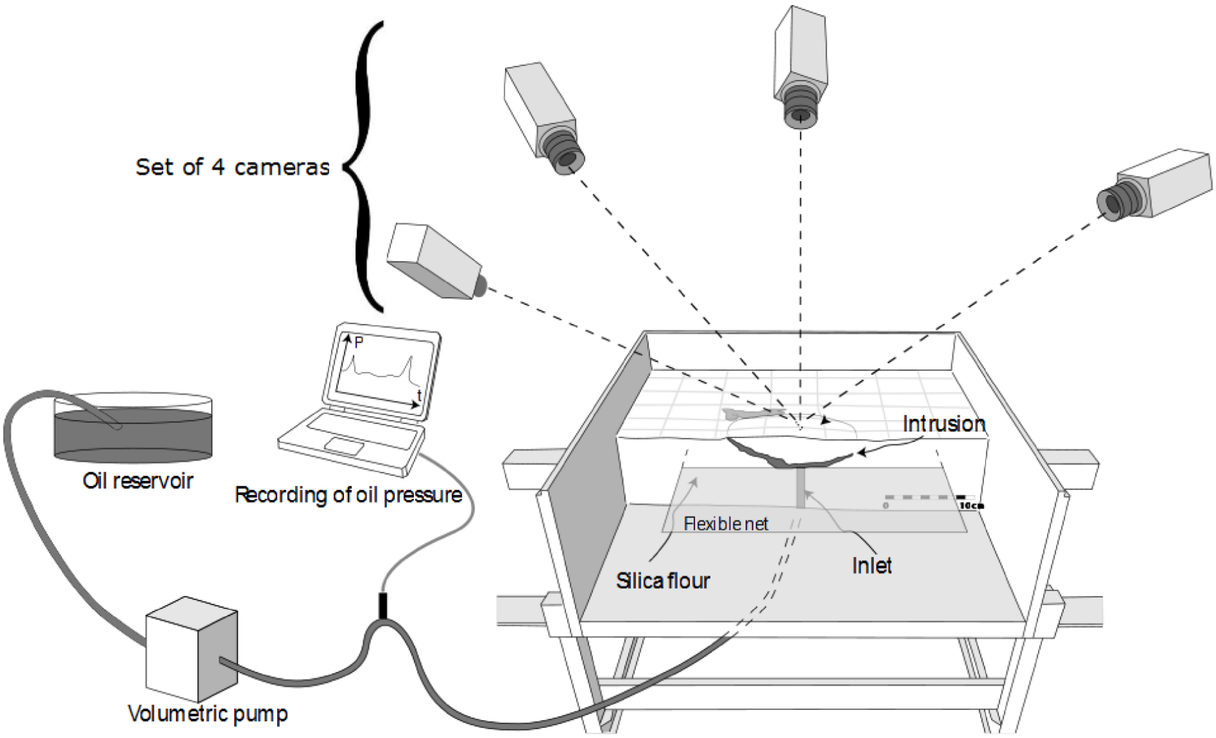
The PGP works on modeling geological processes by both surveying Norwegian and international geological events and experimenting digitally and in laboratory settings. My work with them was divided into two projects, one in the lab on a volcano model and the other on the study of outcrops.

1.Lab setting : surface changes from magmatic push

a)Introduction

The second project I investigated was in a lab setting. Dr. Olivier Galland from the PGP works on modeling the modification of the surface of volcanoes around the time of an eruption, when the magma pushes its ways out. To simulate this and get data sets, he uses a 40x40cm box filled with silica flour, a volumetric pump and liquid vegetable oil. In order to get 3D models, he used an interferometric setup but the interferometric fringes were producing localized, impossible to smooth noise.

