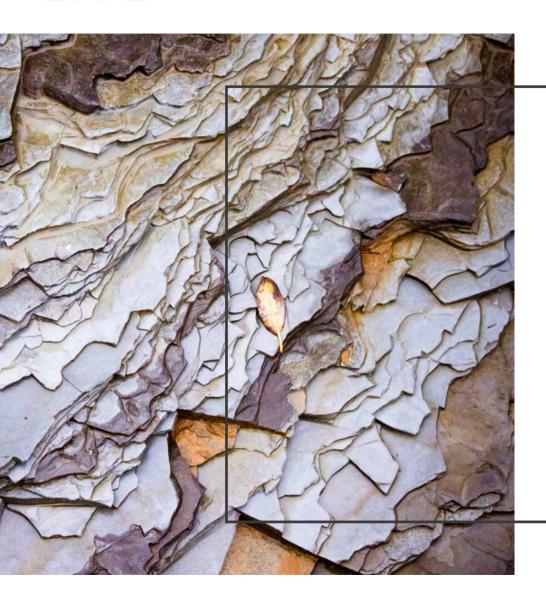
EPFL



THE LALOUI GROUP

ANNUAL REPORT 2022

ANNUAL REPORT 2022

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LYESSE LALOUI

DIRECTOR

WELCOME

SUSTAINABLE GEOTECHNICAL SOLUTIONS FOR SOME OF OUR WORLD'S GREATEST CHALLENGES.

"Our global society continues to evolve at a rapid pace, and we must continually evolve with it, developing new and innovative ideas and solutions to meet the needs of our ever-changing world."

Dear readers,

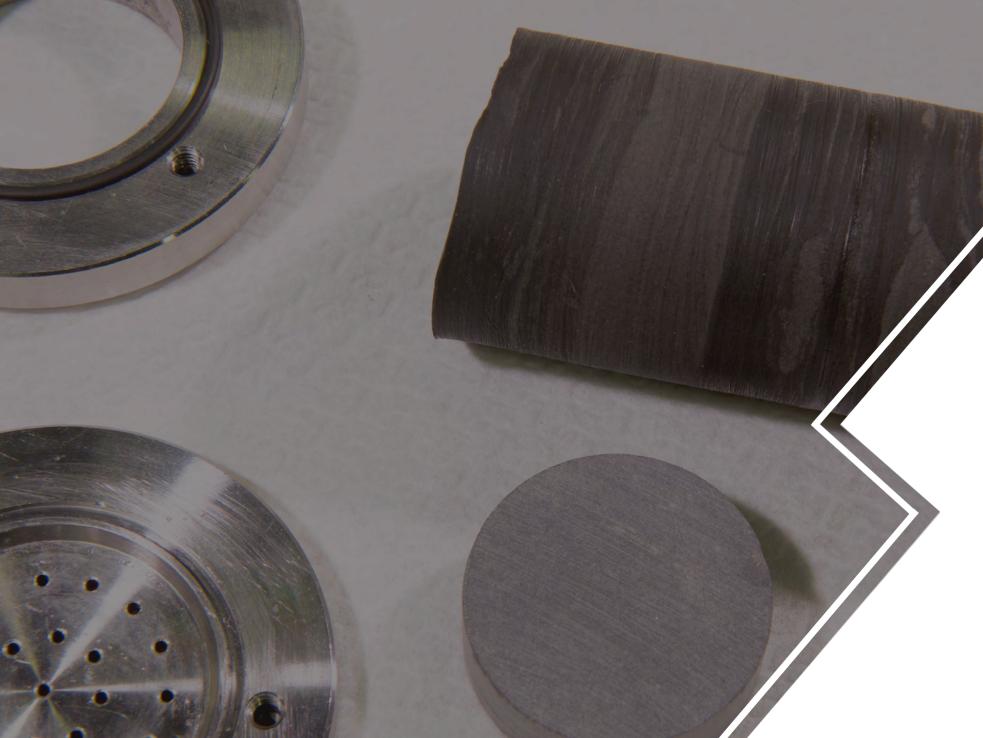
I am delighted to present our annual report for 2022, a remarkable year for us here at the Laloui Group. We emerged from the COVID-19 pandemic resilient and reinvigorated, and our confidence in what we can achieve is reflected in our high-quality research and ongoing innovation in the dynamic space in which we work. I am grateful to our collaborators, partners, team members, and other stakeholders for their relentless enthusiasm and engagement to make this happen.

This year we have completed several long-term projects whilst commencing some new and exciting areas of research with new collaborators and fresh ideas. Our Ph.D.

candidates have once again done us proud with some outstanding research, and our team has been recognized with several awards and a strong presence in the media throughout the year. As our group continues to grow, we are evolving in our quest to seek new and innovative approaches to research and scaling up collaboration and investment. As we look to 2023, we will continue this quest.

I thank you for your ongoing interest and continued support of our endeavors, and wish you an enjoyable exploration of our achievements in 2022.

Lyesse Laloui



OUR MISSION



RESEARCH



EDUCATION



TECH-TRANSFER AND INDUSTRY SUPPORT

WE STRIVES TO DEVELOP AND PROVIDE NOVEL GEOTECHNICAL SOLUTIONS FOR OUR SUSTAINABLE FUTURE.

Based at EPFL in Lausanne, Switzerland, we develop and utilize the very latest approaches in research, education, and technology transfer to ensure our global society and the environment have the tools and technology needed to adapt and thrive in the 21st century.

.2022____ HIGHLIGHTS







CHF 6 000 000

grants for all ongoing projects in 2022

16 1661

journal papers published in 2022

scopus citations

amounting to...

...more than 4 citations per day!

DEMO UP STORAGE

Our group has joined a Swiss initiative to develop the storage of CO2 deep underground.

More on page 14



VALP PROJECT

A metro style train system in the Alps? Read about the possibilites being explored by the group.

More on page 16



BIOCIMENTATION CHIP DEVELOPMENT, ERC

The team view biocementation in real time thanks to the adaptation of a chip.

More on page 18



NEW SNSF PROJECT

We have started a new project exploring the properties of expansive clays.

More on page 22



TWO DOCTORATE HONORIS CAUSAE

Congratulations to our Director, Prof. Laloui who was award not one but two honouris causae in 2022!!!

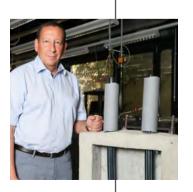
More on page 50



TOP 1000 SCIENTISTS

Prof. Laloui recognised in the top scientists in his field.

More on page 51





RESEARCH AND INOVATION

WE ARE DRIVEN BY THE DESIRE TO PUSH THE BOUNDARIES OF WHAT IS POSSIBLE IN THE FIELD OF GEOTECHNICAL ENGINEERING.

Already recognized as a global leader in the field of geotechnical engineering, the Laloui Group continues to develop new ideas and seek out new collaborations in research, development and innovation to harness the power of the earth beneath our feet and address some of this century's greatest challenges including energy security, climate change, sustainable cities and construction.

OUR EXPERTISE

TO DELIVER ON OUR AMBITIONS OF ENSURING A SUSTAINABLE FUTURE FOR US ALL, WE FOCUS ON FIVE KEY AREAS OF RESEARCH.



BIO-IMPROVED SOILS



CO2 STORAGE



ENERGY GEOSTRUCTURES



SHALES MECHANICS



NUCLEAR WASTE



A mineralized basaltic sample. White zones are where injected CO2 has turned into new minerals.

DemoUp Storage

EXPLORING THE POTENTIAL STORAGE OF CO2 DEEP UNDERGROUND IN ICELAND

Following the successful demonstration of the capture of atmospheric carbon within Switzerland, Swiss authorities have approved a new phase of research focusing on the transportation and injection of the Swiss CO2 in the form of carbon-rich water into deep basaltic repositories in Iceland. Known as DemoUpStorage, the project aims to demonstrate that over time, the CO2 will be permanently stored within the basaltic



"One of our fundamental objectives is to characterize the connected porosity of basalts and determine how the injection of CO2-rich seawater affects the material's microstructure. This will give us an understanding of the transport properties of the host rock to achieve efficient and optimal injection of the CO2."

- Eleni Stavropoulou Scientist



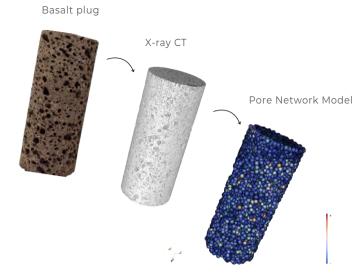
Carbfix igloo where underground injection takes place. On the right, a Swiss CO2 storage cylinder.

repositories through mineralization, turning the CO2 into stone and locking the carbon away forever.

