Geosciences for the energy system transition | GeoT

The **interdisciplinary thematic** institutes of the University of Strasbourg & CNRS & Inserm

Activity Report

Université de Strasbourg

2021-2022

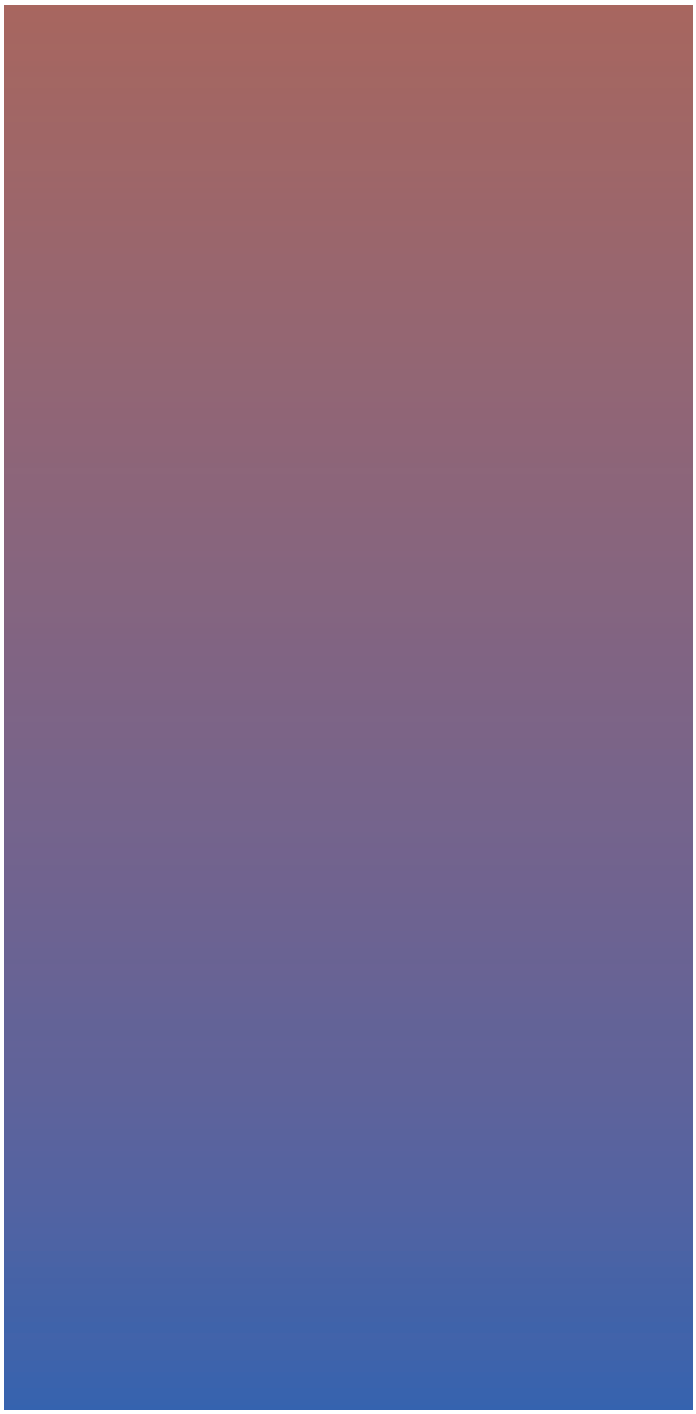
Illustrative picture @freepik.com

Funded under the **Excellence Initiative** program & France 2030

Contents →

Geosciences for the energy system transition | GeoT

The **Interdisciplinary thematic** institutes | ITI of the **University** of Strasbourg & cnrs & Inserm



Institut **Terre & Environnement** de **Strasbourg** | ITES | UMR 7063 de l'Université de Strasbourg & cnrs & ENGEES

In partnership with :

École et observatoire des **sciences de la Terre** Université de Strasbourg

lisec UR 2310

iCUBE

ifp SCHOOL

crem centre de recherche sur les médiations communication • langue • art • culture

sage Sociétés, Acteurs, Gouvernement en Europe UMR 7363

Publication director: J. Schmittbuhl & C. Correia
Editor: C. Correia with the participation of all the working group leaders
Layout: C. Correia with advice from V. Sellani
Printing: University of Strasbourg printing works
@ITI GeoT

Looking back at 2021 and 2022 - *The start of ITI GeoT*

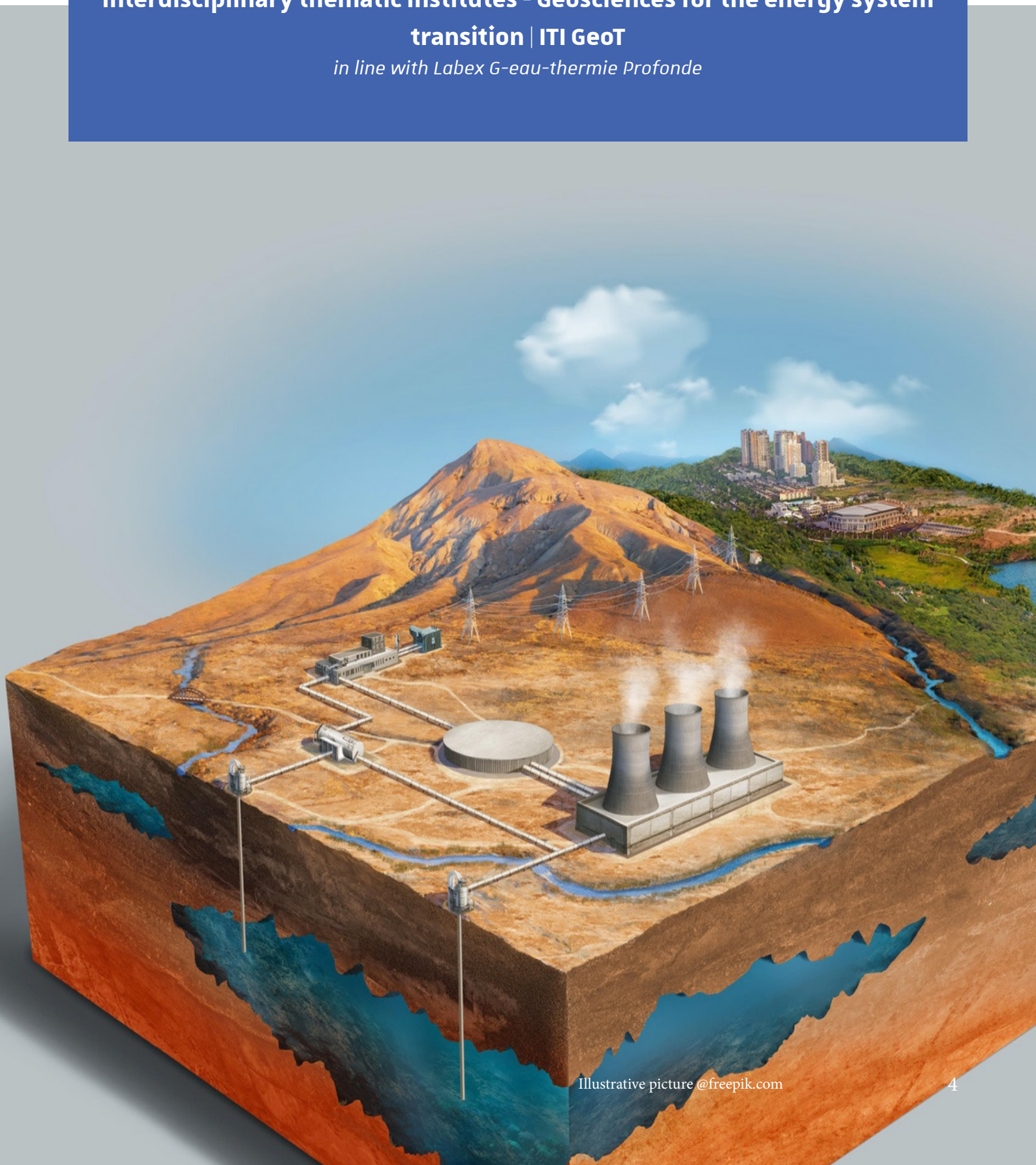
By Jean Schmittbuhl
ITI Director

The ITI GeoT is one of 15 investment projects approved by the Université de Strasbourg through its Excellence Initiative program. The aim of these ITIs is to enable the University of Strasbourg to respond more effectively to the scientific challenges of the future, in health, life sciences and science and technology, as well as in the humanities and social sciences. The GeoT ITI draws on the scientific expertise acquired by the LabEx G-eau-thermie Profonde. The project is led by the Ecole et Observatoire des Sciences de la Terre and its ITES research laboratory. The project also brings together the ICUBE laboratory for its engineering research and development skills, and the LISEC, CREM and SAGE laboratories for their expertise in the social sciences. The GeoT ITI extends the scope of the G-eau-thermie Profonde LabEx into the field of the role of deep water in the energy transition.

It benefits from expertise in deep geothermal energy that is recognised at European level. It plays a major role in research in this field in the Grand Est region and nationally, in conjunction with industrial and institutional players. It demonstrates the University's commitment to thinking about the new energy resources needed for the energy transition. This interdisciplinary skills centre is positioned as a major player in the dialogue between science and society, providing answers to the many questions raised by society in relation to the use of the subsoil. The role played by the ITI GeoT in managing the socio-economic implications of recent seismic events in the Strasbourg region is a hallmark of this strategy. Steering the 'Rhine Graben' project of the recent PEPR (Priority Research Programme and Experimentation) for the next 7 years in partnership with BRGM, is also recognition of the strategic role of ITI GeoT in the national structuring of the scientific community in this field.

Interdisciplinary thematic institutes - Geosciences for the energy system transition | ITI GeoT

in line with Labex G-eau-thermie Profonde



Illustrative picture @freepik.com

A unique structure linking research and education


Students field trip @G. Manatschal

The ITI GeoT is one of 15 projects accredited for 8 years (2021-2028) by the University of Strasbourg. Launched in January 2021, the ITIs are at the heart of the University of Strasbourg's development strategy, playing a key role in reshaping the research and education landscape.

The ITI is led by the University of Strasbourg, in partnership with the CNRS and Inserm, as part of the "Beyond borders" initiative of excellence and the Stras'us project (Structuring training through research in initiatives of excellence).

The ITIs are a continuation of the graduate schools, university research schools (EUR) and laboratories of excellence (Labex). The ITI GeoT draws on the scientific expertise acquired by the Labex G-eau-thermie profonde during its 8 years of existence (2012-2020) in conjunction with industrial and institutional players.

The ITI GeoT focuses its research and education activities on the role of deep underground water in the development of low-carbon energy resources: geothermal energy, hydrogen, lithium, heat or CO2 storage, in order to meet the challenges posed by the global ecological crisis. The ITI aims to increase scientific knowledge about understanding deep geological systems, their use and monitoring, risk management and respect for the environment, as well as public perception.

ITI GeoT also marks a shift in the geosciences education offered at EOST towards the energy transition. The school's ambition is to become a leader in training the next generation of geoscientists specialising in renewable energies, with the creation of the international master's degree 'Geosciences for the Energy Systems Transition', in partnership with the IFP School.


Rittershoffen power plant @J. Schmittbuhl

Several objectives through various research areas:

Deep geothermal energy for a low-carbon future
- Developing innovative geological models of deep fractured reservoirs, particularly in a continental context (e.g. the Rhine Graben), to enable the widespread development of deep geothermal energy in Europe
- Improving the economic viability and profitability of deep underground water reservoirs through the co-production of resources, in particular lithium, hydrogen, heat and storage

Exploration and characterisation of deepwater reservoirs
- Developing innovative and "low-cost" geophysical imaging techniques to reduce the cost of exploration (e.g. imaging using ambient seismic noise)
- Studying the rock-fluid interactions involved in deep reservoirs in order to improve anthropogenic stimulation of these reservoirs and anticipate their long-term deformation

Exploiting deep underground water resources
- Developing robust approaches to real-time optimisation of onsite operations, combined with monitoring of risks, particularly seismic risks
- Developing the engineering of production pumps at high temperatures and under conditions of exposure to corrosive fluids and massive precipitation

Risk management
- Improving monitoring of asismic deformation in the reservoir and the nucleation of seismic events
- Developing geomechanical reservoir models that use artificial intelligence (AI) tools to better calibrate warning systems (TLS)
- Proposing multi-stakeholder expertise and monitoring structures that include industrial operators and public institutions
- Drawing up best practice guides

Public engagement and perception
- Understanding the role of socio-technological interactions in public perception of geo-energy projects involving deep underground water
- Track changes in media coverage of projects
- Measuring the impact of emerging citizen science initiatives

Organisation

ITI GeoT is composed of a large number of researchers, technicians and students with a wide range of skills from different laboratories recognised for their excellence.