Figure 5: The setup of the experiment



Olivier Galland/Luc GIROD, 2012

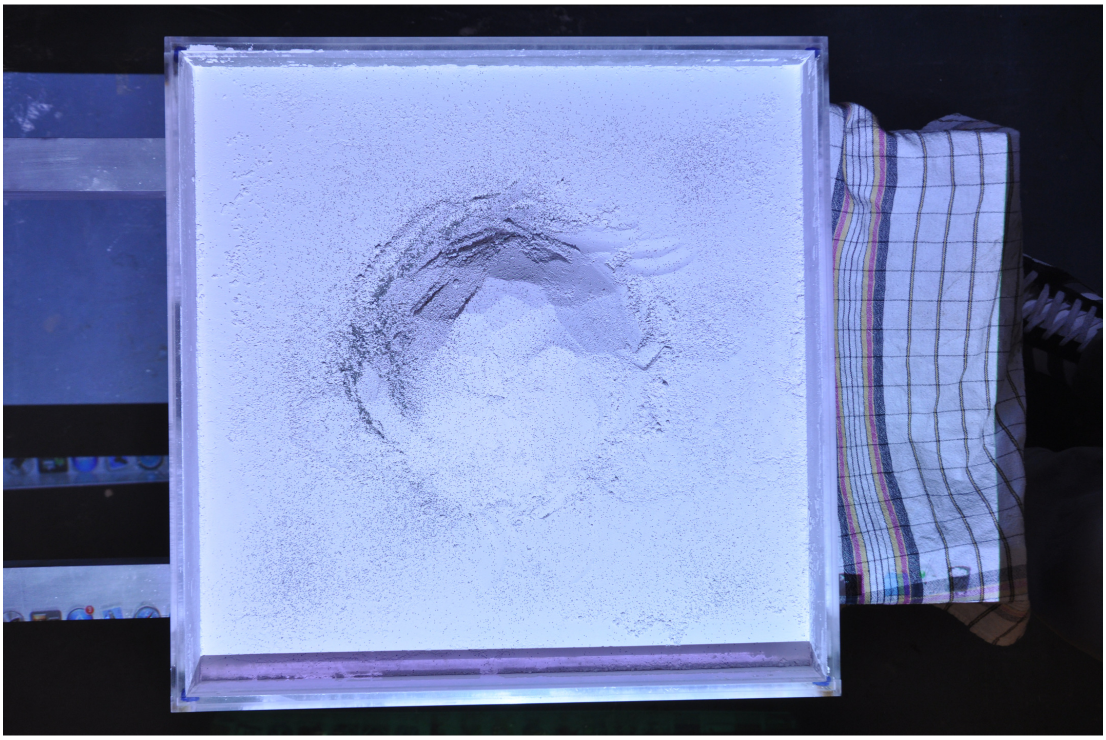
The idea of using MicMac to compute the models then arose. The idea would be to create a four fixed cameras setup. Using a software to synchronize the triggering of all the cameras, it would then be easy to get a collection of four pictures sets taken across the duration of the experiment from which models would be extracted and compared.

b)Data collection

Considering the cost of a four cameras setup - estimated to be around 30.000NOK=4.000€ - and the time the construction of a frame to fix the cameras would take, preliminary experiments from the initial and final states of the process. Since they are both stable, no synchronization is needed and therefore the pictures were taken with a single, hand handled, camera. The camera was my own Nikon D90 + 18-105 Nikkor lens.

Since the MicMac process uses features to compute the cameras positions and parameters and that silica flour is very white and feature less we tried different things : projecting an image from a video projector and randomly cover the setup with some black grains of sand. The first technique worked but prevented any feature tracking between different step of the experience (since the image does not move with the silica). The second one turned out to be very efficient and feature tracking ready.