We have been asked to join the consortium due to its expertise in hydromechanical characterization of geomaterials and microstructural analysis with live x-ray imaging. Headed by Dr. Eleni Stavropoulou, the team has been tasked with:

- · providing a mineralogical, petrophysical, and hydromechanical characterization of the field cores.
- evaluating the coupled geomechanical and geochemical response of basalt reservoir rocks to CO2-rich seawater injection under realistic conditions, and
- quantifying the time-dependent response of mineral trapping.

Currently, we are exploring the micro-scale; however, the project will also analyze larger, real-world scenarios. Based on the hydromechanical results generated by the experiments, Stavropoulou and her team will then develop a model which will be used to enhance further the calibration and resolution of the field-scale models developed throughout the DemoUpStorage project.



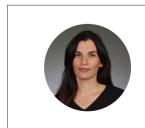
A 3D pore network model that relates microstructural and hydraulic properties of the material is currently developed at EPFL, aimed at demonstrating where CO2 mineralisation is more prone to take place.

Funded by:



Schweizerische Eidgenossenschaft Confédération suisse Confederazione Svizzera Confederaziun svizra

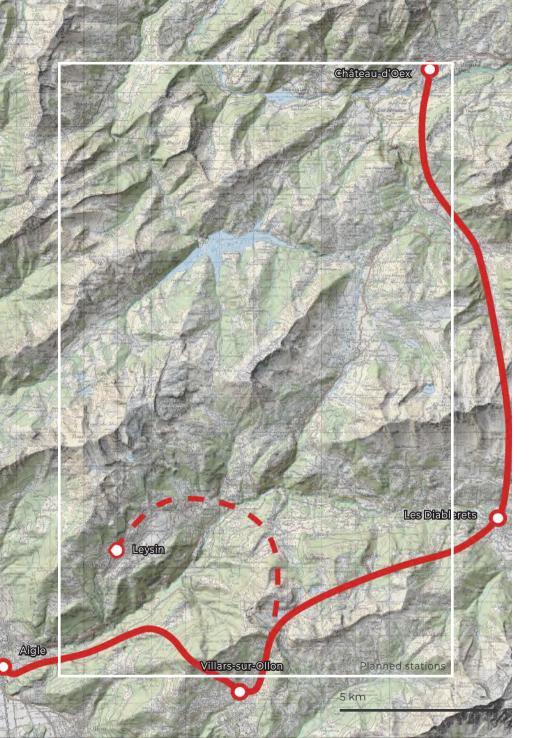
Swiss Federal Office of Energy SFOE Federal Office for the Environment FOEN



TEAM Eleni Stavropoulou Scientist



Lyesse Laloui Full Professor



VAlp

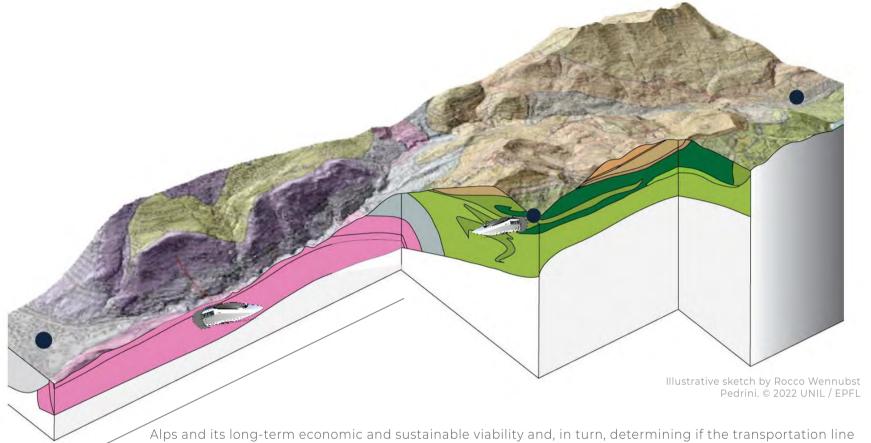
A HIGH-SPEED METRO IN THE SWISS ALPS?

A COLLABORATION BETWEEN THE LALOUI GROUP AND THE UNIVERSITY OF LAUSANNE'S INSTITUTE OF EARTH SCIENCES (ISTE) IS EXPLORING THE POTENTIAL OF HIGH-SPEED TRANSPORTATION IN THE VAUD ALPS.

Could a high-speed metro line ensure sustainable alpine tourism and help regional communities remain viable?

The project is exploring the key challenges in developing such transportation infrastructure including geology, boring and tunneling, and local community impacts, as well as the unique challenge of operating high-speed, metro-style trains at gradients of up to 12 percent, which would be a world first.

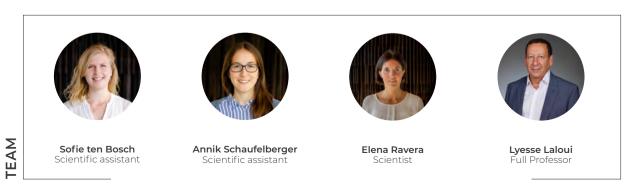
While the project is scoping out the potential for such a transportation system, a key component is evaluating life in the



Alps and its long-term economic and sustainable viability and, in turn, determining if the transportation line has a positive impact on energy use and the local economy. If the team can demonstrate that the VAIp high-speed metro line has a positive, long-term impact, this concept may have an enormous potential as a possible blueprint for other similar projects around the world.

Funded by:





BIOGEOS

BIOGEOS IS AN ERC-FUNDED PROJECT WITH THE OBJECTIVES OF DESIGNING, TESTING AND ULTIMATELY STANDARDIZING INNOVATIVE AND ENVIRONMENTALLY RESPONSIBLE SOLUTIONS THROUGH BIO-MEDIATED, NATURE-INSPIRED GROUND REINFORCEMENT.

BIOGEOS has had a busy 2022, continuing to push the boundaries of research and innovation in bio-mediated reinforcement. The research has led to the publishing of several strong papers and associated broad media coverage including the adaptation of a chip that allows the team to observe biocementation occurring in real-time.





BIOCEMENTATION CHIP

THE TEAM HAVE USED A CHIP THAT WAS ORIGINALLY DESIGNED FOR ENVIRONMENTAL SCIENCE TO STUDY THE PROPERTIES OF BIOCEMENT FORMATION.

This ground-breaking work was completed by Ariadni Elmaloglou, and Dr. Dimitrios Terzis, who used the credit card-sized chip to observe fluid behavior using time-lapse microscopy. The material has the potential to replace traditional cement binders in certain civil engineering applications.

TEDX TALK

CIVIL ENGINEERING "THAT WILL CHANGE THE WORLD"

Our Senior Researcher Dr. Dimitrios Terzis took us on journey into space in a TEDx talk he presented in early 2022 in Geneva. Dr. Terzis tells the story of how bacteria evolved to generate energy from sunlight, the mineral structures they built to reach that light and how we as humans can mimic these natural processes.



Expansive clays

NEW INSIGHTS FOR CHEMO-HYDRO-MECHANICAL MODELING OF ENGINEERED GEOTECHNICAL BARRIERS

Due to their high adsorptive properties, various industries commonly use expansive clays, ranging from color bleaching, filtering, and food production to mining and engineered geotechnical barriers. As a result, research is extensive, and due to the high demand for waste disposal facilities, investigations into engineered geological barriers have been ongoing for more than 50 years.

Expansive clays are used in nuclear waste disposal sites as a separate material or can exist as a part of a composite material called a "geosynthetic clay liner" when used in landfills.



However, higher predictive accuracy is needed due to the evolving needs of hazardous waste disposal (for instance. nuclear waste conservation for thousands of years). Yet, despite this, many of the chemicalphysical complexities of these geomaterials are not fully known and, consequently, not implemented within suitable predictive frameworks. Our research focuses on bentonite. as it is one of the most widely used materials for engineering barriers due to its high swelling and adsorption properties.