ITI GeoT's research activities are organised into 9 thematic working groups: Seismology, Geodesy, Potential Methods, Rock Physics, Hydrogeochemistry, Geology, Social Sciences, Deep Geothermal Data Centre and Modelling.

Illustrative picture @freepik.com

Founding members

7 research laboratories and observatory :
- École et Observatoire des sciences de la Terre (EOST)
- including the national sismologic service BCSF-RENASS
- Institut Terre et Environnement (ITES)
- Laboratoire des sciences de l'ingénieur, de l'informatique et de l'imagerie (ICube)
- Laboratoire Interuniversitaire des Sciences de l'Éducation et de la Communication (Lisec)
- Centre de recherche sur les médiations (CREM, Université de Lorraine)
- Sociétés, Acteurs, Gouvernement en Europe (Sage)

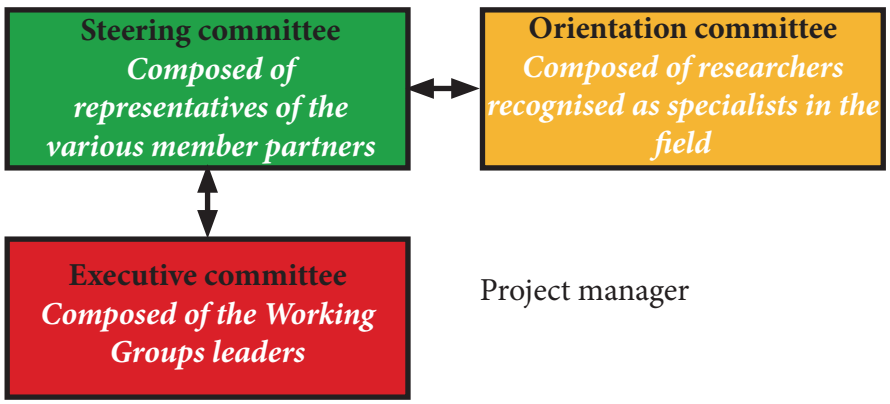
2 engineering schools :
- École et Observatoire des sciences de la Terre (EOST)
- IFP School (IFPEN)

1 doctoral school :
- Sciences de la Terre et l'Environnement (ED413)

Gouvernance

The ITI GeoT is managed by a team of scientists who ensure effective coordination, administrative and financial management as well as strategic development:
- Director: Jean Schmittbuhl, CNRS Research Director
- Deputy Director: Patrick Baud, Professor, University of Strasbourg
- Project Managers: Alexandra Kushnir (01/2021 to 07/2021), Imane Barbara-Bokeloh (11/2021 to 10/2022) then Caroline Correia (14/11/2022 to present)

In addition, a number of committees ensure the coherence, decision-making and execution of the actions implemented by the ITI GeoT.



Gouvernance

Executive committee

Director: Jean Schmittbuhl
Deputy director: Patrick Baud
Projet manager: Alexandra Kushnir puis Imane Barbara-Bokeloh
Eductaion supervisor: Florence Herrmann-Beck
Working gourp leaders:
Jérôme Vergne
Frédéric Masson puis Baptiste Rousset
Jacques Hinderer puis Jean François Girard
Micheal Heap
Damien Daval puis Damien Lemarchand
Gianreto Manatchal
Philippe Chavot
Marc Schaming
Christophe Fond

Orientation committee

President :
Philippe Jousset (GFZ)
Membres :
Florent Brenguier (Univ Grenoble-Alpes)
Tomas Fischer (CUNI)
Emmanuelle Klein (INERIS)
Bernard Sanjuan (BRGM)
Chrystel Dezayes (BRGM)
Beata Orleka-Sikora (IG PAS)
Frédéric Cappa (Univ Cote d'Azur)
Virginie Harcouët-Menou (VITO)
Thomas Kohl (KIT)
Thomas Reinsch (IEG)
Reiner Keller (Uni Augsburg)

Steering committee

Jean Schmittbuhl - ITI GeoT
Patrick Baud - ITI GeoT
Jean François Girard - EOST
Fédérique Masson - EOST
Renaud Toussaint - ITES
Michel de Mathelin - Icube
Jacques Audran - Lisec
Florence Herrmann-Beck - EOST (engineer school)
Damien Lemarchand - Master STPE/EOST
Jérôme van der Woerd - ED413
Fédérique Fournier - IFP School

Working Groups

Intern research projects

The ITI GeoT supports the numerous research projects of its members.
To do this, ITI GeoT allocates annual recurrent funding for each working group, as well as project-based funding following the annual calls for projects.
Over its first two years of activity, this funding has enabled the ITI GeoT to finance a large number of experiments and to obtain a large number of major results for research in the fields associated with geosciences for the energy transition.

Illustrative picture @freepik.com

WG 1 : Sismology

The Strasbourg seismic sequence

The ITI GeoT, and more specifically the Seismology WG, was heavily involved in analysing the seismic crisis affecting Strasbourg between 2019 and 2022. Thanks to the close interaction between the BCSF-RENASS experts and the seismology researchers, the group was able to provide detailed and relevant analyses of the situation throughout the crisis, and to ensure the independent dissemination of information to the general public and to the institutions responsible for monitoring the GeoRhin site. A first article on the analysis of this crisis was published in the Compte-Rendu de l'Académie des Sciences (Schmittbuhl et al, 2021). The expertise acquired was recognised through participation in the group of experts appointed by the Bas-Rhin prefecture to analyse the Vendenheim geothermal loop.

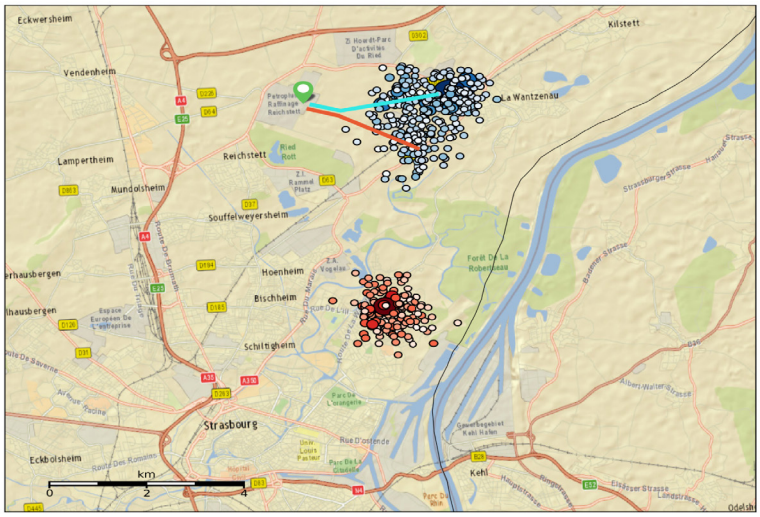


Figure: Location of seismicity between March 2018 and January 2021 near the Geoven deep geothermal site (green pine)

Ratio between hydraulic energy and energy expended by movement on faults in the reservoir

After harmonising the magnitudes of the seismological catalogues for the Soultz-sous-Forêts reservoir, which is necessary for calculating earthquake energy, Kamel Drif was able to show, as part of his thesis work, that the ratio between hydraulic energy and energy expended by movement on faults in the reservoir is a constant, whatever the type, depth or duration of injection carried out in the Soultz reservoir over the last 30 years. This suggests that this ratio is an intrinsic property of the reservoir, which means that this method can be used to estimate the seismic hazard associated with a grouting operation. An article under review

Collective behaviour of asperities subjected to shear

The observations made by Weiwei Shu as part of his thesis show how a heterogeneous medium evolves when loaded at constant speed. In particular, it is shown that the coupling at the interface is both a global function of the normal stress at the interface and a local function due to the different shear strength at different asperities. The results also show that the transient sliding episodes observed have the same characteristics as those observed on a large scale. Finally, the evolution of disorder at the interface is an increasing function of normal load and evolves between 2 large-scale failures. Weiwei Shu is now working on a numerical model capable of reproducing the experimental results and on developing the experiment by adding acoustic sensors. An article submitted

Optimising the detection of induced microseismicity in an urban context

A number of deep geothermal projects have been developed in urban environments in recent years. The associated human activity generates significant seismic vibrations (also known as seismic noise) that limit the ability to detect microseismicity induced by traditional seismic networks. As part of Rémi Fiori's thesis (co-funded by ADEME), we are developing new approaches based on antenna systems composed of miniaturised sensors (nodes) spaced a few metres apart. This geometry makes it possible to filter the surface waves associated with ambient noise and to locate seismic events by analysing the azimuth and apparent speed of the volume waves emitted. Three antennas of this type were deployed in the Reichtett-Vendenheim area following the magnitude 3.6 event on the 4th December, 2020. They enabled a 5-fold increase in the number of earthquakes detected compared with the BCSF-RéNaSS catalogue. This new catalogue shows puffs of earthquakes and highlights the persistence of activity in both the northern swarm (the geothermal drilling zone) and the southern swarm (the Roberstau zone), even several months after operations were completely shut down. An article accepted in Geophysics

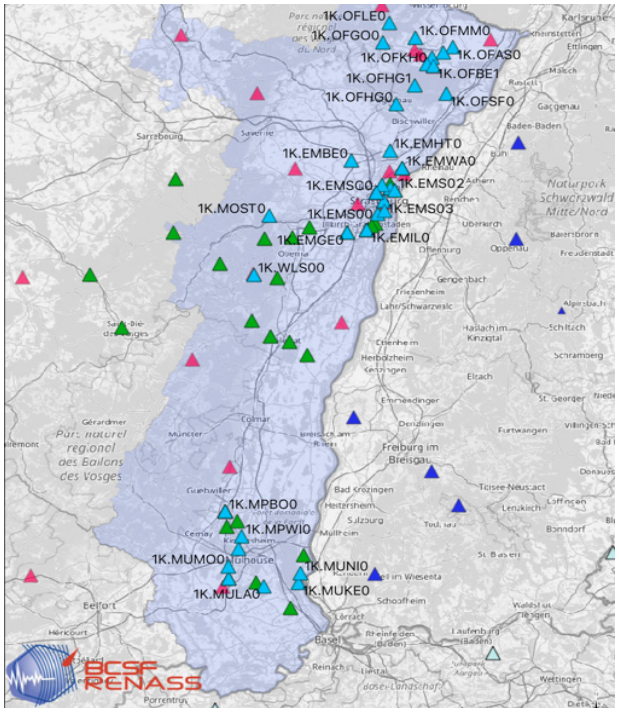


Figure: Location of seismometers in the region, including permanent observatory, industrial and temporary ("low-cost" citizen seismometer) stations.

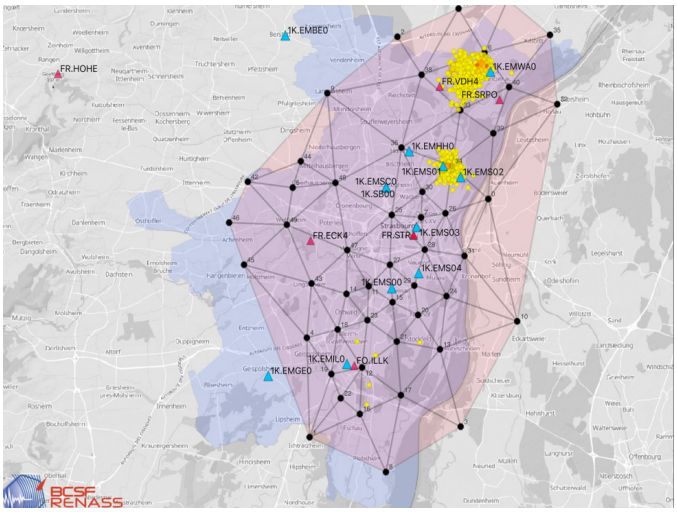


Figure: Target zone (black spots) for the ANR PrESENCE Eurometropole seismo-citizen network

Development of citizen seismological networks

Permanent seismological networks for monitoring underground reservoirs are traditionally made up of a small number of stations, which intrinsically limits the threshold for detecting and analysing induced earthquakes or using them for fine imaging of the reservoir. The ANR PrESENCE project (2022-2025) proposes to test a new paradigm of collaborative geohazard monitoring using a large number of low-cost seismological stations installed in connected buildings and operated by citizens, associations or local public authorities. Within this framework, ~70 'RaspberryShake' stations have been acquired, tested and validated by EOST's seismology instrumental platform. They are currently being deployed in 2 areas: the Outre-Forêts region around the operational deep geothermal sites of Soultz-sous-Forêts and Rittershoffen, and the Strasbourg Eurometropole area where several projects are under development. This seismological approach is coupled with work in the human and social sciences (see WG7).