Figure 6: Top image of the first step of the experiment



Luc Girod, 2012

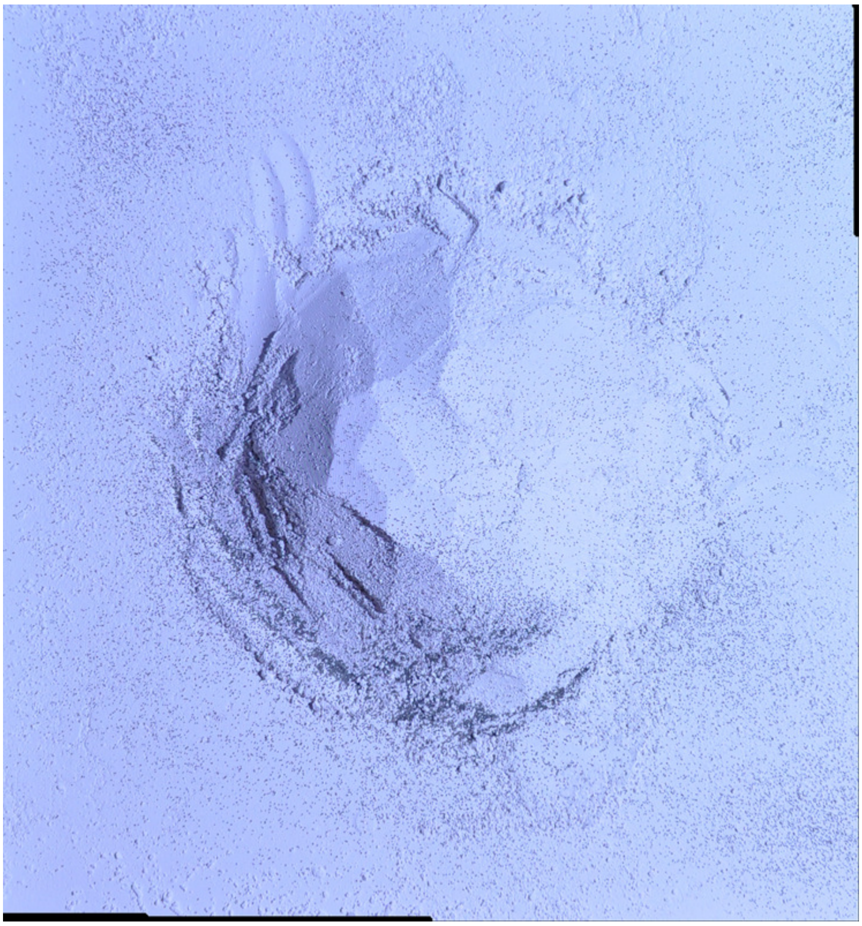
c)Data processing

The images were renamed 1.JPG, 2.JPG, 3.JPG and 4.JPG for each set, so that the exact same work flow could be applied each time, and could also be applied in the future without any modifications. A local reference system was created, with the top right point being given the coordinate (10, 10, 10) in meters. The box is exactly 40cm large, so the other corners were given coordinates like (10.4, 10, 10). Appropriate Mesure-Appuis.xml and Dico-Appuis.xml files were created then the work flow was launched (see Annexe 1).

d)Outputs

The outputs are a point cloud (≈5.000.000 points) and a georeferenced orthoimage.

Figure 7: Orthoimage of the first step of the experiment (40x40cm, light from the right)



Both their intrinsic and georeferencing quality turned out very satisfactory and using them to compute the movement that has occurred during the experiment is clearly possible.Luc GIROD, 2012

2.Outdoor work : outcrops

a)Introduction

The idea behind this project is to be able to study and measure the features of rocky outcrops accurately and more extensively without the need to stay in the field during long periods of having to use rock climbing equipment.

b)Data collection

The data acquisition was made on the beach in the south of Bigdøy (Oslo) with O.Galland Canon 20D 8Mpix SLR camera +50mm lens+10mm lens depending on the outcrop.