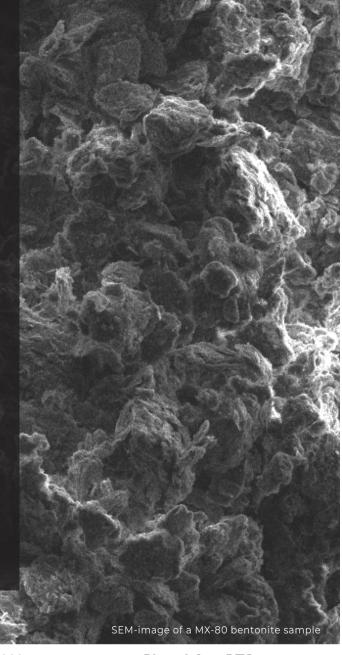
The complexity of bentonite behavior lies in its multi-physical couplings, multi-phase system, and its heterogeneity as it exists in granular form. However, the material's properties vary greatly depending on the chemical composition of the bulk water

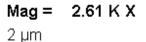
Funded by:



and the degree of saturation, as it changes the concentration gradients and the amount of water adsorbed.

Svetlana Babiy is conducting the research as part of her Ph.D. with the main focus of the study devoted to the connection between elementary physical-chemical mechanisms and the modeling of swelling behavior which she will investigate using instruments that are unconventional in the field of geomechanics (e.g. thermogravimetric analysis). Svetlana hopes the insights will help us understand and predict swelling pressures or strains after wetting and how the water's chemical composition affects the swelling process.





EHT = 3.00 kV WD = 5.7 mm Image Pixel Size = 42.85 nm

Signal A = SE2
Aperture Size = 10.00 µm
Stage at T = 0.0 °



Svetlana Babiy Doctoral assistant



Angelica Tuttolomondo Scientist



Yoonsung LeeDoctoral assistant



Lyesse Laloui Full Professor

(left) and Alessio Ferrari visiting the Meuse/Hauteléloïse Fuseli nderground research laboratory (MHM-URL) in Bure

CIGEO Project

WE ARE COLLABORATING WITH ANDRA (THE FRENCH NATIONAL AGENCY FOR RADIOACTIVE WASTE MANAGEMENT) ON THE VERY LONG-TERM DEEP DISPOSAL OF RADIOACTIVE WASTE

The CIGEO project is a French concept for radioactive waste storage of high-level, long-life, and medium-level waste produced by the French nuclear industry. The CIGEO project aims to build a repository at Bure in Eastern France at a depth of 500 meters in the Callovo-Oxfordian geological formation. This repository will host waste previously cooled to a maximum temperature of 90°C that will decay and decrease in temperature for around 100'000 years. Currently, the host formation is being investigated at the Meuse/Haute-Marne Underground Research Laboratory (MHM-URL) in Bure. Lead by Héloïse Fuselier, our work with ANDRA focuses on the experimental investigation of the behavior of their host geological formation, the Callovo-Oxfordian



High pressure oedometric ring developed by Héloïse Fuselier for thermo-mechanical testing



A sample of Callovo-Oxfordian claystone



Meuse/Haute-Marne Underground research laboratory (MHM-URL) in Bure



Héloïse FuselierDoctoral assistant



Alessio Ferrari
Researcher and lecturer



Lyesse Laloui Full Professor

Claystone, under temperature changes and the development of a behavioral/constitutive model able to reproduce and predict the observed behavior. We were particularly interested in the volumetric deformation of the claystone over the short term during temperature increases and over the long term during cooling, as well as the evolution of its strength with temperature changes. Our experimental activities include conducting an experimental campaign on the thermomechanical behavior of the COx claystone with high-pressure oedometric tests, heating-cooling tests, and conventional triaxial compression tests.

We have also developed a constitutive model based on the framework of hardening thermo-elasto-plasticity adapted to enable the reproduction and prediction of the "rock-like" quasi-brittle response under deviatoric loading. We will then numerically implement this constitutive model in a finite-element software package to assess its ability to reproduce the behavior of the claystone observed in situ through large-scale tests performed at the MHM-URL.

Our expertise in radioactive waste storage in highly indurated geomaterials allows us to use advanced experimental and modeling procedures that bring new insights to the behavior of Callovo-Oxfordian claystone.

Funded by:



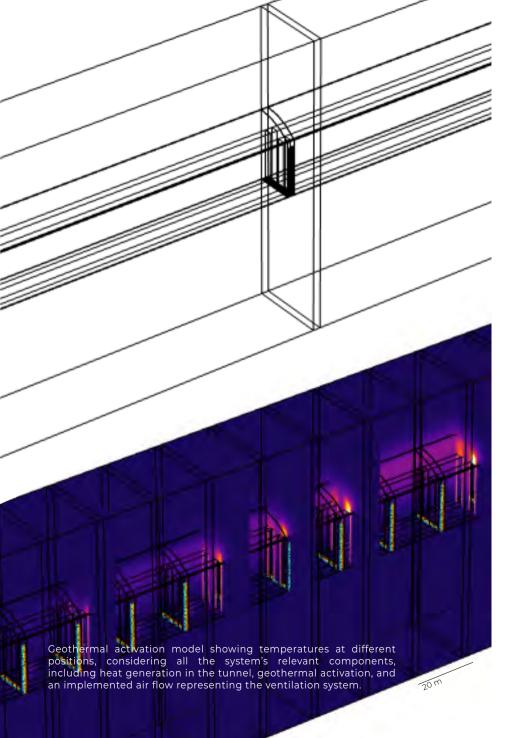
TEAM

4.5 m 3.5 m 8.04m Bucharest metro station - 3D model

Transportation Tunnels as Energy Geostructures

THE HAS PIONEERED THE
DEVELOPMENT AND USE OF GEO
ENERGY STRUCTURES AT THE BASE
OF BUILDINGS. COULD OTHER
BUILT INFRASTRUCTURE, SUCH AS
TRANSPORTATION TUNNELS, ALSO
PLAY A ROLE IN ENERGY TRANSFER?

The interaction between geothermal and ventilation systems was studied for the very first time during this unique project led by Sofie ten Bosch in partnership with Amberg Engineering. Through the simulation and numerical modeling of geothermal activation, ten Bosch determined its impact on air temperature in underground infrastructure via two different case studies, which allowed her to ascertain the effect of tunnel ventilation on the geothermal potential.



Over twelve months, the project established the interaction between ventilation and geothermal systems. Furthermore, it evaluated the profitability of the new energy tunnel system enabling Amberg Engineering a competitive advantage in project design in this field while ensuring a broader application of the research results.

In fact, the project identified a potential reduction in ventilation requirements

through geothermal activation, which can lead to environmental and economic reductions through appropriate tunnel design. This optimization of complete systems considering different components, emphasizes the advantages of energy tunnels as providers of renewable energy.



Sofie ten Bosch Scientific assistant



Elena Ravera Scientist



Lyesse Laloui Full Professor

Funded by:

Innosuisse - Swiss Innovation Agency



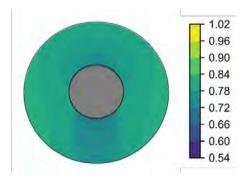
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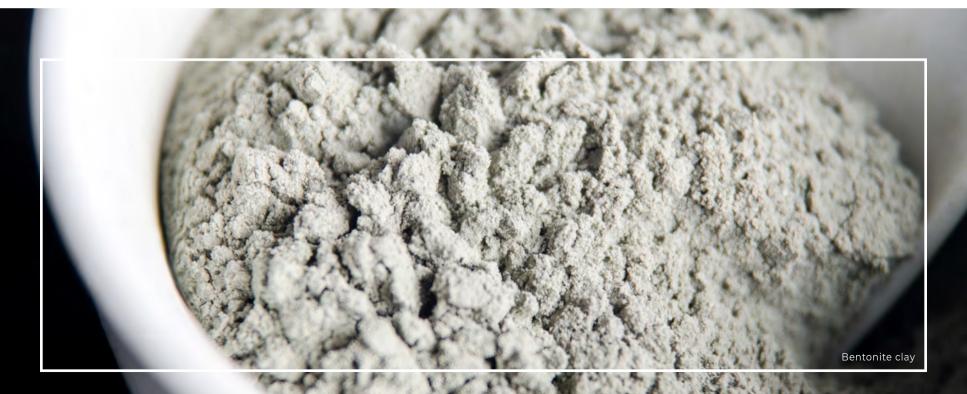
BEACON Project

ENHANCING NUMERICAL MODELS FOR PREDICTING THE BEHAVIOR OF BENTONITE SEALS, BUFFERS, AND BACKFILLS IN DEEP NUCLEAR WASTE DISPOSAL REPOSITORIES.

The BEACON (Bentonite Mechanical Evolution) project was wrapped up this year, with the final workshop and conference taking place in May. We have been deeply involved in the project since it commenced in June 2017.