Development of citizen seismological networks
At the end of 2022, additional funding was obtained as part of the University of Strasbourg's Idex Université&Cité funding (SismoCité project), which will enable the purchase of around fifteen additional stations, the co-construction of new monitoring approaches by involving local associations and communities more closely, and the development of mediation in partnership with the Jardin des Sciences and the Pechelbronn Oil Museum.

Monitoring the deformation of deep geothermal reservoirs using ambient seismic noise interferometry
In recent years, a new monitoring method based on the interferometry of ambient seismic noise has been developed to continuously monitor the evolution of deep geothermal reservoirs. This method complements more traditional approaches based on the use of induced seismicity, and thus provides new observations for characterising the elastic and hydraulic properties of rocks, local and regional stress fields and transient landslides. This new technique, called Coda Wave Interferometry (CWI), focuses on correlating the late part of seismic waveforms recorded at distinct moments in the evolution of the medium and is based on the sensitivity of this part of the wave to slight perturbations in the medium. CWI is an easily implemented method for monitoring geothermal reservoirs, but the link between observed changes in CWI measurements and physical changes occurring in the reservoir is not yet well understood. As part of Yunliang Wang's thesis, we are seeking to gain a better understanding of the physical changes in the environment deduced from CWI by focusing on the influence of elastic deformation on CWI measurements.
Our approach is based on a comparison between laboratory experiments and numerical simulations of wave propagation through diffusing and/or fractured samples that are mechanically loaded and/or thermally heated. In addition to small-scale modelling, we are also seeking to extend numerical simulations to the scale of the geothermal reservoir. Yunliang Wang's recent work on the latter demonstrates our ability to simulate the propagation of scattered waves through a geothermal reservoir during deformation, taking account of non-linear acousto-elastic effects. The proposed numerical model is verified by reproducing the evolution of CWI measurements made at the surface in the natural environment and linked to seasonal pressure variations induced by fluctuations in groundwater elevation. The numerical model allows us to test different parameters to reproduce the observations, such as the thickness of the layer sensitive to variations in the height of the groundwater layer. These preliminary results open up prospects for the application of the ambient noise technique to the continuous monitoring of in-situ deformation in deep geothermal reservoirs.

WG 9 : Modelisation

Creation of two experimental set-ups (metal beam with or without mortar coating) instrumented with Φ-OTDR and FBG fibre-optic sensors

Demonstration of the feasibility and reliability of measurement with the Φ-OTDR sensor for a frequency range of 0.125 Hz to 500 Hz up to a distance of 10 km

Finite element modelling of the device and study of the influence of the materials making up the fibre

Design of an experimental bench (metal tube coated with geothermal grout) instrumented with Φ-OTDR and FBG fibre optic sensors

Implementation of different fibre coatings to study the feasibility of measurement in terms of vibrations and temperatures

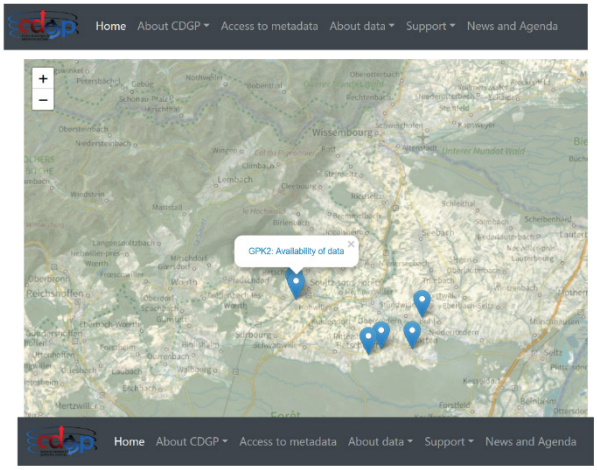
WG 2 : Geodesy

In 2021/2022, the Working Group Geodesy (WG2) analysed all the available data associated with the 2019-2020 Vendenheim seismic sequence. No deformation signals were observed on the InSAR time series. The differential GNSS time series between the Fonroche site station and the nearest stations showed transient events that were not temporally correlated with the fluid injections. In addition, the fact that these transient events are only present at a station located near major industrial activities means that the transient signals cannot be interpreted as being of tectonic origin. This highlights the need to instrument future geothermal sites with dense networks of GNSS stations. With the development of low-cost GNSS stations, GNSS networks of 5 to 10 stations are becoming feasible at reasonable cost. The WG2 has therefore undertaken to purchase 6 "low-cost" GNSS stations in order to take technical ownership of these new stations and set up a surveillance network for the Robertsau fault. In addition, WG2 has undertaken a collaboration with Frédérick Boudin of the École Normale Supérieure in Paris to install a long baseline inclinometer to record possible transient deformation events associated with the active geothermal sites of Soultz-Sous-Forêts and Rittershoffen. This instrument is one of the most sensitive to localized low-amplitude deformations in the Earth's crust. Finally, we would like to point out that Baptiste Rousset replaced Frédéric Masson at the end of 2022 as leader of WG2.

WG 8 : CDGP
"Data center for deep geothermal energy"

Collection of new data and continued publication on the CDGP and, when possible, on the TCS-AH Episodes platform.

- Access to GNSS data for geothermal sites in the Rhine Graben
- Updating the abstracts of the Episodes sheets by adding the Episode datasets, in response to the requirements of scientific journals
- Monitoring publications based on distributed data, contacting/informing data providers
- Revision of documentation



The Episode contains the following datasets:
- Microseismic catalogue of the downhole network by B.C. Dyer - Soultz-sous-Forêts 2005 Stimulation
- Microseismic downhole network - Soultz-sous-Forêts 2004 and 2005 Stimulations
- Seismological waveforms - Soultz-sous-Forêts 2005 Stimulations
- Hydraulic data - Soultz-sous-Forêts 2005 Stimulation
- Velocity model and station corrections used by B.C. Dyer to locate seismic events recorded by the downhole network Soultz-sous-Forêts 2004 and 2005 Episodes

WG 3 : Potential methods

Geothermal energy represents around 30% of the produced electricity in Iceland with a cumulative capacity being equal to 755 MWe. In particular, the Theistareykir geothermal plant, which is located on the Mid-Atlantic ridge in North Iceland, produces 90 MWe using two turbines in operation since autumn 2017 and spring 2018, respectively. This project uses the hybrid micro-gravity monitoring and its main goal is to show how this technique contributes to the sustainable management of this renewable energy. Indeed, the gravity method highlights the mass redistribution and, consequently, helps to quantify the mass transfer (recharge/discharge) within the geothermal reservoir. On one hand we first show the new results of the repetition of the Theistareykir relative micro-gravity network of 27 stations measured in summer 2017, 2018, 2019, i.e. before and after the beginning of the geothermal production, with a Scintrex CG5 gravimeter. We also show preliminary results (no height correction) from the 2022 campaign that seem to confirm the gravity decrease in the production area. On the other hand, in the frame of a cooperation with GFZ Potsdam, we also benefit from the continuous gravity changes recorded since fall 2017 at 3 permanent stations with iGrav superconducting gravimeters (SG). The SGs have been calibrated with a FG5 ballistic absolute gravimeter (AG) and the yearly AG campaigns allow to remove the (small) instrumental drift of the iGravs. The combination of these different types of gravimeters defining the hybrid micro-gravity method is used to investigate the gravity changes in relation to geothermal activity parameters like injection and extraction rates. The comparison of the gravity changes due to mass redistribution to what is expected from the injection/extraction volumes and rates allows us to speculate on the sustainability of the Theistareykir power plant since the start of exploitation in terms of discharge/recharge of the geothermal reservoir. Improved knowledge aimed to mitigate the risk of depletion of the Theistareykir geothermal system is expected from these new datasets.

2022 measurement campaigns

The measurements carried out in 2022 as part of the ITI GeoT are of two types:

1/ Relative gravity measurements

Repetition of micro-gravity measurements using a Scintrex-CG5 mechanical gravimeter on the Theistareykir geothermal network in June-July 2022 (27 stations). This repeat follows on from the previous campaigns (2017, 2018, 2019) as part of the G-EAU-THERMIE Labex, which were interrupted in 2020 and 2021 due to Covid.

2/ Absolute gravity measurements

Repetition of absolute gravity measurements in May-June 2022 at the Theistareykir site: permanent relative gravity stations installed by our partners at GFZ Potsdam (Germany) (3 superconducting gravimeters + 1 gPhone mechanical gravimeter) and reference station for the micro-gravity network. This repetition follows on from the annual campaigns carried out previously from 2017 until 2020.

Preliminary results from measurement campaigns in 2022

Repeating the micro-gravity network in June-July 2022 compared with the last repeat in 2019 gives the results shown in Figure 1 below.

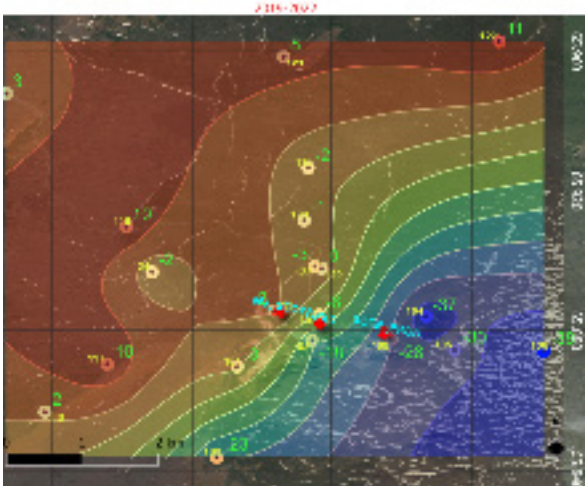


Figure 1. Temporal variations in gravity (2022-2019) on the Theistareykir network.

This figure shows the preliminary temporal and spatial variations (without correction for vertical displacement effects) (values in µGal in green, station code in yellow, location of permanent stations (injection, power station and production) in red).

The first result is that the decrease in gravity (of around 20-30 µGal) extends into the production zone (towards the east) at a rate comparable to that already observed (Portier et al. 2022).

The second result comes from absolute gravity measurements made in May 2022 at the permanent stations (two superconducting gravimeters and one gPhone gravimeter) (see Figure 2).

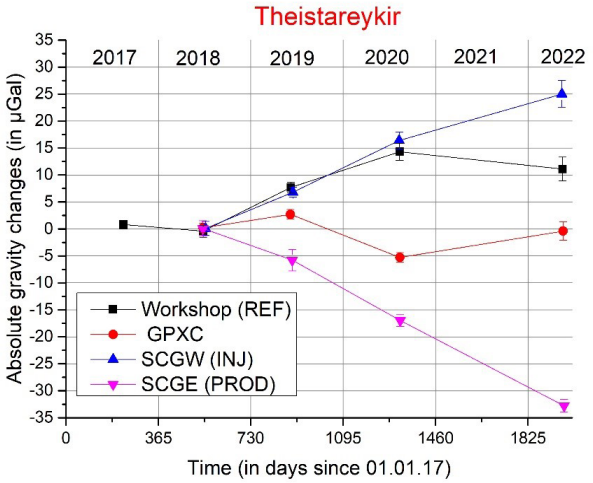


Figure 2. Absolute gravity variations at Theistareykir from 2017 to 2022.

While the central station (GPXC) varies very little, it is very clear that gravity continues to decrease at the production station (SCGE) and increase at the injection station (SCGW), but at different rates. Nevertheless, without correction for vertical displacement variations, these preliminary results should be treated with caution.

Full processing with correction for vertical effects (using GNSS and InSAR measurements) is under progress, as is the processing of data from the permanent gravimeters.

It will only be possible to make a comparison with the plant's operating parameters (injection and production rates) once all the gravity data have been obtained. The ultimate objective is to determine the sustainability of the power plant in terms of charge/discharge of the geothermal reservoir.

WG 4 : Rocks physics and geomechanics

WG4 worked on several different topics related to the ITI Geo-T from 2021 to 2022. In total, three research projects were funded: Influence of the intermediate principal stress on inelastic compaction and compaction localization in porous sandstone" (PI: Baud; 2021-2022 and 2022-2023), "Permeability anisotropy in sandstones from the Soultz-sous-Forêts geothermal reservoir (France)" (PI: Heap; 2021-2022), and "Mechanical behaviour and permeability of porous volcanic geothermal reservoir rock" (PI: Heap; 2022-2023). As well as these projects, summarised in the section below, we also explored the influence of water on fracture toughness, the influence of water on the deformation and failure of gypsum, and the permeability of porous volcanic rock during deformation in the brittle and ductile regimes. This work resulted in the publication of three papers in peer-reviewed international journals, summarised below.

The manuscript "Effect of water on sandstone's fracture toughness and frictional parameters: Brittle strength constraints", published in the International Journal of Rock Mechanics and Mining Sciences in 2021, shows that water saturation causes a reduction of fracture toughness, fracture energy, and static friction coefficient from 6 –35%, 21–52%, and 0–19%, respectively (Figure 1). The results of this paper suggest that the water weakening in sandstones (with a reduction of the uniaxial compression strength of 0–30%) is due to the reduction of the fracture toughness and of the static friction coefficient.