c)Data processing

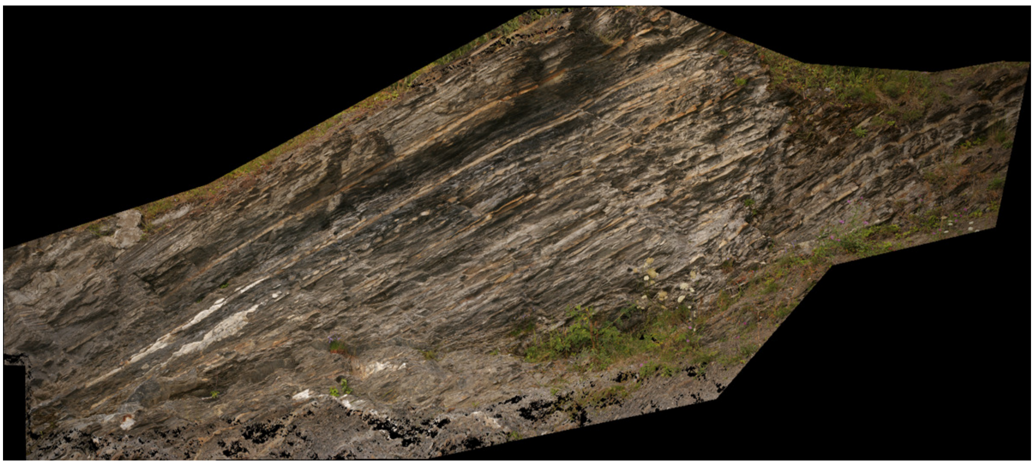
Since this project was the last of my internship, the data was treated through my ready to use work flows (see Annexe 1). With both the ground geometry process and an image geometry process, depending on the group of images.

d)Outputs

Several point clouds and orthoimages were produced. The quality of the result were beyond the expectations of the researchers working with me, with clouds with up to 42230943 points.

The accuracy and clarity of the products clearly satisfy the needs when it comes to analyzing the features in the rocks.

Figure 8: Orthoimage of an outcrop in Bygdøy (~10m wide)



3.Feedback from Olivier Galland

I am researcher at the Physics Department of the University of Oslo, in the center for Physics of Geological Processes (PGP), with a geology background. I am studying the physics of geological processes through integrated fieldwork and laboratory experiments. Notably, I am studying the subtle deformation field associated with magma transport in the Earth crust. So far, both our field and experimental approaches were limited in terms of 3D quantification. For example, measurements of deformation in the lab were limited to 2D, and measurements of fracture network in the field were also limited to 2D. In addition, such measurements were time demanding, as the measuring person has to stand in front of an outcrop as along as he/she has not measured every single fracture. Finally, some geomorphological features such as landslides are hardly measurable as a whole without heavy and very costly equipment.

The program MICMAC introduced by Luc Girod both at the Department of Geology and PGP is a fantastic tool that will push the limits of our investigations. First, in the laboratory, it will allow us to quantify in detail topographical features. The fact that MICMAC integrates the texture of the original images also allows us to perform image correlation, and so to calculate 3D displacement vectors. Applied to volcanic hazard assessments, our experimental approach using MICMAC will become the worldwide reference. In addition, the 3D models calculated from photographs of outcrops will allow us to perform detailed 3D mapping of fracture networks. The power of MICMAC is that the mapping can be done in the office, avoiding spending days or weeks on a single outcrop mapping all the structural features. Finally, quantitative measurements of geomorphological features, such as landslides, will become easy and almost costless. We already have in mind the design of an ambitious catalogue of all landslides occurring in Norway. By far, the cheap and very fast advantages of MICMAC will make this approach beyond any expectations, and so essential, for the Norwegian Geological Survey, which is charge of landscape hazards in Norway. Obviously, this approach will be extended worldwide.

Olivier Galland, August 2012

C)Mapping sub-glacial bedrock

1.Introduction

a)The Svartisen Sub-Glacial Lab

The Svartisen sub-glacial laboratory is a unique place in the world : a laboratory situated 200 meters below the ice of the Engabreen glacier. It is operated by the Norwegian Water Resources and Energy Directorate (NVE) and owned by Statkraft, a Norwegian “green-power” company. The laboratory is used to do research on the behavior of glaciers, sub-glacial water flow and sub-glacial bedrock, among other things. The tunnels in which the lab and living quarters are situated were tunneled at the same time the tunnels were made for the hydro-power plant in Glomfjord. They are also used as monitoring access for the power plant's water supply.