Predicted distribution of bentonite void ratio and canister position after saturation (100 years post-closure)



Funded by:



Involving 25 European partners, BEACON aimed to enhance the existing numerical models used to predict the behavior of bentonite seals, buffers, and backfills in deep nuclear waste disposal sites. In particular, the understanding the density homogenization of the material that takes place upon water uptake from the surrounding host rock. Through robust numerical tools, we can predict the long-term performance of such elements, vital for the implementation of planned geological disposal sites.

Post-doctoral researcher at the Group, Dr. Jose Bosch, presented the results of his Ph.D. thesis, which he completed in 2021, at the final conference held in London. Within BEACON, Bosch developed a model for predicting the response of bentonite-based materials used to model the long-term evolution of deep geological repositories. In parallel, a set of experiments performed at the LMS and coordinated by Dr. Alessio Ferrari, were used as a benchmark for the development of constitutive models by the different teams involved in the project.





Alessio Ferrari Researcher and lecturer



Lyesse Laloui Full Professor

TEAM

FE-M TASK FORCE

CONTINUING OUR RESEARCH WITH NAGRA AND THE SITE SELECTION FOR RADIOACTIVE WASTE DISPOSAL SITE IN SWITZERLAND, THE GROUP IS NOW DEVELOPING MODELS TO FORECAST LONG-TERM THERMO-HYDRO-MECHANICAL INTERACTIONS WITHIN THE SITES.

As the waste from nuclear power generation continues to grow, the need for a long-term solution for the treatment of nuclear waste is paramount. In response, the concept of deep geological storage has been developed in several countries to dispose of long-lived high and medium-level wastes safely. Numerous perturbations in the repository's geologic system are expected to occur during the construction, operation, and post-closure phase including heat emitted as the nuclear waste decays which may increase the in-situ temperature to more than a hundred degrees celsius. These temperatures may directly impair the integrity of the various protective barriers with any breach possibly inducing local overpressure, gas generation, causing desaturation/saturation, potential fracking of the host rock, or even the re-activation of fault zones. Therefore, developing reliable numerical tools to simulate the long-term



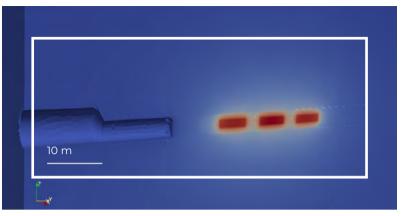
response repositories is vital.

The FE Modelling Task Force (TF) is an initiative developed by the National Cooperative for the Disposal of Radioactive Waste (NAGRA) that aims to build confidence in model-based assessments of repository-induced effects to assist in site selection based upon the THM interactions studied at the Mont Terri Underground (Switzerland) rock laboratory since the 1990s.

The mission of the TF is threefold. First was to generate the fully coupled THM model following the steering team specifications via the modeling of the complete history of the experiment. Beyond the preliminary software quality assurance (SQA) verification, the numerical models were also compared to each other in a code-to-code comparison verification exercise. Secondly, to calibrate and quantify the inherent model uncertainties through the development of tools working within a probabilistic framework. Using the results, the numerical model was

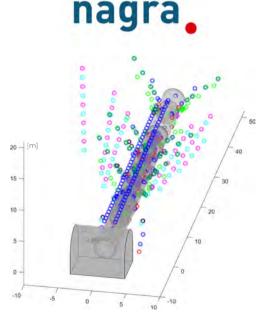
then calibrated for the FE experiment data resulting in a relatively good match. Finally, the last task consists of a prediction evaluation exercise where the model will be used to forecast THM interactions induced by changes in thermal load. The project also involved a preliminary subtask designed to verify the advective/diffusive transport of the fluid phases and provide insights on the parametrization.

Overall, the obtained numerical model should enable the forecast of the long-term THM interactions induced by the excavation and waste emplacement, providing solid bases for the repository's long-term safety assessments.



Simulation of the temperature front development around the nuclear waste packages.

Funded by:



Monitoring system around the FE experiment.

TEAM



Matthias Wojnarowicz Doctoral assistant



Aldo Madashi Scientist

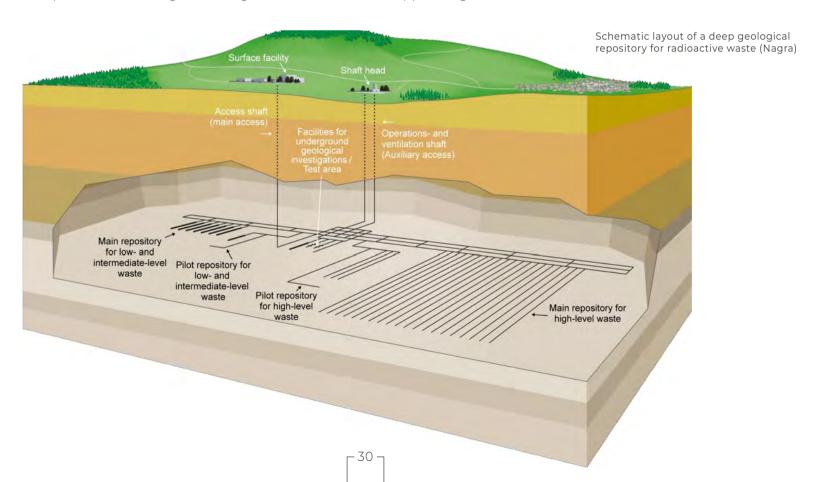


Lyesse Laloui Full Professor

IMPACTS ON BARRIER INTEGRITY

GAS TRANSPORT IN CLAY MATERIALS

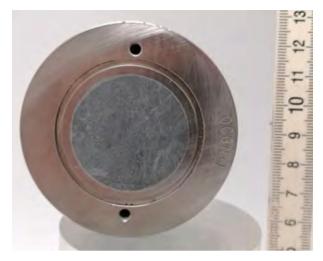
The European Joint Programme on Radioactive Waste Management (EURAD) was launched in June 2019 as part of the EU Research and Innovation program Horizon 2020 to coordinate specific activities between European Waste Management Organisations, Technical Support Organisations, and Research Entities.



Our group is involved in Work Package 6 (WP6-GAS – Mechanistic understanding of gas transport in clay materials).

Gas generation and transport through a repository is an important issue for the geological disposal of radioactive waste. Increasing the understanding of gas transport through low permeability porous materials such as clays (Opalinus Clay in Switzerland) is therefore considered a high priority on the EURAD Roadmap. Our contribution is aimed at gaining a mechanistic understanding of the hydromechanical phenomena and processes associated with the gas-induced failure of clay barriers and the effectiveness of self-sealing processes along gas-induced pathways in the clay barriers of a geological repository. To do this, an advanced experimental program, model-supported data analyses, predictive modeling, and the application of newly developed modeling tools are used.

Qazim Llabjani is leading the research as part of his Ph.D. As the research requires advanced and rigorous experimental set-ups and testing protocols, special devices designed and manufactured at EPFL are used. These allowed the precise assessment of the hydro-mechanical response of the tested material during the fluid injection tests.



Opalinus Clay specimen for the injection test

Within this framework, gas injection tests performed on Opalinus Clay, together with H2M modeling analyses (multiphase flow in deformable porous media), allowed us to highlight the complex and strong coupling between the H-M response, the gas injection rate and the material permeability. To capture, visualize and understand this highly complex H-M behaviour, further laboratory tests will be conducted using an advanced triaxial test set-up with multiple strain measurements and a small-scale triaxial cell allowing live x-ray tomography during testing to be performed (see our DemoUpCarma project and Stavropoulou and Laloui, 2022).