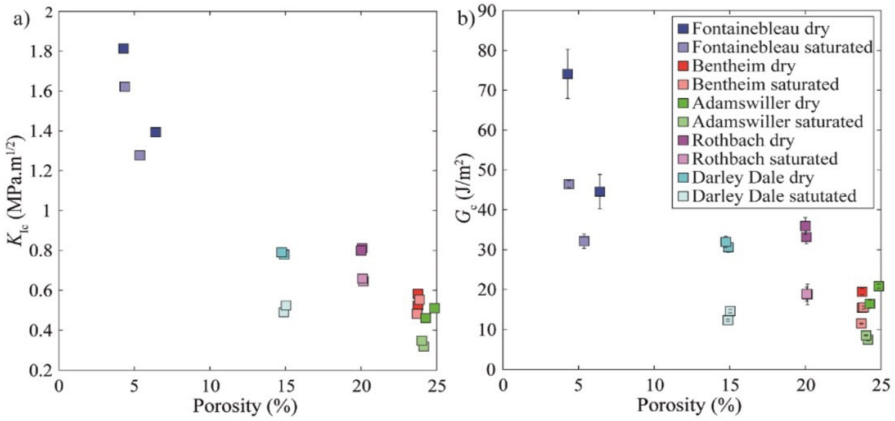


Figure 1. Fracture toughness and fracture energy as a function of porosity (from Noël et al., 2021).

The manuscript "Influence of water on deformation and failure of gypsum rock", published in Journal of Structural Geology in 2021, quantifies water-weakening in a natural gypsum facies from Monferrato (Italy) by performing experiments on nominally dry, oil-saturated, and water-saturated samples. The results of this paper show that there is significant water-weakening in Monferrato gypsum (Figure 2), as well as a strong strain-rate dependence of uniaxial compressive strength.

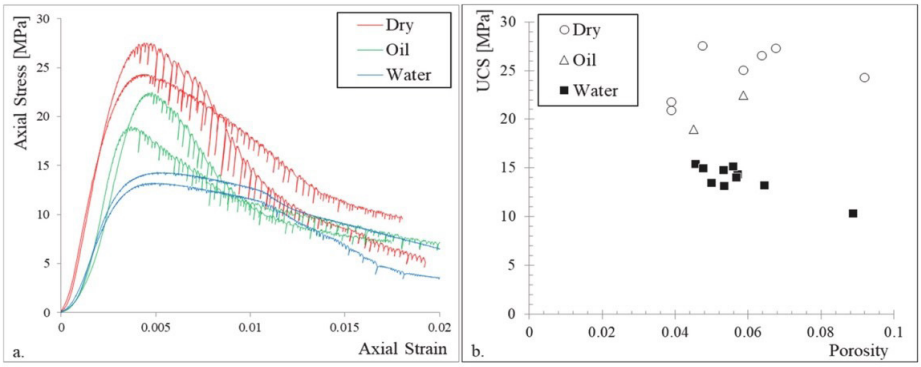


Figure 2. (a) Stress-strain curves for dry gypsum and gypsum saturated with oil and water. (b) Uniaxial compressive strength as a function of porosity for gypsum (from Caselle et al., 2021).

The manuscript "The Permeability of Porous Volcanic Rock Through the Brittle-Ductile Transition", published in the Journal of Geophysical Research: Solid Earth in 2022, provides measurements of the porosity and permeability of a porous volcanic rock during deformation in the brittle and ductile regimes. This paper shows that, in the brittle regime, permeability decreases by a factor of 2–6 up to the peak stress but, following shear fracture formation, remains approximately constant as strain is accommodated by sliding on the fracture (Figure 3). In the ductile regime, permeability continually decreases, by up to an order of magnitude, as a function of strain (Figure 3).

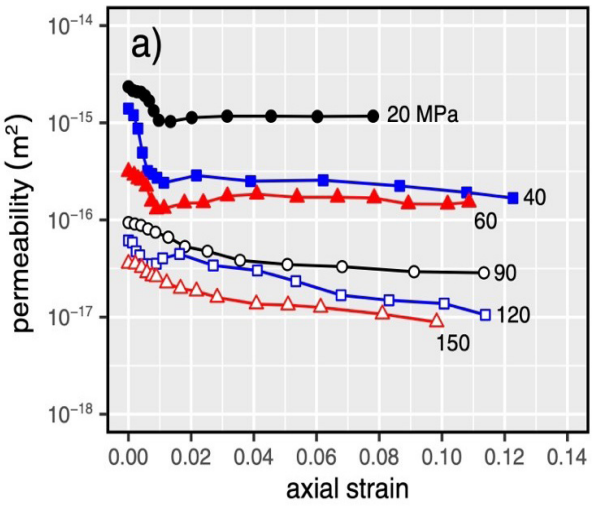


Figure 3. Permeability as a function of axial strain for experiments on Volvic trachyandesite performed at different effective pressures (indicated on the curves) (from Heap et al., 2022).

There were two projects funded in 2021: "Influence of the intermediate principal stress on inelastic compaction and compaction localization in porous sandstone" (PI: Baud) and "Permeability anisotropy in sandstones from the Soultz-sous-Forêts geothermal reservoir (France)" (PI: Heap).
For the project "Permeability anisotropy in sandstones from the Soultz-sous-Forêts geothermal reservoir (France)", we employed an M2 student, Margaux Goupil, to perform the permeability measurements. The goal of the project was to understand whether the sandstones above the granitic reservoir are anisotropic in terms of their permeability. Our results, published in 2022 in Geothermal Energy (Goupil et al., 2022), show that these sandstones can be very anisotropic (Figure 4). We concluded, therefore, that permeability anisotropy should be considered in future large-scale hydrothermal modelling of geothermal in the Upper Rhine Graben.

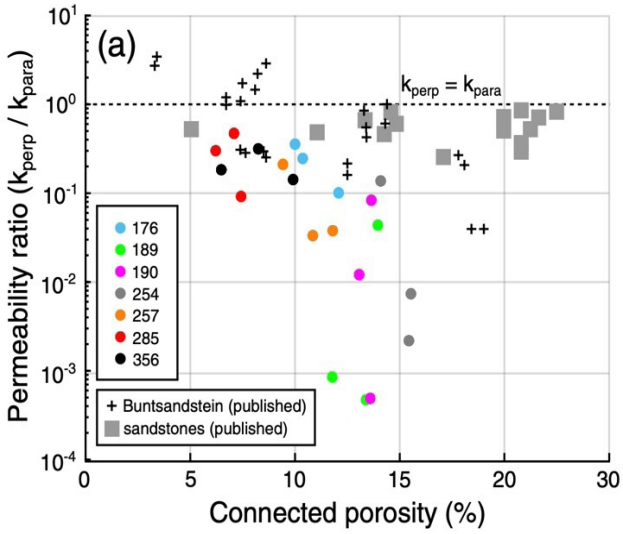


Figure 4. Permeability ratio as a function of connected porosity (from Goupil et al., 2022).

There has also been significant progress on the project "Influence of the intermediate principal stress on inelastic compaction and compaction localization in porous sandstone". The results are as follows: (1) the first set of systematic true triaxial data in the ductile regime, (2) the extension of the pore collapse model to true triaxial conditions, and (3) an analysis of the localisation conditions and compaction band geometry (e.g., angle) under true triaxial conditions. This project is currently ongoing, and received an extension in 2022.

WG 5 : Hydro-geochemistry

PROJECT: **Enhancing native hydrogen generation by CO2 injection into a deep granitic geothermal reservoir in the Rhine Graben (2021-2022)**

- The experiments done in ISTO Orleans gave a first interesting result: there is indeed Hydrogen production in the titanium autoclave reactor and most probably in the gold capsules.

- The autoclave experiments show that H2 production with biotite is relatively low compared to that with granite. This could be related to the grain size which is larger for pure biotite (average 25 µm) compared to the finer granite (average 2.21 µm). This shows the importance of improving the homogenization of the grain size (Jesica Murray made a fraction separation to test).

- Given the technical problems observed with the titanium autoclaves, the next experiments will be focused on the gold capsules.

- Ideally, it would be good to become independent to perform the experiments in Strasbourg. This experimental independence will take time, however, we can start exploring the possibilities. Can we use the existing autoclaves at ITES? For example, can these autoclaves be used to "cook" the gold capsules?

- Regarding the simulations with KIRMAT, there is a constrain with clays precipitation (solid solutions simulations were not possible with the H2 KIRMAT version). Bertrand Fritz and Yann Lucas suggested to contact Alain Clément for help. This will allow us to simulate the precipitation of clays, not only magnetite or Fe oxides

PROJECT: **Enhancing native hydrogen generation by CO2 injection into a deep granitic geothermal reservoir in the Rhine Graben (2021-2022)**

The objective of this project was to produce experimental data to test the two different models of amorphous silica precipitation. To allow discrimination of the two approaches, the critical data to produce are the evolution of the particle size distribution and Si isotopes transfers during nucleation and growth of amorphous silica. Both tasks are technically particularly challenging because of the very small size (<10 nm) and reactivity of the particles produced. The use of "classical" methods to observe such small particles are made under vacuum and therefore includes a drying step that modifies the properties of the particles and make their shape to evolve. In this project, we collaborated with the Institut Charles Sadron (CORTEX platform of the university of Strasbourg) to apply the new technic of cryo-MET. This has implied technical development and image processing to lower the detection limit. To date, the experimental setup is fixed. Super saturation state of the solution with respect to amorphous silica is obtained by lowering the pH with HCl of a stock solution prepared by dissolution of a given amount of Na2SiO3 pelets. This leads to instantaneous rise of the supersaturation state in a slightly saline solution (about 0.01 M of NaCl). The particle suspension can then be analyzed by cryo-MET which has the advantage of producing a vitreous glass that freezes the particles without affecting their shape. The images produced (Fig. 1) can then be processed to determine the size distribution (Fig. 2).

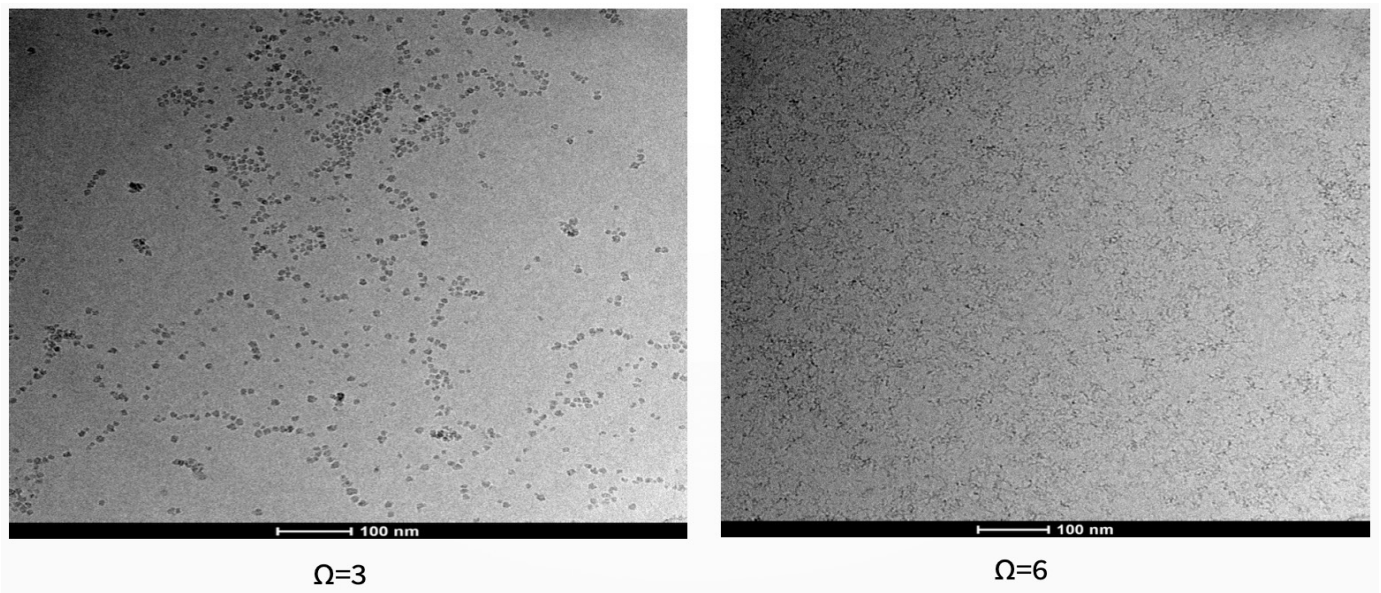


Fig. 1: ICryo-MET images of the particle suspension produced after 4 days of reaction, starting at different supersaturation state (3 for the left image and 6 for the right one). Note the difference in size and number of the produced particles depending on the initial supersaturation state.

