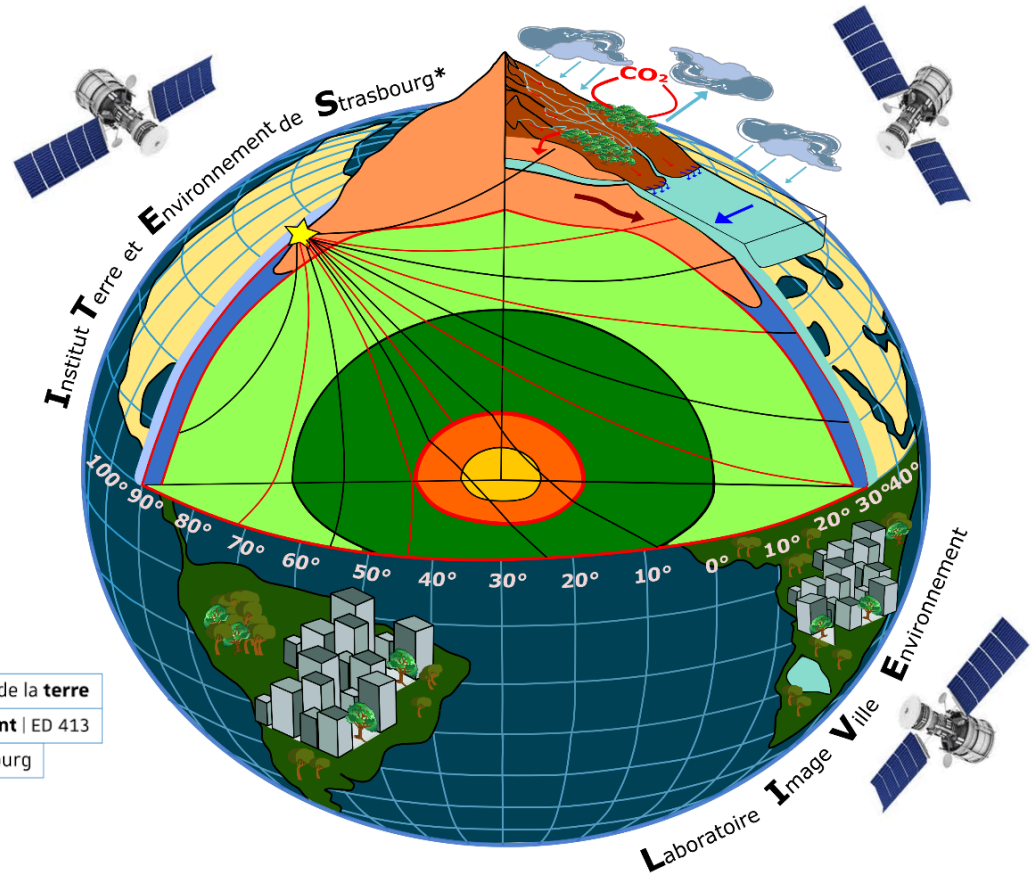
Institut Terre & Environnement de Strasbourg | ITES | UMR 7063 de l'Université de Strasbourg & cnrs & ENGEES

Laboratoire image, ville, environnement | LIVE de l'Université de Strasbourg de l'ENGEES et du cnrs

PhD Congress of ED413

L'Ecole Doctorale: Sciences de la Terre et de l'Environnement



École doctorale Sciences de la terre et de l'environnement | ED 413 Université de Strasbourg

Wednesday, March 20th, 2024

CDE, 46 Bd de La Victoire

KEYNOTE SPEAKER

Sophie GIFFARD-ROISIN

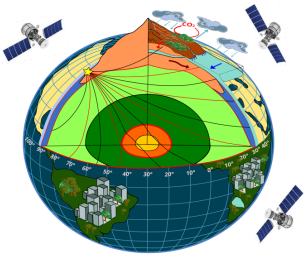
ISTerre Laboratory, Grenoble

IRD Researcher

"AI in Geoscience: Opportunities, Challenges and Limitations"

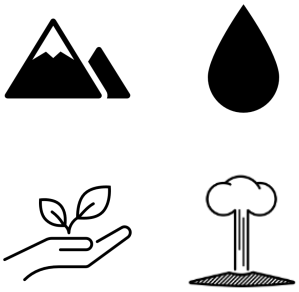
For all the additional information:
(scan the QR code)
http://eost.u-strasbg.fr/stue/
or contact us via e-mail:
congressdesdoctorantsed413@gmail.com

The congress in 5 points



A talk session and a poster session on the 20th of March 2024 with a total of **17 presentations**!

The perfect occasion to meet new people, share sciences and win the best oral and poster prize!