Funded by:





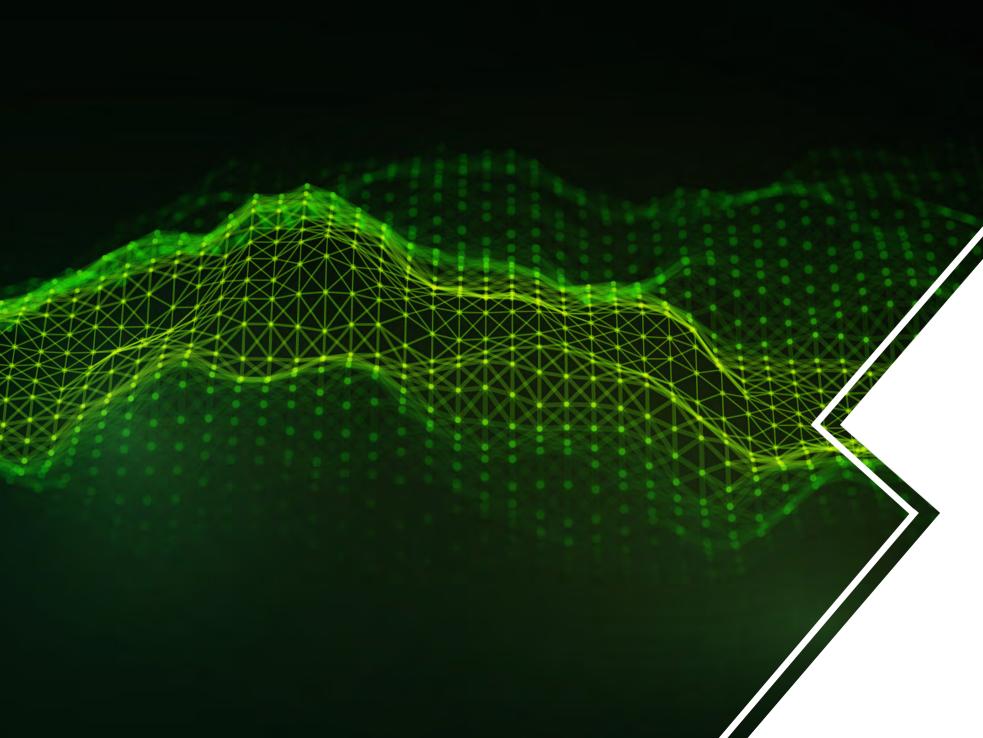




TEAM

Qazim LlabjaniAlessio FerrariDoctoral assistantResearcher and lecturer

Lyesse Laloui Full Professor



TECHNOLOGY TRANSFER

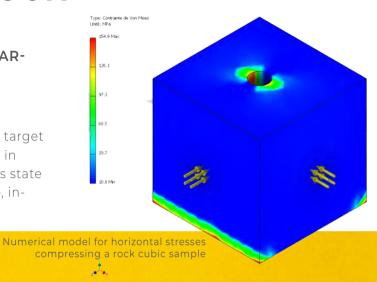
CONTINUING TO BRING OUR RESEARCH TO SOLVE REAL-WORLD PROBLEMS.

Whether its nuturing our ideas in start-ups or spinning off successful products or businesses, technology transfer is core to what we do.

InSituStreTech

EXPLORING IN-SITU STRESS TO DEVELOP SUSTAINABLE CARBON CAPTURE AND STORAGE (CCS) TECHNOLOGIES.

Carbon Capture Storage (CCS) projects can only be successful if the target reservoir is suitable for CO2 sequestration and storage. A key factor in determining suitability is understanding the horizontal in-situ stress state of the reservoir. As CCS reservoirs are up to several kilometers deep, in-



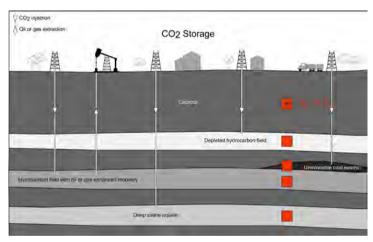


situ stresses can be particularly difficult to measure due to these high stresses and temperatures.

The project has assessed existing in-situ stress measurement technologies and found them not to be suitable for these extreme environments, as they are incapable of retrieving the full horizontal in-situ stress state and cannot provide accurate measurements

The InsituStreTech project is developing a new technology specifically designed for CCS project needs that can accurately measure the full horizontal in-situ stress state. Numerical simulations and methodology have already been developed and tested on the proposed technology, with laboratory testing about to commence. An instrument prototype is currently under development which will use a horizontal uniaxial compression test bench designed to compress 200x200x200 mm cubic rock samples to stresses up to 20MPa to simulate the high in-situ stresses.

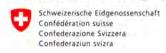
Should the proof of concept be successful, the technology will be further developed in collaboration with the stakeholders already conducting CCS projects and will involve realworld conditions and the development of ad-hoc tools required to perform in-situ stress measurement assays.



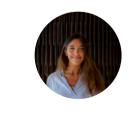
An accurate knowledge of the reservoir in-situ stress state is necessary to enable safe and efficient CO2 storage



Innosuisse - Swiss Innovation Agency







Angelica Tuttolomondo Scientist



Alex Miska Horvath Scientific assistant



Lyesse Laloui Full Professor

TEAM

ENERDRAPE

OUR CLEANTECH SPIN-OFF OPERATES THE WORLD'S FIRST PREFABRICATED GEOTHERMAL PANEL TECHNOLOGY.

After incubating the 'energy panels' project at the Laboratory of Soil Mechanics since 2019 and successfully prototyping and validating the technology in 2021, 2022 marked a turning point for the spin-off as it commenced the technology transfer of these innovative geothermal panels, moved into new offices, grew the team and started to penetrate the market

The year started on a high note for Enerdrape with its participation at several events, increasing industry recognition and gaining market traction. By spring, Enerdrape won its first in a series of awards. Starting with RENT Switzerland's "Award of Innovation," where the innovative panel technology captured the attention of the real estate sector. It was then recognized as the Sustainable Startup of the Year thanks to the Prix SUD organized by the Swiss newspaper Le Temps which saw Enerdrape promoted to a larger audience through articles and portraits throughout Switzerland. Enerdrape was also recognized for its entrepreneurship and innovation with the "Prix PERL" and "Fondation Technologique pour l'Innovation (FIT)." At a national level, Enerdrape won one of the most prestigious Swiss startup awards">>> Venture>>" in June, and was part of the Swiss national team of the Cleantech Venture Leaders for an investor roadshow in Munich last October.

Enderape will be looking to consolidate its fantastic year by further enhancing the product and continuing to grow the business in 2023.





"2022 has been quite an intense year, several awards and major recognition for the technological solution. I'm very proud of the evolution of Enerdrape, the identity we are currently building and the milestone reached in the last year: a company has now grown from this science-based project that we started in the lab in 2019."

- Margaux Peltier



Enerdrape proposes a solution that allows the use of heat from basements, such as parking lots



Enerdrape wins the Grand Prize at the 25th >>venture>>. Margaux Peltier receives the Grand Prize from Doris Leuthard, former Swiss Federal Councilor



Enerdrape's geothermal panels

Full scale operations

In total, half a million additional funds were raised by the spin-off to trigger the product launch on the market. The spin-off is now logging its first major clients and preparing its first full-scale installations.

Future plans

If 2022 marks the end of incubation at the Laloui Group and wrapped-up related research projects ongoing with EPFL, then 2023 marks the start of operation of the new company.

enerdrape



EDUCATION

EDUCATION IS CORE COMPONENT OF WHAT THE LALOUI GROUP DOES, TEACHING AND GUIDING STUDENTS IN VARIOUS EDUCATIONAL EXPERIENCES FROM INTERNSHIPS, UNDERGRADUATE AND ADDITIONAL COURSES TO MASTER'S PROJECTS AND PH.D. THESES.



COMPLETED Ph.Ds

2022 saw three of our Ph.D. candidates successfully complete and defend their theses. All were of a high standard, and we would like to acknowledge their hard work and contributions to our group during their time with us. We wish them the very best in their future endeavors.

MECHANICAL PERFORMANCE AND UPSCALING OF BIO-IMPROVED SOILS

Ecological awareness, critical climate considerations, and the rising need for soil stabilization push forward the quest for alternative solutions to current practices in geotechnical engineering. Dr. Harran's dissertation focused on the main components currently governing biocementation for soil improvement, namely, the mechanics of treated materials and the upscaling of the technique. Therefore, much of his research focused on experimental campaigns completed at different scales and complementary frameworks. This included mechanical tests, microstructural investigations, and constitutive considerations of the physical roots of biocementation known as densification and bonding and involved the exploration of the elasticity, peak, softening, and critical state of these processes.

Ray Harran

Mirroring bench-scale practices such as treatment homogeneity, monitoring control, waste elimination, treatment permanence, and economic competitiveness on field sites cannot meet all upscaling considerations. Therefore Harran used a state-of-the-art upscaling setup and a novel injection approach based on ex-situ hydrolysis in a bioreactor, specifically tailored to address the biochemical quality control and the bottleneck of residual ammonia. Overall, his thesis offers new insights and consolidates existing understandings of bio-cemented sand's mechanical response and upscaling.