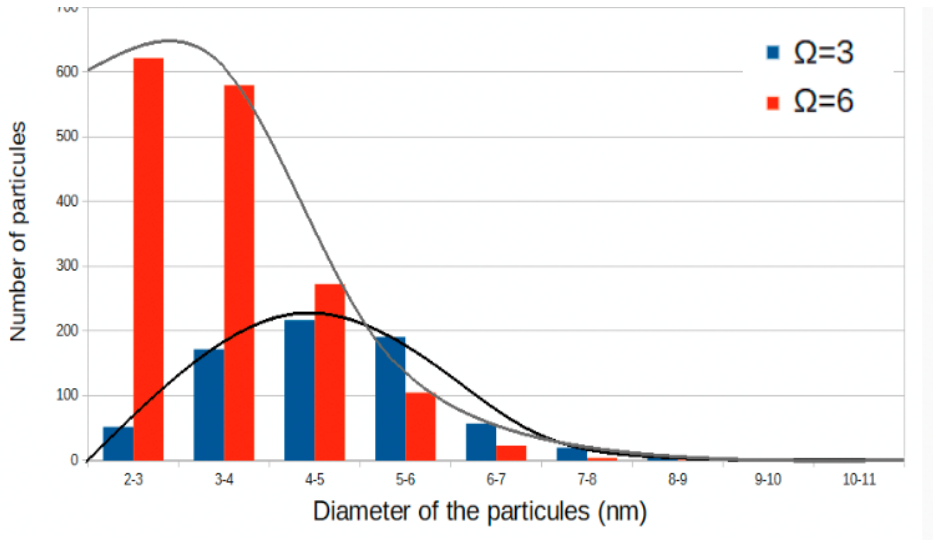


Fig. 2: Size distribution pattern produced after image processing. This is part of the critical results needed for validation and calibration of the numerical models.

WG 6 : Geology

Four teams have been set up in the WG Geology. The first team, led by Guilherme Bozetti, is working on the Buntsandstein reservoir using a sedimentological/ stratigraphic approach.

The main objective is to understand the control of facies and depositional environments on the hydraulic properties of the Buntsandstein reservoir. This study, funded by the ITI GeoT, involves a PhD student (Lucas Bofill) and collaborations with national and international researchers and hydrologists. A second team, led by Benoit Petri and Francis Chopin, is working on basal heat flow in the Rhine Graben. The main aim of this study is to define the composition of the lower crust and assess the implications for basal heat flow in the upper Rhine Graben. This study is financially supported by the ITI GeoT and includes a Masters student as well as national and international collaboration. The other two teams have not yet received funding from the ITI GeoT project, but are in the process of preparing projects to be submitted in the next funding round. These are a project on native hydrogen led by Marc Ulrich and in collaboration with the WG Geochemistry and a project on the link between Li and palaeoenvironments led by Mathieu Schuster.

PROJECT : "**New insights on the nature, age and origin of the URG lower crust**"

The project aims to determine the composition of the lower crust of the Rhine Graben in order to estimate its heat production and its influence on surface heat flow. We have compiled existing data on the various potential outcrop candidates, supplemented by obtaining new data following exhaustive sampling of the lower crust xenoliths documented in a number of recent volcanic systems around the Graben (4 main geographical areas: Swabian Jura - Bad Urach, Eifel, North Hesse Depression - Cassel, Heldburg-Gangschar). The (preliminary) petrological data show that the xenoliths from the deepest origins (~ 10 kbar) seem to confirm the systematic presence of a lower crust of a mafic nature and poor in heat-producing elements (HPE) not documented at the surface (not outcropping) and common to the different palaeogeographic and orogenic domains.
Conversely, the more superficial xenoliths (~ 6 kbar) are metasedimentary in nature, fairly rich in HPE and appear to be a high-grade equivalent of syn-orogenic Variscan metamorphism. Geochronological work is currently underway to provide an absolute date for the magmatic and metamorphic episodes and to determine their geodynamic origin. Initial modelling results show that variability in the composition of the lower crust can lead to a 30% modulation in surface heat flux.

PROJECT : "**Caractérisation architecturale de la formation du Trias inférieur du Buntsandstein** ".
The Buntsandstein Group has long been described as an arid, predominantly braided fluvial system, coexisting with a much less expressive eolian system. From a sedimentological/stratigraphic point of view, the Buntsandstein has always been considered as a monotonous system, mainly composed of fluvial-type cross-bedded sandstones, with little heterogeneity, but we believe that this is mainly due to the lack of detailed work.
We propose here a very high-resolution study of the Middle Buntsandstein (mainly the Vosges Sandstone and the Main Conglomerate), revisiting the cyclic origin of deposition already highlighted by previous studies, but focusing on the reasoning behind these cycles, and more specifically on the impact this has on fluid flow through the rocks. We also propose a much more systematic approach to aeolian sandstones in order to best represent them in the geological record and reassess their importance within the Buntsandstein Group.
To carry out this work, we have a full-time PhD student working on this subject (PhD project: To what extent is the 3D anisotropy of clastic geocodes significant for detailed fluid flow modelling?), assisted by three sedimentologists and two modellers from UNISTRA, and two sedimentological collaborators from Brazil, both specialising in fluvio-olian deposits. We will also have another PhD student fully funded by the ITI working on a similar topic starting in September 2023.
To date, a large number of permeability measurements have been collected, always in parallel with measured sections (e.g. sediment logs), mainly in outcrops where we have also acquired large-scale panoramas, and sometimes 3D models, all to support the architectural analysis of the individual elements making up the depositional system, aimed at facilitating the scaling of permeability data throughout the reservoir. The idea is to continue collecting additional permeability data, recently combined with gamma-ray data, in order to best represent not only the fluid flow conditions through the rocks (or their dam), but also to have a better chance of correlating the large-scale outcrops with subsurface wireline well data, thus generating a better understanding of Buntsandstein in the subsurface through similar work in outcrops.
In the next phase of the project, starting in March 2023, alongside the acquisition of new field data, we will begin to develop the fluid flow modelling and compile the sedimetological and permeability data for a manuscript, as there is new evidence of very distinct features of aeolian sandstones interacting with fluvial sandstones/conglomerates that could evoke interpretations of a not-so-dry depositional environment, with the record of aeolian dunes and interdunal ponds. New concepts of fluvial discharge were also applied to the many different types of cross-bedded sandstone, allowing us to tell a much more accurate story of the discharge regime of the fluvial system throughout the Buntsandstein deposition.
More recently, our attention has turned slightly to the Upper Buntsandstein (Viollete Zone, Intermediate Layers and the Voltzia Sandstone), as we are convinced that the high micas content of these deposits can be directly associated with the anomalous presence of lithium in the hot fluids extracted for geothermal energy production. In addition, the Voltzia Sandstone displays extremely intriguing sedimentary structures, never before recognised in the Buntsandstein, which may provide very good information on the transition between the Buntsandstein and the Muschelkalk.

WG 7 : Social sciences

In 2021 and 2022, part of WG7's work was devoted to the project: "**Governing risks. Analysis of the political and discursive reconfigurations induced by the Strasbourg earthquakes**".

The aim of this research project is to analyse the reconfigurations of policies and discourses concerning the uses of the subsoil that are emerging between 2015 and 2021. The project has two main components: an analysis of the discursive reconfigurations appearing in the media, together with monitoring of the debates taking place in the consultation bodies set up by the Strasbourg prefecture and Eurometropole. Two case studies were carried out in 2021. The first focused on the period of public enquiries organised by the Préfecture in 2015-2016, during which several deep geothermal energy projects were the subject of controversy. The aim was to analyse the trajectory of various arguments put forward by opponents of the projects and the responses provided by the local authorities. We showed how the latter have imposed the idea that what is at the root of the controversies is not so much the risks induced by the projects as the lack of public information. The results of this study were published in the journal *Natures Sciences Sociétés* (https://www.nss-journal.org/articles/nss/full_html/2021/03/nss210044/nss210044.html).

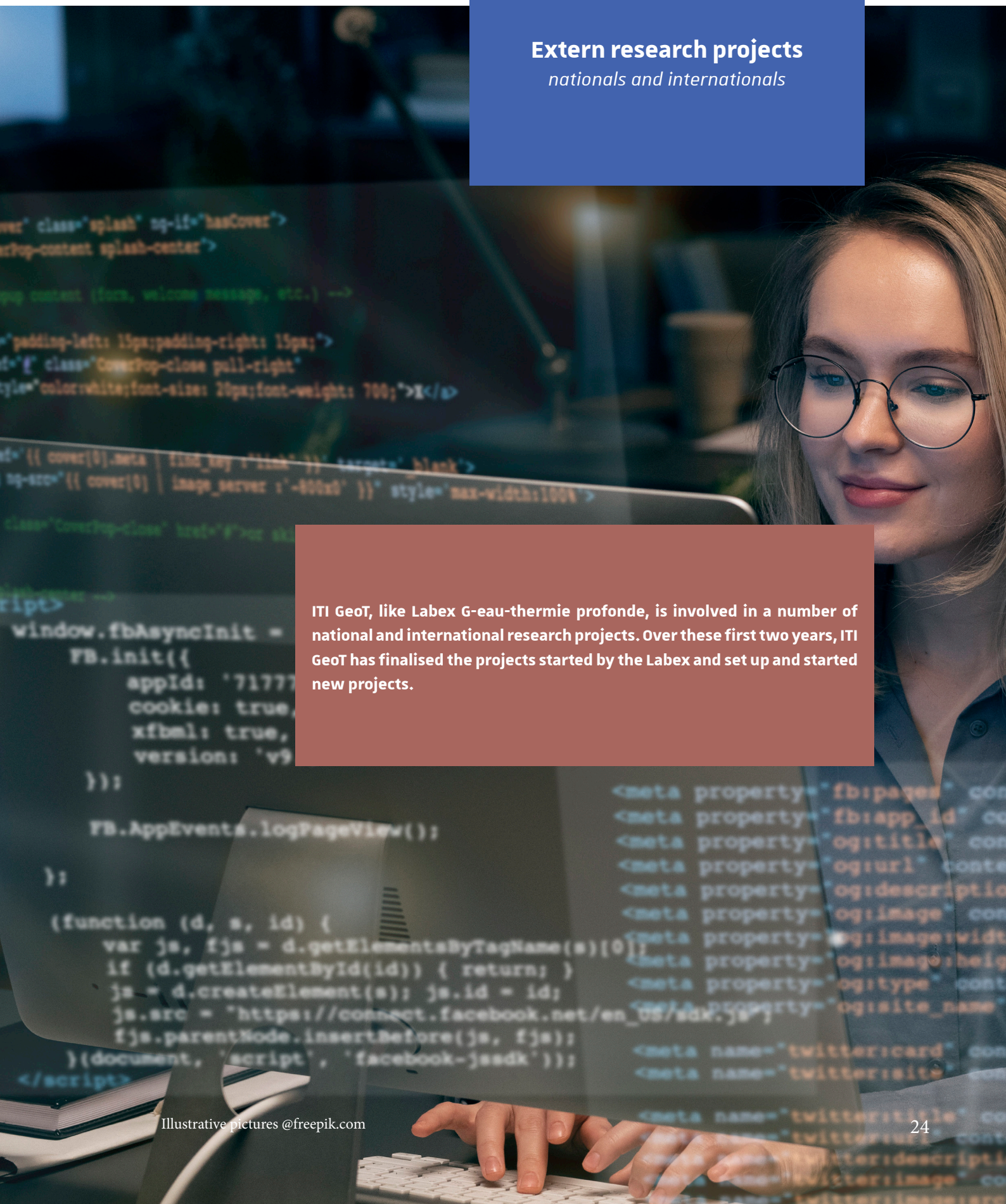
A second study concerns the reconfiguration of representations of the subsoil following the Strasbourg earthquakes (2019-2021). We have shown how, in public discourse, the subsoil has gone from being a patient agent (one that allows itself to be exploited) to an acting agent (one that acts and reacts and is difficult to domesticate). At the same time, the stories told about the subsoil by scientists and local residents are gaining in importance in the public arena, undermining the credibility of industrialists. The results were presented in June 2021 at the Soil and subsoil in the socio-energy transition conference. As for the second part, observation work was carried out as part of the information and assessment mission organised by the Strasbourg Eurometropolis (March 2021-June 2021). These observations complement those made by the site monitoring committees set up by the Préfecture in 2017. This work led to the writing of an M2 research dissertation, to be defended by Clara Millet in September 2021.