4 topics:

- Rock mechanics
- AI in Geoscience
- Sedimentology and Hydrosystems
- Clustering and Seismology

A **KeyNote** from ISTerre, Mrs **Sophie GIFFARD-ROISIN**, will do a presentation “AI in Geoscience: Opportunities, Challenges and Limitations ”

For any questions do not hesitate to contact us at congresdesdoctorantsed413@gmail.com. You also will find a lot of information on the congress **website**.

Schedule of the day

Appointment at 8:50 a.m. at the room “Amphithéâtre” of the **Collège Doctoral Européen (CDE)** **(**46 Boulevard de la Victoire, 67000 STRASBOURG)

Keynote

We are very honored to receive **Mme Sophie GIFFARD-ROISIN**, researcher at the ISTerre (Institut des Sciences de la Terre), in Grenoble

10:45 a.m. to 11:30 a.m.	Mme Sophie GIFFARD-ROISIN
“AI in Geoscience: Opportunities, Challenges and Limitations”	ISTerre

Oral presentations

The oral presentations are divided in **4 sessions**:

- Rock mechanics
- AI in Geoscience
- Sedimentology and Hydrosystems
- Clustering and Seismology

For more information, please find the detailed program in the next pages and the abstracts in the website http://eost.u-strasbg.fr/stue/prog.html

Poster Session

At lunch time, poster editors will be present to discuss their research project !
This session will be held from **12:15 p.m to 14:00 p.m** in the Patio space (1st floor) of the Collège Doctoral Européen (CDE) **(**46 Boulevard de la Victoire, 67000 STRASBOURG) . For more informations, please find the abstracts in the website http://eost.u-strasbg.fr/stue/prog.html

Prize for the best poster and the best presentation

After the presentations, we will count the votes for the best poster and the best presentation and give the prizes to the winners

After conference drinks and foods

Please join us at the **EOST/ITES 4th floor cafeteria** for a convivial moment. (5 rue Descartes, 67000 Strasbourg).

Session I. Rock mechanics

(from 09:00 a.m. to 10:15 a.m.)

09:00 to 09:15 a.m.	Agata POGANJ (ITES)
Alteration and strength heterogeneity distribution of the volcanic dome at La Soufrière de Guadeloupe (Eastern Caribbean)	

09:15 to 09:30 a.m.	Lingai GUO (ITES)
An efficient Crouzeix-Raviart finite element model for coupled hydro-mechanical processes in variability saturated porous media	

09:30 to 09:45 a.m.	Rashad ABBASOV (ITES)
Uncertainty analysis for rainfall-induced landslide models	

09:45 to 10:00 a.m.	Ali MOHAND-SAÏD (ITES)
Joint Inversion of electromagnetic and electrical data	

10:00 to 10:15 a.m.	Émile SERRA (ITES)
Vp/Vs tomography in South-East Asia using SOLA-Backus-Gilbert inversion	

Take a break (coffee, tea, pastries)
from 10:15 to 10:40 a.m.

Doctoral School Director speech. M Damien LEMARCHAND

(from 10:40 to 10:45 a.m.)

Session II. AI in Geoscience

(from 10:45 to 11: 30 a.m.)

Keynote. Mme Sophie GIFFARD-ROISIN

(from 10:45 a.m. to 11:30 a.m.)

10:45 a.m. to 11:30 a.m.	**Mme Sophie GIFFARD-ROISIN**
"AI in Geoscience: Opportunities, Challenges and Limitations"	

11:30 to 11:45 a.m.	Joachim RIMPOT (ITES)
Self-Supervised Learning Strategies for Clustering Continuous Seismic Data	

11:45 a.m. to 12:00 p.m.	Charlotte GROULT (ITES)
Toward exhaustive instrumental catalogs from massive seismological data and machine learning : application to the European Alps	

12:00 to 12:15 p.m.	Camille HUYNH
A complete feature set for classification of seismic sources with Distributed Acoustic Sensing (DAS) in the context of long-range monitoring	

Lunch time and poster session

(from 12:15 to 14:00 p.m.)

Join us for a snack prepared by our caterer and take the opportunity to discuss and meet the PhD students and supervisors. **Poster editors will present their work**. You can ask questions and **vote for the best posters**.

Session III. Sedimentology and Hydrosystems

(from 14:00 to 15:15 p.m.)