Figure 9: The living quarters in the Svartisen sub-glacial lab

Luc GIROD, 2012

The maximum capacity of the laboratory was fixed to 10 people working during the day and 8 staying overnight, mostly for safety reasons. The living quarters provide rooms, a kitchen, a living room and a bathroom. Therefore, teams of scientists can stay in the tunnel for long periods (sometimes up to three weeks), which is quite welcomed, since the access to the lab is done by a hard climb up a mountain or via helicopter only.

b)The ice cave

One of the field that is explored in the laboratory is the micro-topography of the sub-glacial bedrock. Knowing it's precise geometry can give an insight on how the glacier moves and how the sub-glacial water flows operate. A cave in the ice is therefore melted with hot water and the bedrock exposed.

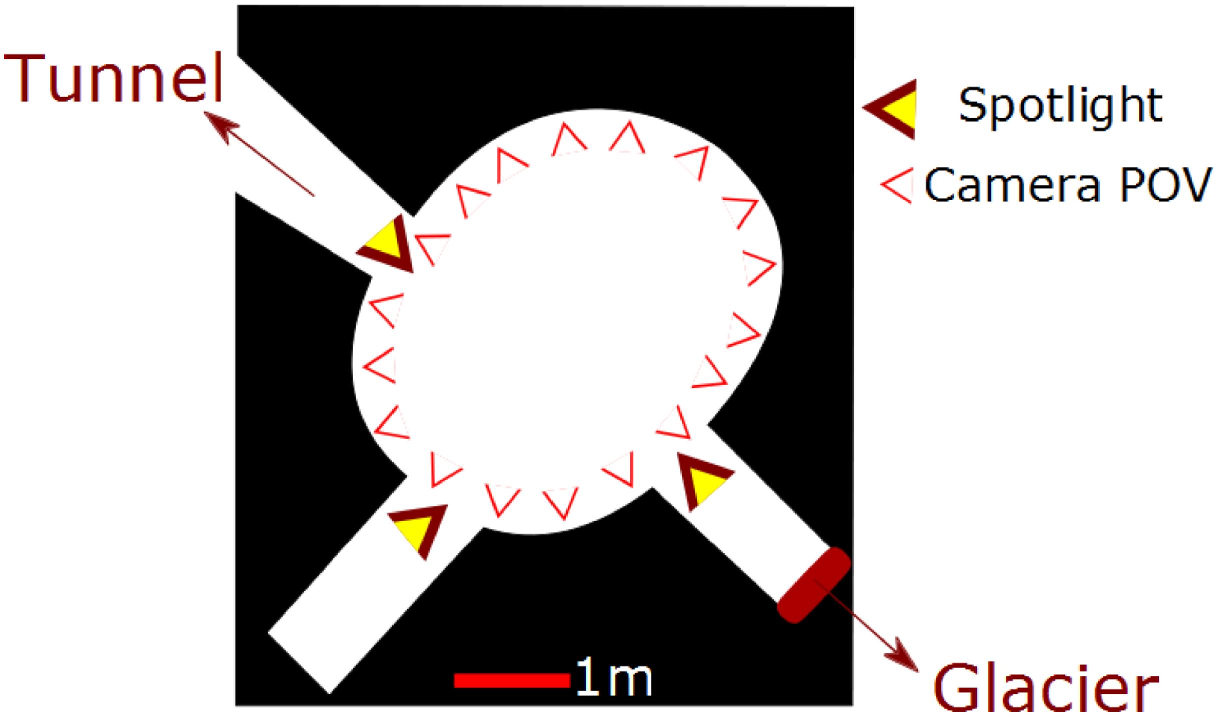
The technique previously used was laser-based, but since the area is quite wet, cold and hard to access, using a stat-of-the-art laser scanner is out of the question. So Pierre-Marie Lefeuvre, a PHD researcher at UiO and NVE used the Microsoft Kinect (c) to scan the ground. Since SfM requires even less gear to operate, the idea of trying it arose.

2.Data collection

Working on image based techniques in this laboratory rises an important problem : there is no natural light. In order to prevent moving, inconsistent, shadows that cause false tie points to be identified by the SIFT algorithm, the use of the flash is also prohibited. Fixed lamp are then required, but need to be oriented away from the camera's different positions, since a direct light would saturate the image. Three spots were placed around the area of interest and a tripod was used to be able to use long shutter speeds -3 seconds was the final choice- on the camera that allow a closed aperture and therefore a good depth of field.