Two new case studies have been carried out. The first focuses on the evolution of disagreements between the worlds of industry and science concerning the degree of maturity of deep geothermal energy in Alsace (2015-2021). This dispute, in which scientific interpretations and industrial interests intersect, reflects differences of opinion regarding the way in which science and scientists should be involved in geothermal energy projects. These disagreements are coming to the surface following the earthquakes affecting the Strasbourg Eurometropolis in 2019-2021. The results of this study were published in the journal *Les enjeux de l'information et de la communication* in 2022 (https://lesenjeux.univ-grenoble-alpes.fr/2021/supplement-b/la-science-est-elle-soluble-dans-des-projets-techno-industriels-querelles-autour-de-la-geothermie-profonde-a-leurometropole-de-strasbourg-2012-2020/).
The second case study looks at how the media and social media are used by different audiences between 2016 and 2021. This study, presented at EGC 2022, highlights the changes in the local media, which diversified their sources of information as soon as the first earthquakes occurred. It also looks at the way in which social media are being used to relay information to the various players involved, and the ways in which they are being used during the earthquake crisis of 2019-2021.

Finally, preliminary work has been carried out as part of the ANR PrESENCE project. A student has carried out a series of observations aimed at analysing the way in which the scientific community sees the relationship between science and society, and the place that participatory science can occupy in this context. This work will continue in 2023 with the writing of a research dissertation.

Extern research projects

nationals and internationals



ITI GeoT, like Labex G-eau-thermie profonde, is involved in a number of national and international research projects. Over these first two years, ITI GeoT has finalised the projects started by the Labex and set up and started new projects.

Illustrative pictures @freepik.com

H2020 DESTRESS

Study and development of innovative stimulations to improve reservoir productivity while minimising environmental risks (EGS technology)

A total of 16 partners, comprising 4 research organisations, 4 universities and 8 industrial companies (including ÉS Géothermie), are involved in the project. EOST and LISEC represent the University of Strasbourg. EOST is mainly carrying out multidisciplinary studies (seismology, geodesy, rock mechanics, water-rock interactions) during the development and post-stimulation operation of the reservoir, while LISEC is conducting studies on social acceptability. For more information, www.destress-h2020.eu

DESTRESS
Demonstration of soft stimulation treatments of geothermal reservoirs

ANR Geresfault

Geothermal resources of crustal fault zones: exploring new systems for producing competitive geothermal energy

A total of 8 partners, including 5 research organisations, 5 universities and 3 industrial companies. ITES represents the University of Strasbourg. Through a combination of field studies, experimental rock physics, geophysics and numerical modelling, the project is investigating how the physical properties of rocks measured in the laboratory can be used in 3D geological and numerical models at different scales. For more information, https://anr.fr/Projet-ANR-19-CE05-0043

ANR Monidas

Natural hazard monitoring using Distributed Acoustic Sensing (DAS)

A total of 5 partners, including 3 research organisations, 3 universities and 2 industrial companies. EOST represents the University of Strasbourg. The DAS sensors use standard telecommunications optical fibres to measure cable deformation in the acoustic range of 0.1 to 1 kHz. In doing so, a single fibre coupled with point data processing techniques can act as a dense distribution of sensors over tens of kilometres to improve the detection and characterisation of seismic sources, seismo-volcanic deformation and landslides, among others. The ultimate aim of the Monidas project is to provide the French geophysical community with a new instrument, based on a technology that has shown promising results in terms of monitoring and data processing. For more information, https://anr.fr/Project-ANR-19-CE04-0011

EPOS (European Platform Observing System) ERIC: TCS AH

Collecting, managing, archiving and disseminating data in the earth sciences

In total, 250 partners from 25 European countries. The ITI GeoT plays an active role in the "Anthropogenic hazards" (AH) axis, particularly as regards deep geothermal energy. As part of this, it manages the Deep Geothermal Data Centre (CDGP). The approach is multidisciplinary and is in line with the open science dynamic to meet the challenges of the Earth sciences, including those related to resources and geohazards. One of the main aims of the project is to improve access to and use of multidisciplinary data from monitoring networks and European laboratories.
For more information, www.epos-eu.org
and the TCS AH platform: www.tcs.ah-epos.eu

Geothermica DEEP / ADEME

Innovation for De-Risking Enhanced Geothermal Energy Projects – DEEP

A total of 10 partners, including 7 universities and 3 industrialists. EOST represents the University of Strasbourg. The DEEP project brings together an interdisciplinary team of scientists and professionals from all over the world to develop innovative approaches to the governance of geothermal risks. These are based on recent advances in seismic monitoring technologies, modelling and process understanding. As part of this project, co-financing was provided by ADEME, the French Environment and Energy Management Agency, to fund a 3-year PhD project.

ANR PrESENCE

Provide and share more advanced open-access scientific knowledge to stakeholders (the general public, journalists, politicians, citizens) through a new paradigm for monitoring induced seismicity in an urban environment

A total of 3 partners, including 1 university. ITES, EOST and LISEC are running the project. The project aims to deploy a large set of low-cost seismometers in distributed buildings with (near) real-time transmission via the Internet, with the participation of local public authorities and residents. The aim is threefold: to improve subsurface imaging and monitoring, to provide advanced public scientific information to the local community, and to develop a social science framework to monitor changes in societal perception of the technology.
For more information, https://anr.fr/Projet-ANR-21-CE05-0033

Horizon Europe DT-Geo

Deployment of a digital twin (DT) prototype on geophysical extremes, made up of interdependent digital twin components (DTC), dealing with geological hazards linked to earthquakes (natural or anthropogenically induced), volcanoes and tsunamis triggered by earthquakes or landslides

A total of 19 partners in Europe. ITES represents the University of Strasbourg. Its general objectives are as follows:

1. Deploy a pre-operational prototype of DT for future integration into the Destination Earth initiative.
2. Contain 12 DTCs at TLR 6-7 dealing with specific hazardous situations
3. Provide a flexible framework for FAIR validation, uncertainty analysis and integration into EPOS and EuroHPC (HPC/virtual cloud computing) research infrastructures.
4. Verify DT-Geo in 13 particularly relevant demonstration sites.

For more information, visit https://dtgeo.eu/

Horizon Europe Geo-INQUIRE

Integration of a large number of different data and products thanks to services already available to the geoscientific community in Europe and provided by the participating research infrastructures

In total, 52 partners in Europe. ITES represents the University of Strasbourg. The scientific objectives of Geo-INQUIRE are summarised in the following six priorities:

1. Consolidate and improve access to multidisciplinary and interoperable datasets: towards higher spatial and temporal resolutions that will enable curiosity-driven research, previously unattainable.
2. Improving access to new and innovative observables and products
3. Opening up new research opportunities to enable a better understanding of the interface between the solid earth and its fluid envelope
4. From single hazard to multiple risk: support for transdisciplinary and integrated studies of extreme geohazards
5. Unprecedented research opportunities in the field of georesource management through the provision of innovative data, products and services
6. Provision of innovative data management, simulation and visualisation techniques at the interface with supercomputing facilities

Find out more, https://www.geo-inquire.eu/

Dissemination and Communication

Illustrative picture @freepik.com

Publications

WG1 :

Schmittbuhl, J., Lambotte, S., Lengliné, O., Grunberg, M., Jund, H., Vergne, J., et al. (2021). Induced and triggered seismicity below the city of Strasbourg, France from November 2019 to January 2021. Comptes Rendus. Géoscience, 353(S1), 1–24. https://doi.org/10.5802/crgeos.71

Aquino, M., Marquis, G., Vergne, J. (2022) Joint one dimensional inversion of Magnetotelluric Data and Surface Wave Dispersion Curves using Correspondence Maps. Geophysical Prospecting.https://doi.org/10.1111/1365-2478.13239

WG3 :

Forster, F., Güntner, A., Jousset, P., Reich, M., Mannel, B., Hinderer, J., & Erbas, K., (2021). Environmental and anthropogenic gravity contributions at the Þeistareykir geothermal field, North Iceland, Geothermal Energy, 9:26 https://doi.org/10.1186/s40517-021-00208-w

Portier, N., Forster, F., Hinderer,J., Erbas, K., Jousset, P., Drouin, V., Siqi Li, Sigmundsson, F., Magnússon, I., Hersir, G., Ágústsson, K., Guðmundsson, A., Júlíusson, E., Hjartasson, H., & Bernard , J.-D., (2021). Hybrid microgravity monitoring of the Theistareykir geothermal reservoir (North Iceland), PAGEOPH, 179, 1-30. https://doi.org/10.1007/s00024-022-03018-8

Hinderer, J., Warburton, R.J., Rosat, S., Riccardi, U., Boy, J., Forster, F., Jousset, P., Güntner, A., Erbas, K., Littel, F., & Bernard, J.D. (2022). Intercomparing Superconducting Gravimeter Records in a Dense Meter-Scale Network at the J9 Gravimetric Observatory of Strasbourg, France. PAGEOPH, 179, 1701 - 1727. https://doi.org/10.1007/s00024-022-03000-4

13 publications

WG4 :

Michael J. Heap, Gabriel G. Meyer, Corentin Noël, Fabian B. Wadsworth, Patrick Baud, Marie E. S. Violay, (2022). The Permeability of Porous Volcanic Rock Through the Brittle-Ductile Transition. JGR Solid Earth. https://doi.org/10.1029/2022JB024600

Margaux Goupil, Michael J. Heap, Patrick Baud (2022). Permeability anisotropy in sandstones from the Soultz-sous-Forêts geothermal reservoir (France): implications for large-scale fluid flow modelling. Geothermal Energy. https://doi.org/10.1186/s40517-022-00243-1

Chiara Caselle, Patrick Baud, Alexandra R.L. Kushnir, Thierry Reuschlé, Sabrina M.R. Bonetto (2022). Influence of water on deformation and failure of gypsum rock. Journal of Structural Geology. https://doi.org/10.1016/j.jsg.2022.104722

Effect of water on sandstone's fracture toughness and frictional parameters: Brittle strength constraints. Corentin Noël, Patrick Baud, Marie Violay. International Journal of Rock Mechanics and Mining Sciences. https://doi.org/10.1016/j.ijrmms.2021.104916

WG6 :

Zwaan F., Chenin P., Erratt D., Manatschal G., Schreurs G (2021). Complex rift patterns, a result of interacting crustal and mantle weaknesses, or multiphase rifting? Insights from analogue models. Solid Earth. https://doi.org/10.5194/se-12-1473-2021

Zwaan F., Chenin P., Erratt D., Manatschal G., Schreurs G. (2022). Competition between 3D structural inheritance and kinematics during rifting: Insights from analogue models. Basin Research. https://doi.org/10.1111/bre.12642

WG7 :

Philippe Chavot, Anne Masseran, Yeny Serrano, Jean Zoungrana (2021). L'information comme enjeu ? La controverse autour de la géothermie profonde à l'Eurométropole de Strasbourg. Natures Sciences Sociétés, EDP Sciences, Pour une géologie politique, 29, pp.43-54. 10.1051/nss/2021044.

Philippe Chavot, Anne Masseran, Yeny Serrano, Jean Zoungrana. La science est-elle soluble dans des projets techno-industriels ? Querelles autour de la géothermie profonde à l'Eurométropole de Strasbourg (2012-2020). Les Enjeux de l'Information et de la Communication, n°22/4, 2021, p.63 à 76, [en ligne] URL : https://lesenjeux.univ-grenoble-alpes.fr/2021/supplement-b/la-science-est-elle-soluble-dans-des-projets-techno-industriels-querelles-autour-de-la-geothermie-profonde-a-leurometropole-de-strasbourg-2012-2020/

Congress communication

WG1 :

J. Schmittbuhl, O. Lengliné, S. Lambotte, M. Grunberg, C. Doubre, J. Vergne, F. Cornet, F. Masson (2021). Induced and triggered seismicity from Nov 2019 to Dec 2020 below the city of Strasbourg, France. EGU21-8374

W. Shu, O. Lengliné, J. Schmittbuhl (2021). Role of asperities on the transition from seismic to aseismic slip using an experimental fault slip system. EGU General Assembly Conference Abstracts, EGU21-9751

Schlupp A., M. Grunberg, H. Jund, M. Bes-de-Berc, P. Chavot, J. Vergne, J. Schmittbuhl, F. Masson (2021). Seismocitizen: Contribution of Raspberry Shake dense seismic networks hosted by citizens for natural and anthropic seismicity monitoring. 37th General Assembly of the European Seismological Commission, ESC Vienna, online.