14:00 to 14:15 p.m.	Joé JUNCKER (LIVE)
The Po river-mouth in the 1st millennium BCE: comparative reconstruction of morpho-sedimentary dynamics with archaeological and historical chronologies (Emilia-Romagna, Italy)	

14:15 to 14:30 p.m.	Xiaowei LIU (LIVE)
Low Flow Comparison from 1956 to 2022 in the transboundary River Lauter and an Adjacent Station on the River Rhine (France/Germany)	

14:30 to 14:45 p.m.	Kari-Anne VAN DER ZON (LIVE)
Macrophyte metacommunities in man-made pond networks	

14:45 to 15:00 p.m.	Lucas MEDEIROS BOFILL (ITES)
Sedimentological control on permeability heterogeneity, and its effects in fluid-flow modelling: a case study of the Middle Buntsandstein sandstones (Upper Rhine Graben, Eastern France)	

15:00 to 15:15 p.m.	Bastien MATHIEUX (ITES)
Unravelling the drainage divide migration of a mid-altitude mountain range in a low-deformation context: Integrating morphometry and cosmogenic nuclides in the Vosges Mountains (NE France)	

Take a break (coffee, tea, pastries) from 15:15 to 16:00 p.m.

Session IV. Clustering and Seismology
(from 16:00 to 16:45 p.m.)

16:00 to 16:15 p.m.	Hamza KRISTOU (ITES)
Active deformation in Tunisia from GNSS measurements	

16:15 to 16:30 p.m.	Rachit GAUTAM
Generation of High-Resolution Seismic Catalog Associated With the Production Phase 2021 - 2022 at the Balmatt Geothermal Site	

16:30 to 16:45 p.m.	Houssam OUSMAN
Multidisciplinary approach (geology, satellite imaging, geophysics) to evaluate the geothermal potential of the Alols Lakes region, Republic of Djibouti	

Prize for the best poster and the best presentation

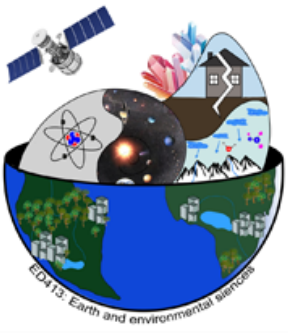
(from 16:45 to 17:15 p.m.)

We will count the votes for the best poster and the best presentation and give the prizes to the winners

After conference drinks and foods

(from 17:30 p.m. to 20:00 p.m.)

Please join us at the **EOST/ITES 4th floor cafeteria** for a convivial moment. (5 rue Descartes, 67000 STRASBOURG).



CONGRÈS DES DOCTORANTS 2024

Alteration and strength heterogeneity distribution of the volcanic dome at La Soufrière de Guadeloupe (Eastern Caribbean)

Agata Poganj[1], M. J. Heap[1,2], P. Baud[1]

[1] *Université de Strasbourg, CNRS, Institut Terre et Environnement de Strasbourg, UMR 7063, 5 rue René Descartes, Strasbourg 67084, France*
[2] *Institut Universitaire de France (IUF), 1 rue Descartes, Paris 75231, France*

Hydrothermal alteration, which alters the chemical composition of volcanic rocks, can weaken the volcanic edifice, potentially leading to instability and collapse, thereby endangering the livelihoods of neighbouring residents. Instability scenarios can be modelled using large-scale numerical models, which depend on acquiring physical and mechanical properties of volcanic rocks from laboratory measurements. Routinely, laboratory studies provide measurements of small sample suites where we miss to understand the range of rock properties that keenly describe modelling parameters, here we introduce a method that can potentially help us grasp how to pick these parameters more carefully.

The fieldwork comprised of collecting nearly 550 volcanic rocks from seven sampling locations at La Soufrière de Guadeloupe in the Eastern Caribbean. The rocks were assigned an alteration grade index, from 1 (least altered) to 5 (most altered). We measured bulk density, that ranges from less than 1000 to 2700 kg/m^3, and strength, using point load tester (PLT), values spanning from 0.012 to 11.3 MPa, emphasising the large heterogeneity of the dome. In the laboratory, we used small samples of the tested rock for porosity measurements that ranged from 0.02 to 0.8 exhibiting a strong correlation with the field bulk density measurements. Moreover, we measured uniaxial compressive strength (UCS) of 69 rocks, strengths ranging from 1.2 to 181.9 MPa. We found that decrease in strength is correlated to increase in porosity, as well as alteration being more progressive in weaker rocks.

The point load test is a field method that can simplify the logistic problems behind strength assessment of the volcanic domes, and likewise enlarge the sampling suite of individual studies. Calibrating field results to uniaxial compressive strength laboratory data could allow our data to be used in volcano stability models and accommodate direct conversion, from point load values to uniaxial compressive strength values, on-site. The potential abundance of available data, and spatial strength and alteration distributions can make the large-scale models more realistic, and consequently more accurate and reliable.