Considering the small size of the area -about 4m in diameter- , the pictures were taken by rotating around the cave, aiming at the opposite side of the cave.

Figure 10: Scheme of the cave with camera positions



Luc GIROD, 2012

3.Data processing

After the Tapioca/Tapas (computing of the camera and tie points positions) step was made, the data was processed through MicMac iteratively in group of five images : images 1-5 with n°3 as central, then 2-6 with 4 as central...

4.Comments on the outputs

a)Quality and quantification

Even if the setting was everything but optimal, quality products resulted of the process, with the 20 point clouds presenting very little noise but in some small, overly enlightened, areas.

The clouds presented accurate small details of the rock surface, which will allow fine analysis of the structure and the way it was formed.

b)Feedback from Pierre-Marie Lefeuvre

PhD student at the University of Oslo, I am part of a project that monitors glacier changes in the Arctic. Within this framework, I am more particularly focusing on the evolution of the hydrological system at the glacier bed and its feedback on ice dynamics.

My work takes place at the Svartisen Subglacial Laboratory (SSL) in Norway, which gives us the opportunity to access the glacier base. There, several installed instruments record changes in bed conditions all year around. To fully understand the variations in those measurements, a map of the bedrock surrounding our sensors became essential. The remote access of the SSL and its wet, confined environment highly constrained our choice. As high accuracy laser instruments couldn't fit the small melted ice cave and were not easily transportable, a low-cost laser-type instrument, the Kinect©, was preferred for our first field season.

After comparison of our preliminary results and the possibilities of MicMac, its potential became obvious as this technique fulfills all our needs: cheap, high resolution, portable and waterproof (to a certain extent, reducing our time for data collection). This SFM codes deliver such a high resolution that we do not only hope to solve models of water pathways at the glacier bed but also to compute millimeter scale erosional rates of the bedrock. This would be a unique result as it would be real time and real scale measurements that would enhance our mathematical understanding of this system.

In the future, MicMac could be a very useful tool in glaciology to produce glacier surface DEM as soon as this program resolves problems linked to brightness and transparency of ice and snow surfaces. As shown during Luc's internship, even white bright surfaces could be mapped very accurately and therefore, the latter could offer fruitful insights on ice dynamics, for instance elevation changes.

Pierre-Marie Lefeuvre

CONCLUSION

Enthusiasm is the main feedback I received. Enthusiasm on the quality of the different outputs of MicMac, enthusiasm on the possibilities offered by the technique...

The capacity to see, show, explain, and analyze different kind of geological features, formations or process through fine 3D textured products created via MicMac is exceptional and won't be ignored by any of the scientists and researchers I have encountered during my stay in Oslo. A great number of subjects it could be applied on were discussed all along the internship and MicMac is already set to be used as a teaching tool in both geology and geophysics at the Universitetet i Oslo for the fall semester.

Yet, a question kept arising: is it possible to analyze change or movement by using MicMac? While the georeferenced products obtained through MicMac can evidently be used this way, there is a clear need for an integrated tool that would analyze MicMac's results. It should for instance compute the differences in elevation or even volume, track the movement of recognizable features- creating 3D displacement vector fields- or analyze random changes in the geometry of an object.

So, even if Structure from Motion appears as a fantastic technology is the fields of geosciences, geology and geophysics, it needs to be completed with integrated “Motion from Structure” software that would allow change monitoring from SfM's outputs.

MacMic, anyone?

BIBLIOGRAPHY

The SfM technologies have already been used for a number of applications, including geology. However, it is still blooming and scientists around the world are unaware of its capabilities.

MicMac has been around for a few years now and starts to be used by a number of people in different scientific fields. Advertising its capabilities around the scientific community seems to be the next important step and is already engaged.

Most of the work presented bellow is

- about MicMac itself
- a description of an other methods to get point clouds of surfaces (LiDAR/SfM)
- important papers on the subjects on which SfM was applied during the internship

Around MicMac

MicMac [Visited last on August 16 2012], http://www.micmac.ign.fr
This is the website where MicMac is to be found along with example of data sets.