SWELLING AND SHRINKAGE OF PARTIALLY SATURATED GAS

Gas shale swelling during hydraulic stimulation is one of the major challenges in unconventional gas development. In his doctoral thesis, Dr. Jinwoo Kim set out to develop an effective stress framework for the volumetric behavior of partially saturated gas shales.

He performed laboratory testing to fill the methodological and evidence gaps based on two overarching goals: to establish the water retention behavior and to quantitatively study the elasticity in partially saturated conditions of the shale. The key contribution of his thesis to our current understanding of shale swelling is the experimentally determined water retention behavior and bulk modulus combined in an effective stress framework. In addition, his work will serve as an empirical basis to improve the prediction of gas shale swelling and shrinkage.

Jinwoo Kim



Geotechnical engineering scenarios engaged in internal erosion or mineral dissolution have been found worldwide. Dr. Kim's thesis aimed to extend the understanding of the effect of dissolution and erosion on the geomechanical behavior of shales and granular materials by attempting to quantify the effect of grain loss on granular soils, and understand the chemical effect of CO2 on Opalinus Clay shales.

Using salt-sand mixtures where the salt was the dissolving species, and the sand was the chemically inert species, oedometer tests were first performed, where the dissolution-induced volumetric response and the post-dissolution compaction characteristics were shown resulting in the proposition of a novel framework for the dissolution-induced mechanical response of granular materials, along with a constitutive model based on the framework and the experimental findings. The second experiment aimed to observe the effect of dissolution on the shear strength of sands tested with a direct shear box apparatus. Finally, the effect of dissolution based on the volumetric response under an isotropic stress state, and the shear response was also studied.

Taeheon Kim

The second subject was Opalinus clay shale extracted from Northern Switzerland where a section with a high carbonate content was tested to study the spontaneous mechanical response during CO2 exposure, the shale sample was confined inside the high-pressure oedometer cell, where deformation and permeability was recorded. The CO2 exposure was forced by injecting carbonated water for approximately 70 days. In parallel with the oedometer tests, an exposure test was conducted by exposing one sample to CO2 and another to deaerated water for about a month. After the exposure, the samples were inspected through SEM, ÎŒCT scan, and XRD analysis to detect any structural and mineralogical alteration.



ACADEMIC YEAR 2021/2022

Undergraduate courses

Geomechanics
Energy geostructures
Engineering geology for geo-energy
Slope Stability
Innovation for construction and the environment

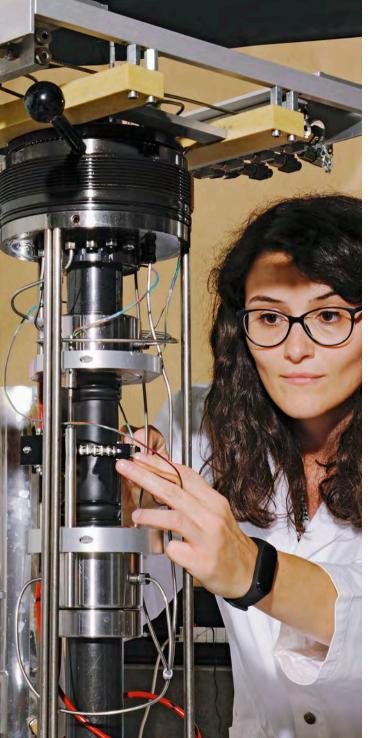
Extra courses

Energy Geostructures: Analysis and Design - continuing education

Internships

Hamza Loubane, Université de Grenoble Léna Olivia Emma Gros, Université de Lorraine, Ecole Nationale Supérieure de Géologie Fabiana Sannasardo, à Politecnico di Torino

Henri Georges Nicolas Lechevalier, Ecole polytechnique, Palaiseau



ONGOING PH.D. THESES

Influence of pore-scale heterogeneity on the precipitation patterns in Microbially Induced Calcite Precipitation (MICP): Ariadni Elmaloglou, thesis directors: Prof. Lyesse Laloui, Dr. Dimitrios Terzis

Performance assessment of FEM models to simulate THM effects in the rock around the FE-tunnel: Matthias Wojnarowicz, thesis directors: Prof. Lyesse Laloui. Dr. Aldo Madaschi

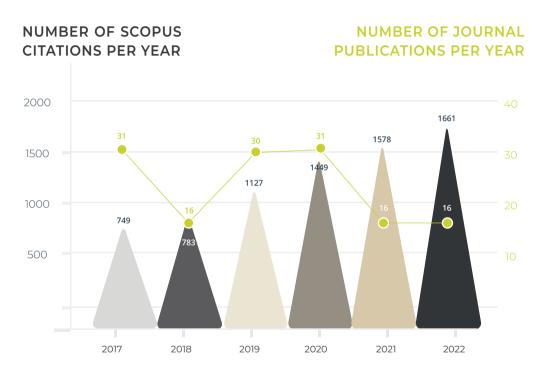
Thermo-Hydro-Mechanical Behavior of the Callovo-Oxfordian Claystone Under Thermal Loading: Héloïse Fuselier, thesis director: Prof. Lyesse Laloui, Dr. Alessio Ferrari

Gas-Induced Impacts on the Barrier Integrity of Deep Geological Repository of Radioactive Wastes (a contribution to the EURAD-Gas project): Qazim Llabjani, thesis directors: Prof. Lyesse Laloui, Dr. Alessio Ferrari

New insights for chemo-hydro-mechanical modelling of engineered geotechnical barriers: Svetlana Babiy, thesis director: Prof. Lyesse Laloui



PUBLICATIONS



MOST CITED PUBLICATIONS IN 2022 (PAPERS PUBLISHED SINCE 2017)

[·] Terzis, Dimitrios & Laloui, Lyesse. (2018). **3-D micro-architecture and mechanical response of soil cemented via microbial-induced calcite precipitation**. Scientific Reports. 8. 10.1038/s41598-018-19895-w.

[·] Rotta Loria, Alessandro & Laloui, Lyesse. (2017). **Thermally induced group effects among energy piles**. Géotechnique 67, No. 5, 374–393. 10.1680/jgeot.16.P.039

[·] Terzis, Dimitrios & Laloui, Lyesse. (2019). A decade of progress and turning points in the understanding of bio-improved soils: A review. Geomechanics for Energy and the Environment. 19. 10.1016/j.gete.2019.03.001.

INTERNATIONAL CONFERENCES

AFTER THE CHALLENGES OF THE PANDEMIC OVER THE LAST TWO YEARS, THE GROUP RE-ENGAGED WITH PEERS AND COLLABORATORS PUBLICLY AND SHARE THEIR KNOWLEDGE WITH A BROADER AUDIENCE ONCE MORE.

Keynote lectures: Prof. Lyesse Laloui

Sustainable Geotechnical Engineering Summit by Deep Foundations Institute (DFI)

Lecture: "Innovation for a Sustainable Geotechnical Engineering Industry"

December 2022

Dubai, UAE

2022 Eshbach Lecture

Lecture: "Tailor-made soil properties by bio-geochemical means" October 2022 Chicago, USA

2nd International Conference on Energy Geotechnics

Keynote lecture: "Field Monitoring and Simulations of Nuclear Waste Barrier Systems" April 2022 San Diego, USA



Northwestern Sustainability Summit

"Sustainable (geo-)energies: Global progress and existing challenges"

Distinguished lecture:

"Earth-Human Interactions: Sustainability and Development" October 2022 Chicago, USA



Sustainable Geotechnical Engineering Summit by Deep Foundations Institute (DFI)



Chicago, USA



Turin, Italy

IACMAG 2022

16th International Conference of the International Association for Computer Methods and Advances in Geomechanics

Keynote lecture: "Tailor-made soil properties by bio-geochemical means" August 2022 Turin, Italy

XXVII Italian National Congress

Geotechnical Engineering for a Sustainable Development

Keynote lecture: "Energy from Geotechnical Constructions: Analysis and Design" July 2022 Reggio Calabria, Italy

Madrid Subterra International Congress

Keynote lecture: "In situ evaluation of the performance of a thermoactive underground station - application to a station of the CEVA line in Geneva" November 2021.

