China Scholarship Council / Université de Lyon
Scholarships for doctoral mobility
Call for Thesis subjects for 2020/2021

RESEARCH SUBJECT TITLE:

Unravelling the strength of hydrothermally-altered volcanic rocks: from small-scale mineral properties to large-scale modelling of volcanic edifices stability.

Keywords: rock alteration, micromechanical properties of rocks, multi-physical and multi-scale modelling.

Name of the laboratory: Tribology and Systems Dynamics Laboratory (LTDS).
Website: http://ltds.ec-lyon.fr

Name of the research team: Geomaterials and Sustainable Construction (GCD)
Website: http://ltds.ec-lyon.fr -> "Géomatériaux et Construction Durable"

Name of the supervisor: Antonin FABBRI (DR, HDR, supervisor)
Benoît PARDOEN (CR, co-supervisor)
University / Institution: University of Lyon,
French National School of State Public Works (ENTPE).
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Doctoral School: Mechanics, energetics, civil engineering, acoustics (MEGA)

Lab Language: English and French

Minimum language level required:
- English: Good / Fluent (in accordance to the doctoral school admission rules)
- French: -
- Other: -

Expected duration of the thesis: 48 months

Application deadline: CSC scholarships application is before the **30th of March 2021**

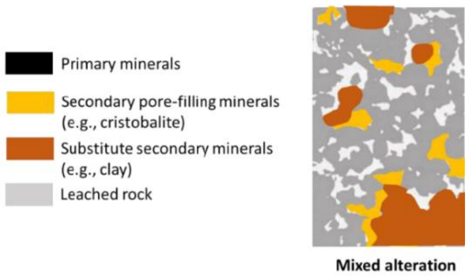
Unravelling the strength of hydrothermally-altered volcanic rocks: from small-scale mineral properties to large-scale modelling of volcanic edifices stability

CONTEXT

Volcanic edifices can lose a huge amount of mass (several cubic kilometers) when their **flanks collapse** (Ui et al., 2000). Such events typically generate fast-moving debris avalanches (debris flows) of disaggregated rock materials, which can occur suddenly as they are not necessarily initiated by an eruption. Thus, catastrophic collapses of steep volcano flanks threaten many populations (e.g. Mt. Rainier, USA), especially in developing countries. Among the factors that promote such instabilities, the central role of **hydrothermal alteration** in weakening volcanic edifices is emphasised (Ui et al., 2000; Zimbelman et al., 2005). Hydrothermal alteration results from reactions between volcanic rocks and corrosive hot fluids (gas and water) within a volcano. These reactions lead to the formation/deposition of a suite of secondary minerals that differ from the primary minerals. Recent geotechnical studies (e.g., Heap et al., 2015; Wyering et al., 2015; Mayer et al., 2016) suggest that hydrothermally alteration induces profound changes in the physical and mechanical properties of the rocks, which in turn may reduce the overall strength of the volcanic edifice (Reid et al., 2001; Detienne, 2016).

OBJECTIVES

Describing the effect of hydrothermal alteration on rock physical and mechanical properties is of prime interest in the development of models that can be used to inform volcano stability assessments (Reid et al., 2001). While geotechnical tests produce valuable measurements, the approach remains largely phenomenological. The **relation between the macroscopic mechanical behaviour of an altered rock and that of the hydrothermal minerals it contains** should be better understood. The latter will strengthen our capacity to build constitutive models that can predict the mechanical behaviour of hydrothermally-altered rocks with known mineralogical composition. This requires a combination of detailed **mineralogical characterisations, mechanical strength measurements** (at mesoscale and mineral level) **and material modelling**. Thus, the main objectives of the proposed research are:
(i) to describe the mechanical characteristics of hydrothermal-alteration minerals (and mineral assemblages);
(ii) to establish a relationship between these estimates and the macroscopic mechanical behaviour of the rock;
(iii) to model the effect of alteration on volcano flank collapse hazard.



Collapse of the flanks of a volcano (Mt. St Helens, USA, 1980) and mixed hydrothermal alteration of rock at small-scale (Detienne, 2016).

METHOD

A selection of rocks, representative of a hydrothermally-altered environment involved in volcano flank collapses, will be done. The hydrothermally-altered volcanic rocks will be studied by the following steps.

Step 1 – *Structure and microscale mechanical properties:*
The mineral structure (e.g. mineralogy, chemical compositions, spatial distribution of minerals, etc.) of primary and altered rocks will be experimentally characterised. Results available in the literature will be analysed and can be completed by small-scale quantification methods. For that purpose, the project will benefit from experimental possibilities at the LTDS (DSC/TGA, SEM, etc.) as well as from collaborations with UCL (Belgium) and IC2Mp (Poitiers).

Step 2 – *Failure modes:*
The prediction of macroscale failure mechanism from small-scale damage should also be deeper studied. Various questions remain unsolved regarding the fragile shear rupture (at low depth) versus the ductile volumetric failure (pore collapse at great depth) of volcanic rocks (Mordensky et al., 2019), related to their porosity. Depending on

the geomaterial nature, the deformations can engender material damage (Xu et al., 2018) and propagation of (micro-)cracking (Pardoen et al., 2020). The latter can be studied from small to large scale, with modelling tools (requiring additional developments) available from the supervising team.

Step 3 – *Macroscale mechanical properties:*
Determining the mechanical properties and strength of altered rocks (Pola et al., 2014) will be performed, and compared with those of fresh rocks and primary minerals. The purpose is to relate the microstructural properties of altered and non-altered rocks to their macroscale properties. Accessibility to rock samples will be considered with possible scientific partners. Dependence of stiffness, deformability, and strength on physico-chemical modifications due to the alteration (Detienne, 2016) should be confirmed. Comparisons of mechanical properties at both scales will allow to estimate homogenised degraded property (e.g. elastic stiffness) due to the presence of secondary minerals.

Step 4 – *Numerical modelling:*
A multi-physical model of the rock behaviour will be developed in a finite element code to reproduce the effect of alteration on mechanical properties degradation. The reproduction of rock behaviour at laboratory scale will allow to validate the model. Then, the model will be applied to large-scale modelling of volcano flank. If time allows, multi-scale numerical methods will be developed (e.g., Kouznetsova et al., 2001; Ulm et al., 2005; Hicher, 2011), from pre-existing numerical developments (Pardoen et al., 2020; van den Eijnden et al., 2016), to predict the macroscale behaviour from the microscale characteristics.

Candidate profile

Chinese candidates can apply for a **4-year PhD scholarship at University of Lyon** (ENTPE engineering school, LTDS laboratory) funded by the **China Scholarship Council**. Candidates must have a Master / Engineer degree in the fields of engineering, mechanics, materials, or geology. The research project requires a basic knowledge in geotechnics, continuum mechanics, constitutive modelling, chemistry and an interest in numerical modelling / experimental investigations. The project will give the applicant the opportunities to develop various skills and to integrate a dynamic geomechanics network having a large experience in experimental and numerical modelling. The ability to communicate orally and write in English is required.

Application

The deadline for the CSC scholarships application is before the **30th of March 2021**. Applications should be submitted by emailing a CV, academic grades (detail of marks), scientific/academic references, and recommendation letter to the supervisors Benoît PARDOEN and Antonin FABBRI at the email address benoit.pardoen@entpe.fr. Any additional document relevant for the application can also be transmitted. The scholarship of the successful applicant is due to start on the 1st October 2021.

References

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