PIERROT-DESEILLIGNY, Marc. *MicMac, Apero, Pastis and Other Beverages in a Nutshell !*. [http://www.micmac.ign.fr/svn/micmac/trunk/Documentation/DocMicMac/DocMicMac.pdf], Last update : 7th August 2012
The official documentation for MicMac. Mostly in English, it's still a work in progress.

BRETAR, F. and al. Generating High resolution surfaces from images: when photogrammetry and applied geophysics meets. In : *EGU General Assembly*, *Vienna*, *22-27 April 2012*. http://www.micmac.ign.fr/svn/micmac/trunk/Documentation/DocMicMac/Paper-UseCase
This poster shows the interest of French geophysicists in MicMac prior to my internship. Their conclusions are similar to mine.

Other techniques/Software

MANKOFF, K.D. and RUSSO, T.A.. *The Kinect: A low-cost, high-resolution, short-range, 3D camera*. Earth Surface Processes and Landforms : British Society for Geomorphology, In Review (2012), 52 p.
This paper reviews a technique to obtain 3D models using the XBOX 360 Kinect, a cheap and easily transportable device. It was used in the Svartisen Sub-glacial Laboratory.

GALLAND, Olivier. *Experimental modelling of ground deformation associated with shallow magma intrusions*. Earth and Planetary Science Letters : ELSEVIER, 2012, 12 p.
This papers explains the lab setup used at PGP prior to my internship, based on interferometry.

WESTOBY, Matt. Structure-from-Motion: a high resolution, low cost photogrammetric tool for geoscience applications. In : *AGU Fall Meeting*, *San Francisco*, *5-9 December 2011*. http://aber.academia.edu/MattWestoby/Talks/67965 : Academia.edu, 9th December 2011

Papers on the projects subjects (non-SfM)

HALLET, Bernard and PRESTRUD, Suzanne. *Dynamics of periglacial sorted circles in Western Spitsbergen*. Quaternary Research : ELSEVIER, 1986, 19 p.
This papers is the first one developing an hypothesis involving clast motion relative to soil and intermittent circulatory motion of soil in the active layer to explain the appearance of sorted circles in Svalbard.

KESSLER, M.A., WERNER, B.T. *Self-Organization of Sorted Patterned Ground*. Sciences, 17 January 2003, 4 p.
This report explores the same hypothesis and the factors explaining the different shapes that might be observed, though the term “sorted patterned” instead of “sorted circles”.

GALLAND, Olivier. *Use of vegetable oil and silica powder for scale modelling of magmatic intrusion in a deforming brittle crust*. Earth and Planetary Science Letters : ELSEVIER, 2006, 19 p.
This papers describes the type of experiment we worked on monitoring on my intervention at PGP.

GALLAND, Olivier and al. *Rise and emplacement of magma during horizontal shortening of thebrittle crust: Insights from experimental modeling*. Journal of Geophysical Research : American Geophysical Union, 2007, 21 p.
This papers presents some results obtained with the experiment presented above.

GALLAND, Olivier and al. *Experimental modelling of shallow magma emplacement: Application to saucer-shaped intrusions*. Earth and Planetary Science Letters : ELSEVIER, 2009, 11 p.
This papers presents some results obtained with the experiment presented above.

ANNEXES

Annexe 1 Work flows

The work flows and their associated parameter files are to be found in a digital format.

The example bellow is the series of commands included in a work flow designed to create a georeferenced point cloud from convergent images :

```
Tapioca MulScale .*.JPG 500 1500

Tapas FraserBasic .*.JPG Out=Init

Apero Apero_all.xml

AperiCloud .*.JPG Ground Out=apericloud.ply

MICMAC Micmac-POV.xml
```

The other work flows are designed to work for a plane-like data collection (georeferenced or not) and for convergent images (not georeferenced).

Annexe 2 How to take pictures for MicMac

This tutorial explains how to configure a camera for image acquisition for MicMac and how to do this acquisition to have a correct geometry for MicMac.

It is also available in digital format.