Madrid, Spain



AWARDS, & ACHIEVEMENTS

THIS YEAR, THE GROUP HAS BEEN WELL-RECOGNIZED FOR ITS ACHIEVEMENTS AND CONTRIBUTIONS IN GEOTECHNICAL ENGINEERING. AS ALWAYS, OUR DIRECTOR HAS LED THE WAY, AWARDED TWO DOCTORATE HONORIS CAUSAE DURING THE YEAR. RECOGNIZED FOR HIS LONG-TERM COMMITMENT AND ONGOING CONTRIBUTIONS TO SUSTAINABLE SOLUTIONS IN GEOTECHNICAL ENGINEERING, WE OFFER PROF. LALOUI THE HEARTIEST CONGRATULATIONS.

But, as always, it has been a team effort, with others in our team also being recognized for their outstanding work in research, development and innovation. Congratulations to all recipients.



Professor Laloui honoured with two DOCTORATE HONORIS CAUSAE

2022 HAS BEEN AN OUTSTANDING YEAR FOR OUR DIRECTOR, WITH HONORIS CAUSAE FROM BOTH HERRIOT WATT UNIVERSITY AND THE TECHNICAL UNIVERSITY OF CLUJ-NAPOCA.

Acknowledged as the highest accolade that a University can bestow on an individual, Professor Laloui received the prestigious titles, in recognition of his ongoing contributions to geomechanics and geotechnical engineering solutions for a sustainable world. Congratulations Professor Laloui!





2022 RIE Prize

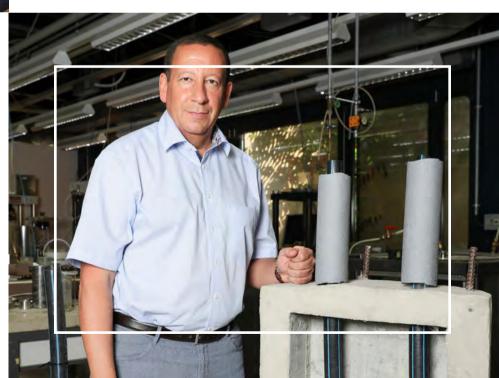
OUR MASTER'S STUDENT ANNIK SCHAUFEL-BERGER HAS BEEN AWARDED THIS YEAR'S 2022 RIE PRIZE.

Awarded by the Association of Research and Innovation in Energy (RIE) for innovative work in the energy technology sector, Annik received the prize for her Master's thesis on storing thermal energy in the ground using underground infrastructure. Congratulations Annik.

TOP 1000 SCIENTISTS

PROFESSOR LALOUI RANKED IN THE TOP 1000 AMONGST ENGINEERING AND TECHNOLOGY SCIENTISTS IN THE WORLD IN 2022.

The results were based on the Microsoft Academic Graph h-index and the number of citations which are compiled by Research.com.







MEDIA & EVENTS







IT HAS BEEN A BUSY YEAR COMMUNICATING OUR RESEARCH AND CONTRIBUTING TO THE SOCIETAL DISCOURSE ON SUSTAINABILITY AND GEOTECHNICAL OPPORTUNITIES BOTH HERE IN SWITZERLAND AND GLOBALLY. EXPLAINING WHAT WE DO AND WHY WE DO IT IS VITAL TO OUR THE WAY WE WORK.

Whether its hosting events to share our knowledge of innovation in geotechnical engineering or providing explanations to the public on radioactive waste storage options within Switzerland, we had a strong public presence in 2022.



ENERGY GEOSTRUCTURES - ANALYSIS AND DESIGN COURSE



ISSMGE EUROPE MEETING

The Group hosted the inaugural meeting of the National Societies of ISSMGE Europe in Lausanne in November. The event brought together representatives of geotechnical engineering societies from across Europe to discuss and share experiences from across the continent.

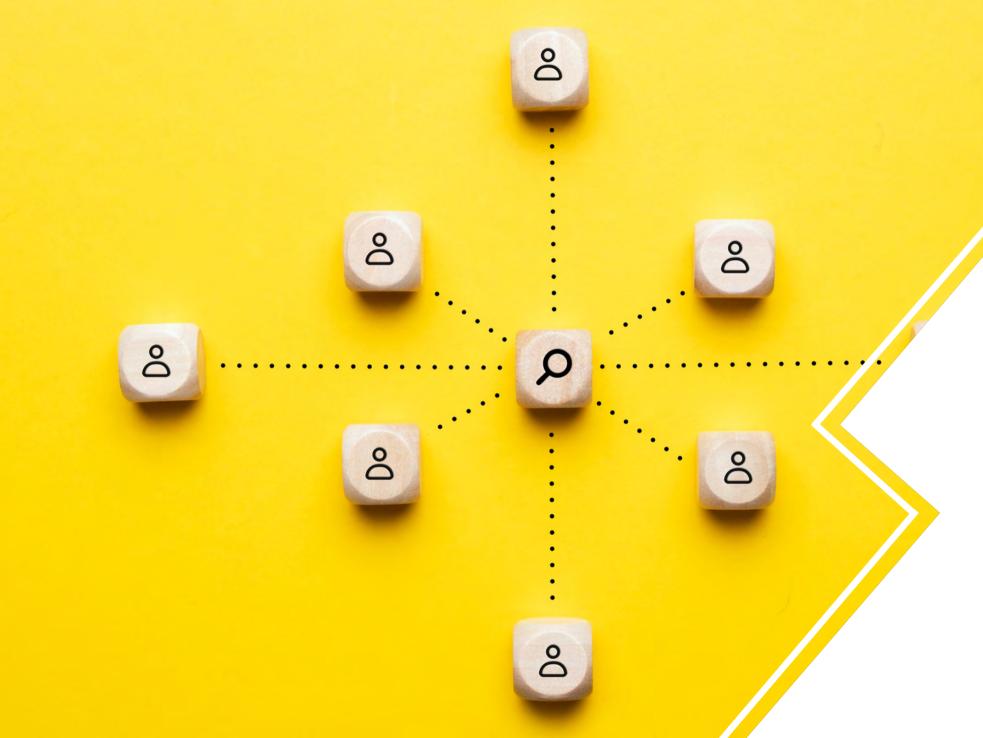
INNOVATION IN GEOTRECHNICAL ENGINEERING EVENT

We also hosted a seminar exploring innovation in geotechincal engineering. Speakers covered topics ranging from the challenges facing innovators, transportation networks, sustainable construction, and our own Medusoil project. The event concluded with a round table discussion.









LECTURER SEN

OUR TEAM













JOSE BOSCH Scientist



ROBA HOUHOU Scientist



ELENA RAVERA Scientist



ELENI STAVROPOULOU Scientist



ANGELICA TUTTOLOMONDO Scientist



SVETLANA BABIY Doctoral assistant



ARIADNI ELMALOGLOU Doctoral assistant



HÉLOÏSE FUSELIER Doctoral assistant



RAY HARRAN Doctoral assistant



JINWOO KIM Doctoral assistant



TAEHEON KIM Doctoral assistant



YOONSUNG LEE Doctoral assistant







MATTHIAS WOJNAROWICZ Doctoral assistant



ALEX HORVATH Scientific assistant



MARO

MARGAUX PELTIER Scientific assistant

SOFIE TEN BOSCH

Scientific assistant



ANNIK SCHAUFELBERGER Scientific assistant



VICENZO SERGIO VESPO Guest PhD candidate



CHARBEL YAZBECK Scientific collaborator



JULIEN BIRBAUM Trainee



PATRICK DUBEY Technical manager



NATACHA ROMANENS Trainee



MARIA LAURA DE CESARE Administrative assistant



BARBARA TINGUELY Administrative assistant



WIOLETTA KUCHARSKA Communications assistant



BRENDAN SMITH Editor



HOSSAM ABOEL NAGA Head of Engineering Department at La Trobe University, Australia



IULIA-CONSUELA PRODAN Lecturer at TU Cluj-Napoca, Romania



ALESSANDRO ROTTA LORIA Assistant Professor at Northwestern University, USA



NIMISHA ROY Lecturer at Georgia Institute of Technology, USA

MEET OUR TEAM

JINWOO KIM SUCCESSFULLY COMPLETED HIS PHD WITH US IN 2022.



I see LMS as a very diverse group with many talented people from different backgrounds. I think this brings a lot of creativity to the research.

- Jinwoo Kim

We started by asking him to tell us a little bit about himself.

My name is Jinwoo Kim. I am just completing my PhD. at the Laloui Group. I was born and grew up in South Korea, where I did my bachelor's study in civil engineering in Soul. I started my graduate studies in the United States, where I did my Master's degree in Geo-technical Engineering. Then I got interested in historical structures, so I did a second Master's, a joint degree program between universities in Portugal and Italy. Then I came here to pursue a PhD. in geomechanics.

What does a typical day or week look like for you?