M. Aquino, G. Marquis, J. Vergne (2022). Joint inversion of Magnetotelluric Data and Surface-Wave Dispersion Curves using Correspondence Maps. EGU General Assembly Conference Abstracts, EGU22-5056

K. Drif, O. Lengliné, J.L. Kinscher, J. Schmittbuhl (2022). Faulting and hydraulic energy balance during fluid injection in the Soultz-sous-Forêts geothermal reservoir. European Geothermal Congress (EGC 2022)

J.L. Kinscher, M. Broothaers, J. Schmittbuhl, F. de Santis, B. Laenen, E. Klein (2022). Induced seismicity related to first circulation tests (2018-2019) at the Balmatt geothermal doublet (Belgium). European Geothermal Congress (EGC 2022)

W. Shu, O. Lengliné, J. Schmittbuhl (2022). Interactions of asperities controlling on fault stability: An experimental approach. EGU General Assembly Conference Abstracts, EGU22-5254

WG3 :

Portier, N., Hinderer, J., Schäfer, F., Jousset, P., Erbas, K., Drouin, V., Li, S., Sigmundsson, F., Magnússon, I., Hersir, G.P., Ágústsson, K., Guðmundsson, A., Júlíusson, E., Hjartasson, H., Mortensen, A., Bernard, J.-D. (2021). Latest results from the hybrid micro-gravity monitoring of the Theistareykir geothermal field (North Iceland), EGW 2021, Karlsruhe, Germany.

Hinderer, J., & Riccardi, U. (2021). Hybrid gravimetry as a tool to monitor geothermal reservoirs and volcanos, ACAG7 (Arab Conference on Astronomy and Geophysics 7th Assembly), Cairo, Egypt.

23 Communications

WG4 :

M.Heap & P.Baud (2021). The influence of compaction bands on the permeability of volcanic rock, The 14th Euroconference on Rock Physics and Rock Mechanics, Heriot Watt University (Scotland).

L. Carbillet, M. Heap & P. Baud (2022). Influence of brittle deformation on the permeability of granite: assessing the geothermal potential of crustal fault zones. European Geosciences Union, Vienna, Austria.

WG5 :

D. Lemarchand (2022). Goldschmidt conference, Hawaï, Etats-Unis d'Amérique.

J. Murray & B. Fritz (2022). GDR HydroGEMM, Bordeaux, France.

WG6:

G. Bozetti (2022). Architectural analysis of a braided fluvial system within an arid alluvial plain and its permeability heterogeneity: Lower Triassic Buntsandstein Group, East France. British Sedimentology Research Group (BSRG) Annual Meeting, Southampton, Royaume-Uni.

WG7 :

P. Chavot, J. Arnaud, A. Masseran, Y. Serrano (2022). How to govern deep geothermal projects? Political, environmental, and scientific issues involved in the debates related to the Strasbourg earthquakes (2019-2021), European Geothermal Congress 2022, Berlin, Allemagne.

C. Bodin, P. Chavot, A. Massseran, Y. Serrano, J. Zoungrana (2021). L'autre face de la participation citoyenne : les formes de reconnaissance de la connaissance dans la controverse sur la géothermie profonde. Colloque Transition en tension, Louvain-la-Neuve, Belgique.

P. Chavot (2021). Qui instrumente qui ? Construire et observer un réseau de sismologie citoyenne en terrain controversé. Seminar Sciences, société et communication, MSH-Alpes, Grenoble, France.

P. Chavot, A. Massseran, Y. Serrano, J. Zoungrana (2021). Sous la terre, l'énergie – étude des récits entourant les projets de centrales de géothermie profonde en Alsace (2014-2020). Colloque : Sols et sous-sols dans la transition socio-écologique. Grenoble, France.

WG8 :

Schaming, M., Fremand, A., Schmittbuhl, J., Bigarre, P., Blanke, A., Dineva, S., Garcia, A., Grasso, J.-R., Karimov, A., Kinscher, J., Kocot, J., Kozlovskaya, E., Kwiatek, G., Lasocki, S., Lizurek, G., Nevalainen, J., Orlecka-Sikora, B., Pringle, J., Roselli, P., Saccorotti, G., Sterzel, M., Szepieniec, T., Toon, S., Urban, P., (2021). The EPOS Thematic Core Service on Anthropogenic Hazards (TCS-AH): a Hotspot for Geothermal Research. World Geothermal Congress WGC2020+1, online.

Turlure, M., Schaming, M., Schmittbuhl, J., Grunberg, M., (2021). Why and how does CDGP limit access to some deep geothermal data. EGU General Assembly 2021, vPICO presentations EGU21-10817.

Schaming, M., Turlure, M., Schmittbuhl, J., Orleka-Sikora, B., Lasoki,S., (2021). CDGP, a data center of EPOS TCS Anthropogenic Hazards, to help analysis of geothermal anthropogenic seismicity. EGU General Assembly 2021, vPICO presentations, EGU21-10763.

Schaming, M., Turlure, M., Grunberg, M., Schmittuhl; J., (2021). CDGP, a gateway to geothermal data EGW2021, 9th European Geothermal Workshop, online.

Schaming, M, Schmittbuhl, J, Fremand, A, Turlure, M, Grunberg, M, (2022). CDGP, the data center for deep geothermal data in Alsace. European Geothermal Congress 2022, Berlin, Allemagne.

Education

The ITI GeoT aims to open up a new range of training courses through a new programme within the EOST 'Earth and Planetary Sciences, Environment' master's degree. The Geosciences for the Energy system Transition (GeoT) programme will train the next generation of scientists specialising in georesources for a low-carbon future. Over the first two years, the ITI has developed a tailored, interdisciplinary training programme rich in practical experience.

Illustrative picture @freepic.dller

EUCOR and Geothermal field school

Field course bringing together students from three French and German universities, focusing on the theory and practical examples of geothermal energy.
A total of 3 partners: the University of Strasbourg, the Karlsruher Institut für Technologie (KIT) and the University of Freiburg.

The Rhine Graben is world-renowned for its geothermal resources, which already provide renewable thermal energy.

The aim of the "Geothermal Master Field School" is to provide transnational training through an innovative 9-day field school, which will take place every year. Held in northern Alsace, in the direct proximity of the Soultz-sous-Forêts and Rittershoffen geothermal sites, the course teaches students to apply theoretical geoscientific concepts to the evolution of a deep geothermal system, from exploration to exploitation. The course thus exposes students to the real-world decision-making processes involved in the industrial exploitation of renewable georesources.


Soultz-sou-Forêt power pant visite @J. Schmittbuhl

In 2022: this course was proposed to students as part of the doctoral school's training programme. A total of 20 students, including 5 EOST doctoral students, took part in the course in October 2022.

Starting 2023: this course will be offered to M2 students in the GeoT master's programme.

Creation of a master's programme

With the aim of offering a highly enriched and interdisciplinary programme, ITI GeoT can rely on its member laboratories to offer courses from EOST, Lisec and Icube. Over the first two years, the programme has been developed and the legal and administrative procedures have been completed within the University of Strasbourg.
In addition, over the period 2021 and 2022, a partnership with IFP school has been set up to offer our future students an even more varied range of courses.
Through its education programme, the ITI GeoT aims to create a course of international stature recognised by academic and industrial professionals.

The GeoT programme will open at the start of the 2023 academic year at both M1 and M2 levels. We hope to welcome a large number of students to whom we can offer interesting internships and subsequent thesis projects.

Welcome to students, young researchers and young engineers

The ITI GeoT is committed to providing high-quality training for future generations of researchers by welcoming students and young researchers into its research teams. To this end, part of its budget is dedicated to funding research projects carried out by students, PhD students, post-docs and young engineers.

Illustrative picture @freepik.com

In these first two years, the ITI GeoT has supported 8 PhD students, 2 post-docs, 10 interns and 3 young engineers.
In 2023, the ITI GeoT will also fund 3 new post-docs, 2 engineers and the total funding of two PhD fellowships, voted in response to the 2022 call for projects for 2023.

Names	Position	WG	Supervisor
Monica Aquino-Guerra	PhD	WG3	G. Marquis
Quiglin Deng	PhD	WG9	J. Schmittbuhl
Kamel Drif	PhD	WG1	O. Lengliné
Dariush Javani	PhD	WG9	J. Schmittbuhl
Weiwei Shu	PhD	WG1/9	O. Lengliné & J. Schmittbuhl
Rémi Fiori	PhD	WG1	J. Vergne
Lucas Bofill	PhD	WG6	G. Bozetti
Yuanliang Wang	PhD	WG1/9	J. Schmittbuhl, D. Zigone & O. Lengliné
Lucille Carbillet	Post-doc	WG4	M. Heap
Jesica Murray	Post-doc	WG5	D. Lemarchand
Muriel Béasse	Engineer	WG7	
Jérôme Arnaud	Engineer	WG7	
Mathieu Turlure	Engineer	WG1	
Margaux Goupil	Intern	WG4	M. Heap
Emma Vairé	Intern	WG4	P. Baud & M. Heap
Cloé Chuchet	Intern	WG5	D. Lemarchand
Vincent Pottier	Intern	WG5	D. Lemarchand
Mickaël Burckel	Intern	WG6	B. Petri & F. Chopin
David Monnet	Intern	WG6	G. Bozetti
Clara Millet-Lacombe	Intern	WG7	P. Chavot
Morgane Platon	Intern	WG7	P. Chavot
Kévin Dos Santos	Intern	WG9	C. Fond
Adnane Talbi	Intern	WG9	C. Fond

Defended PhDs

Qinglin Deng, 2019-2022 "Multi-scale hydro-mechanical behaviour of rough fracture: implications for EGS reservoir stimulation"

Abstract

This thesis focuses on the use of numerical simulations to study the hydromechanical properties of a fracture at the field scale and the hydromechanical responses during hydraulic stimulation. The aim is to improve understanding of the behaviour of fractured reservoirs (e.g. EGS). Firstly, a new approach is proposed for estimating the hydraulic diffusivity of a rough fracture by solving the transient pressure diffusion equation. Then, a 3D model is built to simultaneously calculate the permeability (by solving the Navier-Stokes equation in the fracture and the Darcy flow in the porous matrix) and the normal stiffness (by imposing a stress perturbation on the top of the whole block) of a rough fracture during mechanical fracture closure and mineral precipitation. Finally, a numerical model based on the coupled finite element and cohesive zone method is developed to simulate the hydraulic stimulation process (including hydraulic fracturing and hydraulic shear) around the injection well.

Monica Aquino-Guerra, 2019-09/2022 « Joint inversion of passive geophysical data »

Abstract

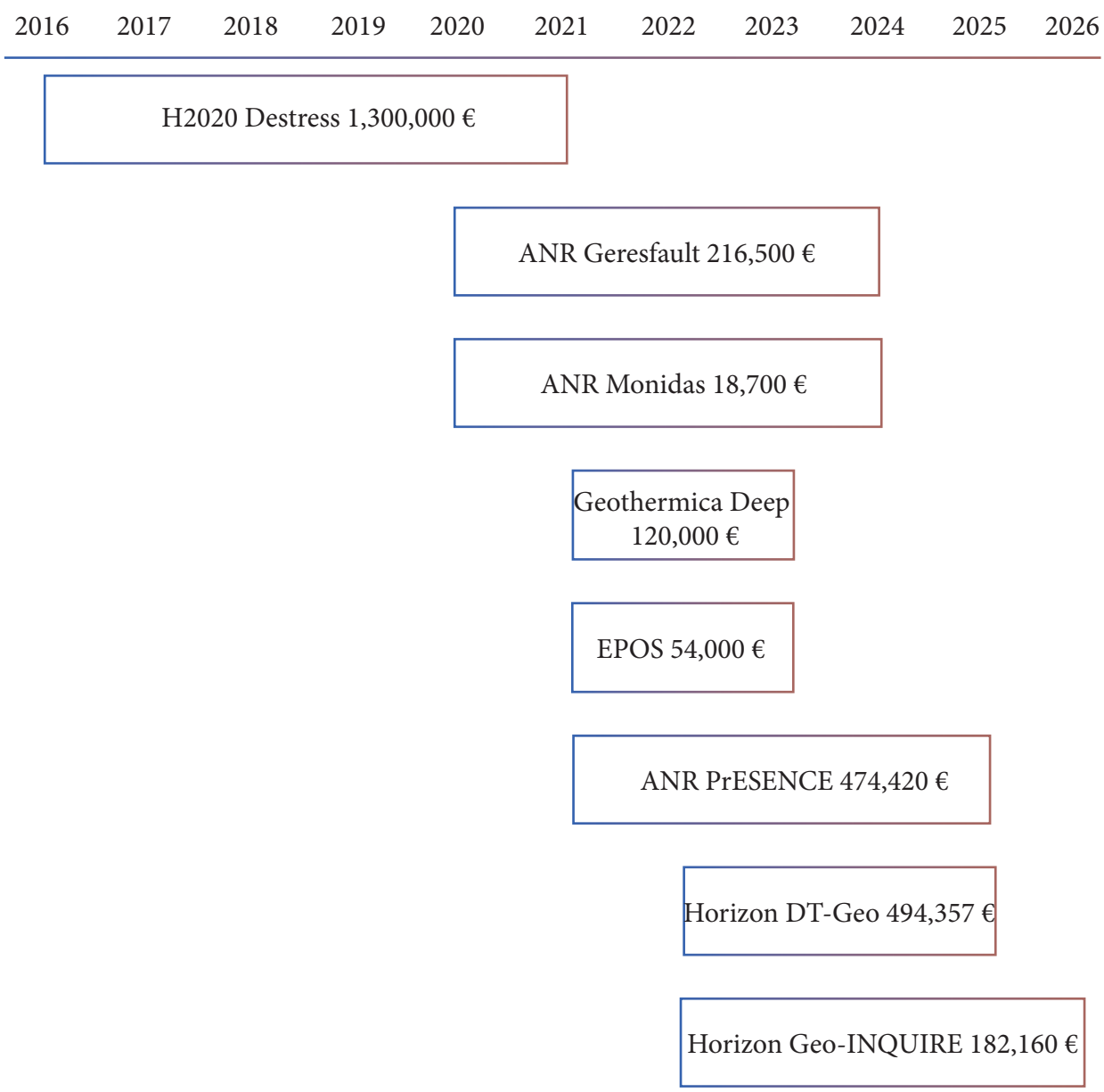
In this thesis, I present a joint inversion framework between surface wave dispersion curves recovered from ambient seismic noise correlations and magnetotelluric data to image shear rate and resistivity with depth, adding correspondence maps (CMs) to find a possible relationship between these physical properties. Initially tested on synthetic 1D models, the method is stable and leads to a reduction in the space of models that satisfy all the data sets simultaneously. A study of the sensitivity of surface waves using 2D velocity models shows the limits of their lateral resolution for small anomalies (<10km) at periods of interest (<10s) and MT data could improve matters here. Synthetic tests of 2D joint inversion using a first-order relationship show that the velocity model is significantly improved by the inclusion of magnetotellurics and the velocity-resistivity relationship is better recovered than with separate inversions. The application of the joint inversion method to field data from northern Alsace illustrates its advantages and disadvantages. For a zone with a subsurface with quasi-1D properties, the inclusion of correspondence maps in the inversion results in petrophysically and structurally more coherent models. In the case of a more complex zone, where several relationships could be observed, the CM term is not able to provide a single relationship valid for all the structurally different zones.