Well, there's no such thing as a typical day, but I would have to say I come to the office in the morning, and I go straight to the lab to check if everything is okay with my experiment. Usually, there is a minor issue that can be tricky to fix and often takes most of the morning. Then there comes a lunch break. Usually, I go together with my lab

mates, and we share our ups and downs throughout our PhD journeys. In the afternoon, I either continue in the lab or do more office work such as reading papers, generating figures, preparing for a conference talk, or sometimes it includes teaching activities like reading papers, going to an exercise session, or even supervising master students. But really, there is no typical day. Sometimes I'd spend the entire day or even a week in the lab to do a complex experiment, or sometimes I wouldn't leave my desk to derive an equation for days.

Could you tell us a little bit about the sort of experiments that you would do in the lab and what your research applications are?

So my thesis was focused on the swelling and shrinkage of shale. Here is a laboratory sample extracted from an unconventional reservoir in North America. So what I was studying in the lab was how changing the saturation state by changing the relative humidity impacted the sample swelling and shrinkage. My research project was in close collaboration with an industry partner, Chevron. We were interested in predicting the swelling in unconventional reservoirs because it can cause wellbore instability, for example, reducing the efficiency in natural gas production. So I anticipate my research outcome will help optimize the hydraulic stimulation process, therefore increasing the efficiency in the field.

What's the one thing you enjoyed the most during your Ph.D.?

I have to say I really liked the discussions with my peers, senior postdocs, of course my supervisors. It gave me a lot of new ideas. Of course, sometimes it rejected my ideas, but still, I really loved every bit.

What's the thing that excites you most about being a researcher?

Regarding my research project, I'm excited that my project's research outcome can help solve engineering problems in the field. On a more general level, I'm excited that it can also benefit other seemingly unrelated fields, generally on the mechanical process in subsurfaces.

Why did you choose to pursue a doctorate in civil engineering? Compared to many other subjects, there are not so many students choosing a civil engineering path these days.

That's true, and it's surprising to me because I personally love the topic. Growing up in a city, I always admired the infrastructure and buildings in urban areas. But on the other hand, I liked physics the most in high school, especially the mechanics part, so I knew I wanted to study civil engineering because it combines the two. I could use these tools to explore how we design and improve our infrastructure.

So you've all but finished your PhD. Where do you see yourself in five years?

I am also very curious to know, but I enjoyed my research and love what I'm doing. So I think I'm going to continue research in whatever form. And I also know that I'd like to use my skills to contribute to tackling energy-related problems, which are one of the grand challenges in our society. For example, it can be related to nuclear waste storage, CO2 sequestration or oil and gas.

What makes the Laloui Group and EPFL a good place to study?

I see the Group as a very diverse group with many talented people from different backgrounds. I think this brings a lot of creativity to the research. I think you can benefit from this by just interacting with these people who are also serious and passionate about what they're doing.

So now that you've finished, what would one piece of advice be that you offer the students who are thinking about doing a PhD?

Well, that's a very tough question. If you're considering doing a PhD and if you like solving hard problems, if you like hands-on experience with a lot of bricolage and collaboration with others, there's nothing like it. But then, when you're considering doing a PhD, I think it's worth considering what kind of PhD you want to do and if the lab you're interested in joining can provide the environment and support you seek.

Lastly, what do you enjoy doing in your free time?

I spend time with my family, hanging out with my wife, and going to nature. We'll go to the mountains or do a low-key hike near the lake on the weekend. I like it because it helps me refresh my mind and come back with more motivation.

SOFIE IS A RESEARCH ASSISTANT LEADING VARIOUS PROJECTS ACROSS THE GROUP.



What I enjoy most are the discussions with everyone and the variety of topics to work on where I can go into detail and see the impact of the different innovations our lab is working on. I really like that.

-Sofie Ten Bosch

We started by asking her to tell us a little bit about herself.

I am Sofie, 26 years old, and I come from the Netherlands. I studied in Delft, a city where I also grew up. I studied civil engineering, both my Bachelor's and my Master's at Delft, and after I finished my Master's, I wasn't really sure what I wanted to do next. After doing some research into options around Europe, I came in contact with Professor Laloui, who gave me the opportunity to come here as a scientific assistant in the lab.

So, I arrived during COVID and after a 10-day quarantine, I started here in the lab, and yeah, I've been happy working here ever since.

What does a typical day or week look like for you?

That's a really good question because, for me, every day looks quite different as I have many different projects going on. But one thing that I really try to keep every day is I come to the office, and I have a cup of tea, just 30 minutes for me to sit down and see what projects I have, which ones are my main priority today, and what meetings do I have coming up? If I can, I try to have one morning for one project and the afternoon for another. Usually, it doesn't work that way, and I end up doing everything for four projects on the same day. Currently, I mostly do modeling, so most of my work is sitting behind my desk and I work there.

Tell us about some of the projects you are working on.

I have been working on various projects. I started working here to explore our soil dynamics testing capability in the lab to see if it would be worth investing more in this and it's potential. That was just the first month if I remember correctly. Currently, I'm working on three or four projects simultaneously, several topics, which is also something I really like. I'm working on the Metro Project exploring high-speed rail in the Swiss Alps, which started recently. I am also involved in the lab's Biogeos project and bio-cementation, mostly numerical modeling at the moment, and then in energy geo-structures and thermal energy recovery in the built environment where we are collaborating with Amberg Engineering.

What's the one thing you enjoy the most in doing your research?

What I enjoy most are the discussions with everyone. I also enjoy the variety of topics to work on where I can go into detail and see the impact of the different innovations our lab is working on. I really like that.

And in comparison, what's been the most challenging part of your research?

I think the most challenging part at the moment is time management, balancing which project needs the most attention right now and how to implement that.

Where does your research find an application?

Well, for the project with Amber Engineering it's quite clear. We assess this specific optimization with a ventilation system, which we hope Amberg Engineering can use in their future projects. For the project on the topic of bio-cementation that we have in the lab where we try to improve soil characteristics through calcite precipitation in the soil, I am working on modeling this improvement and we can then use these models to predict how to best treat the soil. So how to improve these characteristics depending on the project needs would be an overall application.

Why did you choose to pursue civil engineering compared to other subjects?

For me, it's not that I've always dreamed of becoming a civil engineer, but I really liked the courses that were listed in the program. I always liked physics and mathematics and then having the application of the topics. Using this knowledge for something. So that's why civil engineering really fits with me, I think. I also liked the international aspect of the topic; you'll often encounter collaborations between international students.

Where do you see yourself in five years' time?

Like many people, I find this the most difficult question out of all of them because I don't really have a goal in mind. For instance, I've chosen to study civil engineering because that was what I felt at that moment. I didn't really see myself as a civil engineer in 10 years; and that is still how I make my choices. I pick at the moment what feels right for me. But let's say in five years, I really like working with innovation in this sector, so I would like to find a job somewhere in this field but I'm keeping it a bit vague because I don't know exactly what I want to do. Maybe I'll stay in Switzerland because I like it here, I'll have to see. But you never know how life will go.

What's the one piece of advice that you'd offer students that are thinking of becoming a researcher?

I would say just go for it if you feel that after finishing your Master's degree, you don't feel attracted by going into industry, and you think of going for research. Maybe talk to someone you know who is doing research, so you can ask some questions. That's what I also did, I asked people what they like about doing research and what it takes as a person to be a researcher, and then if you still feel good about it, just go for it.

What makes the Laloui Group an excellent place to work and study?

We have many colleagues who specialize in many different topics. So I think together you have many different ideas and always someone willing to help you think about a project. Or, if you are stuck, you can always find someone to chat to.

Finally, what do you enjoy doing in your spare time?

I really enjoy playing field hockey at the hockey club here in Lausanne. I have always played field hockey in the Netherlands, and when I came here I was really happy to find a team. We are a team with people from all over the world, so it's great to train during the week and then play some games in Switzerland.







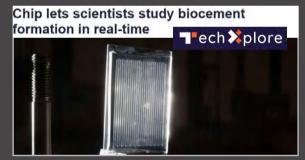




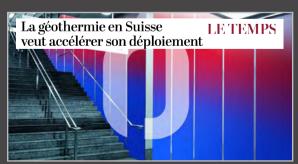
















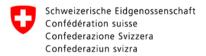
























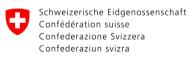












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Printing: Repro EPFL

Ecole Polytechnique Fédérale de Lausanne (EPFL)

2023