Financial statement

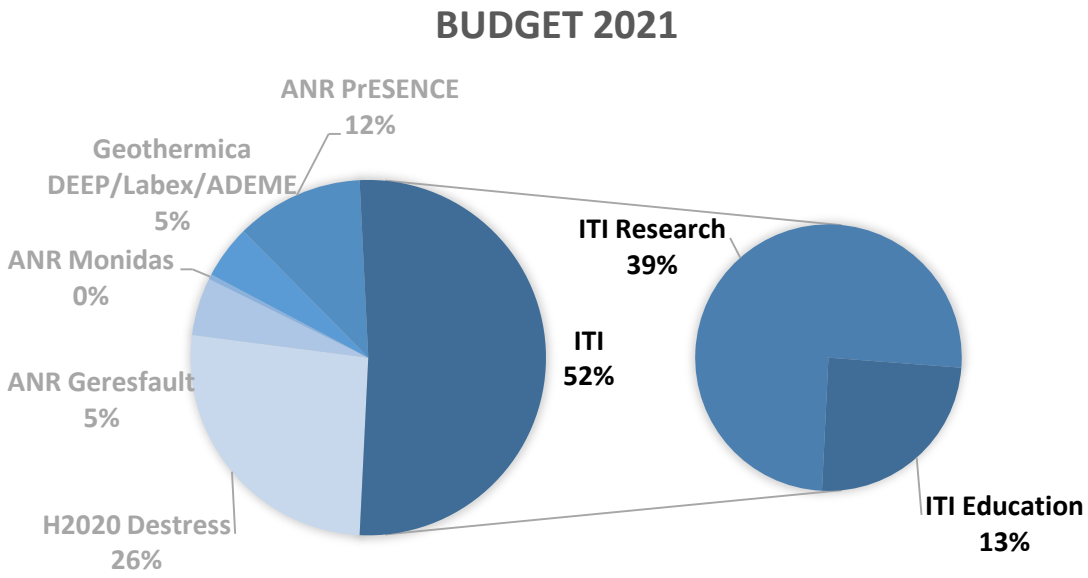
The ITI GeoT is funded over 8 years to the total amount of €2,771,200 for the research part and €903,040 for the education part. To this must be added the additional funding obtained for external projects.

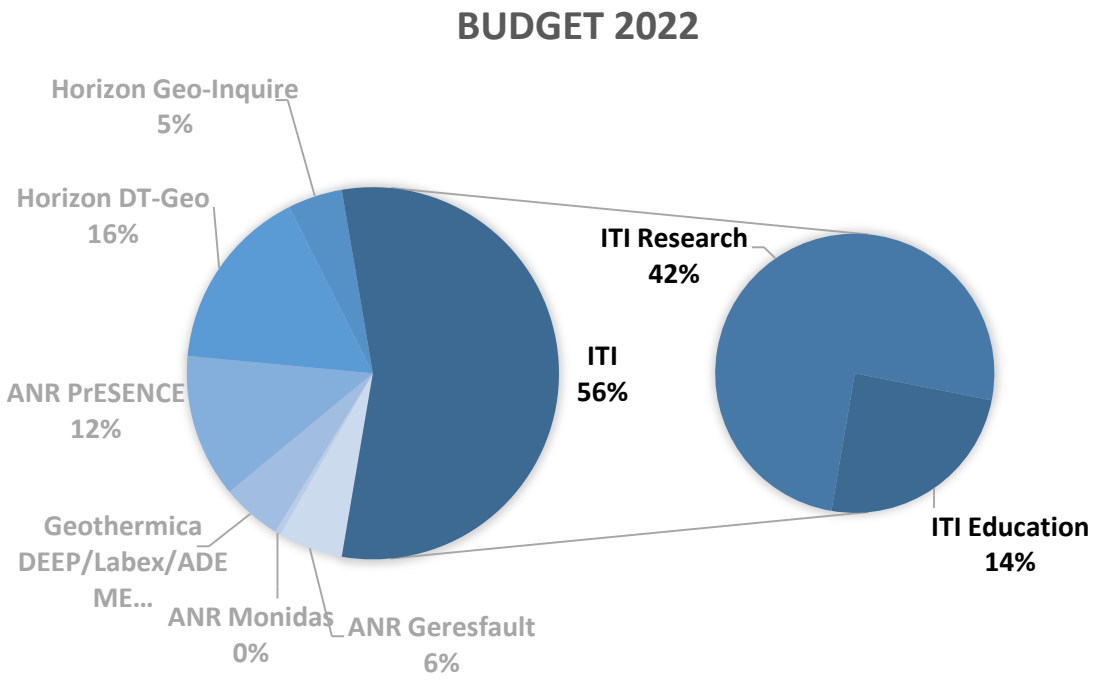
Illustrative picture @freepik.com

Income from external projects over their duration



Approximate distribution





Summary of significant events

Ilustrative picture @freepik.com

From February 2021 to May 2022. Members of the ITI participate in the committee of experts responsible for investigating the seismic events in Strasbourg (2019-2021) and the involvement of the Vendenheim geothermal site.

May 2020. The H2020 Destress project is coming to an end. The project has developed good treatment practices that will be useful in designing future regulatory frameworks for geothermal stimulation.

May 2021. Prof. Hayrullah Karabulut and the ITES | ITI GeoT have been awarded a Gutenberg Chair by the Strasbourg Eurometropole and the Grand-Est Region, which helps research units to host top-level researchers. It will be funded to the amount of €50k over 2023-2024.

October 2021. The ANR PrESENCE project is getting underway. This participatory science project, developing a network of seismo-citizens, is the result of perfect collaboration within the ITI GeoT, involving EOST, ITES and Lisec. It will be funded over the period 2021-2025 with more than €474k.

September 2022. The European Horizon Europe DT-Geo project is starting up with 19 partners. It will be funded for the ITI GeoT over the period 2022-2025 with more than €494k.

October 2022. The European Horizon Europe Geo-INQUIRE project is starting up with 52 partners. It will be funded under the ITI GeoT over the period 2022-2026 with more than €182k.

December 2022. The SismoCité participatory research project has been awarded a grant from the University of Strasbourg's "Université & Cité" Idex programme. It will receive €50k in funding over the period 2023-2024.

Testimonial

Illustrative picture @freepik.com

J. Vergne, WG1 : Seismology

The ITI GeoT makes it possible to bring together a whole group of researchers, engineers and partners around a common research theme of societal importance, both from a disciplinary point of view (the Working Groups) and in a cross-disciplinary manner. This has enabled us, for example, to develop projects at the interface between seismology and the humanities and social sciences (the PrESENCE and SismoCité projects) that would probably not have seen the light of day without the ITI. The ITI GeoT has also become a "label" that is a guarantee of a high level of scientific expertise in the field of the use of the subsoil in the energy transition. It enables the integration of large-scale projects and programmes on a national scale (e.g. PEPR Sous-sol bien commun) and on a European scale (DEEP Consortium, Horizon Europe DT Geo, etc.). The ITI GeoT also has an important role to play in training EOST students and, more broadly, tomorrow's engineers and researchers in the crucial field of subsoil use in the energy transition.

M. Heap, WG4 : Rocks physics and geomechanics

The ITI GeoT is very important for the researchers of WG4. Not only has it opened new research avenues for our laboratory, but it has also provided funding for M2 students (such as Margaux Goupil). The ITI therefore offers important research opportunities for students of the school, and beyond. For example, Margaux Goupil, thanks to the experience she gained during her M2 research internship funded by the ITI, has just been offered a job.

D. Lemarchand, WG5 : Hydro-geochemistry

ITI GeoT brings the possibility to develop research on topics related to the energy transition such as geothermal. In particular, the projects of WG5 (precipitation of Si and natural hydrogen) are innovative and with strong application on the field.

G. Manatschal, WG6 : Geology

The ITI GeoT creates the framework for synergistic work on subjects for which the earth sciences are essential. There is a good balance between fundamental and applied sciences. It is also helping to resolve fundamental questions that are important for the energy transition.

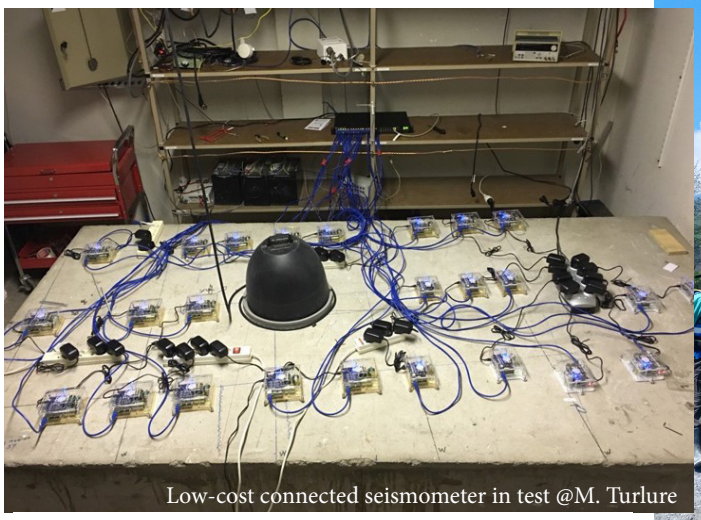
Perspectives

Research

An important prospect for ITI GeoT is the coordination of the "Rhine Graben" project (FP9) of the national exploratory programme PEPR (Programme et Equipement Prioritaires de Recherche) "Sous-sol, bien commun" in collaboration with BRGM. This is a unique opportunity to develop the ITI GeoT's research activity by initiating multiple national collaborations with numerous teams and to promote the programme's activity while obtaining new co-funding to stimulate fundamental research on deep geothermal energy and the associated exploitation of related resources such as lithium or hydrogen.

Education

Our ambition is to create an international training programme recognised by academic and industrial professionals. The GeoT programme will open in 2023 in M1 and M2. We hope to welcome a large number of students to whom we will be able to offer interesting internships and subsequent thesis projects. In addition, the ITI GeoT has voted to fully fund two PhD grants in response to the 2022 call for projects for 2023.



Low-cost connected seismometer in test @M. Turlure

Student field trip @G. Manatschal

Illustration for observatory @J. Simon

Geosciences for the energy system transition | GeoT

The **interdisciplinary thematic** institutes of the University of Strasbourg & CNRS & Inserm

Location

Ecole et observatoire des sciences de la Terre | EOST
5, rue René Descartes
67084 Strasbourg

Contact

iti-geot-contact@eost.unistra.fr
geot.unistra.fr
@Itigeot -