Keywords: Hydrothermal alteration, Volcanic rocks, Point Load Tester, Strength

AN EFFICIENT CROUZEIX-RAVIART FINITE ELEMENT MODEL FOR COUPLED HYDRO-MECHANICAL PROCESSES IN VARIABLY SATURATED POROUS MEDIA

L. Guo[a,b], A. Younes[a], M. Fahs[a], H. Hoteit[b]

[a] *Institut Terre et Environnement de Strasbourg, Université de Strasbourg, CNRS, ENGEES, Strasbourg, France.*
[b] *Physical Science and Engineering Division, King Abdullah University of Science and Technology, Thuwal, Saudi Arabia*

In this paper, we consider coupled hydro-mechanical processes in variably saturated porous media governed by the coupled nonlinear partial differential equations:

- Fluid mass conservation equation

$$\left[S_w S_s + c(h)\right]\frac{\partial H}{\partial t} + \alpha S_w \frac{\partial}{\partial t}\left(\nabla . \boldsymbol{u}\right) + \nabla \cdot \boldsymbol{q} = q_s \tag{1}$$

- Darcy's law

$$\boldsymbol{q} = -k_r \boldsymbol{K} \nabla H \tag{2}$$

- Equilibrium equation

$$\nabla . \left(\boldsymbol{\sigma}_e - \alpha \chi P \boldsymbol{I}\right) + \rho_b g \nabla z = 0 \tag{3}$$

- Generalized Hooke's law

$$\boldsymbol{\sigma}_e = \mu\left(\nabla \boldsymbol{u} + \left(\nabla \boldsymbol{u}\right)^t\right) + \lambda\left(\nabla . \boldsymbol{u}\right)\boldsymbol{I} \tag{4}$$

- Van Genuchten (1980) water content - pressure head relationship

$$S_e = \frac{\theta(h) - \theta_r}{\theta_s - \theta_r} = \begin{cases} \dfrac{1}{\left(1 + \left|\alpha_v h\right|^{n_v}\right)^{m_v}} & h < 0 \\ 1 & h \geq 0 \end{cases} \tag{5}$$

- Mualem (1976) conductivity-saturation relationship

$$k_r = S_e^{1/2}\left[1 - \left(1 - S_e^{1/m_v}\right)^{m_v}\right]^2 \tag{6}$$

with $S_w = \theta/\theta_s$ the saturation [-], θ the current water content [L^3L^{-3}], θ_s the saturated water content [L^3L^{-3}], S_e [-] the effective saturation, θ_r the residual water content [L^3L^{-3}], S_s the specific mass storativity related to head changes [L^{-1}], $H = h + z$ the hydraulic head [L], $h = \dfrac{P}{\rho_w g}$ the pressure head, P the pressure [Pa], ρ_w the fluid density [ML^{-3}], g the

gravity acceleration [LT^{-2}], z the upward vertical coordinate [L], $c(h) = \partial\theta/\partial h$ the specific moisture capacity [L^{-1}], $\boldsymbol{q}$ the Darcy velocity [LT^{-1}], q_s the sink term [T^{-1}], $\boldsymbol{K} = \frac{\rho_w g}{\mu_w}\boldsymbol{k}$ the hydraulic conductivity [LT^{-1}], $\boldsymbol{k}$ the permeability tensor [L^2], μ_w the fluid dynamic viscosity [ML^{-1}T^{-1}], k_r the relative conductivity [-], α_v [L^{-l}] and n_v [-] the van Genuchten parameters, $m_v = 1 - 1/n_v$, α the Biot coefficient, $\rho_b = \rho_s(1-\theta_s) + \theta\rho_w$ the bulk density, ρ_s the density of the solid [ML^{-3}], $\boldsymbol{\sigma}_e$ the effective stress tensor, χ the Bishop's function typically set equal to S_w, $\boldsymbol{u}$ the displacement field [L], λ and μ the Lamé coefficients.

Several challenges emerge from the nonlinear character and the high coupling between the equations when solving the system (1)-(6). In this work, the equations are solved simultaneously using the method of lines (MOL) which avoids operator-splitting errors. The MOL is an efficient procedure for solving highly nonlinear systems of equations (Miller *et al*., 2006). With MOL, all the spatial derivatives are discretized while the time derivatives are kept in their continuous form.

For practical reasons, related to the computational burden of the system (1)-(6), the spatial discretization is often limited to low-order approximation methods, such as standard Galerkin Finite Elements (GFE). However, the standard GFE method can produce unstable and oscillatory pressure results, which is known as locking.

In this work, we use the low-order Crouzeix-Raviart (CR) finite elements for both the hydraulic head of the fluid phase and the displacement of the solid phase. The CR method uses P1 linear test functions with the degrees of freedom allocated to center of the edges, rather than to the vertices. Contrarily to the standard GFEs, the CR method is locally conservative. Further, using the connection between the Discontinuous Galerkin method and the CR method, Hansbo and Larson (2003) developed a locking-free CR formulation for elasticity. This formulation is employed here for poroelasticity in unsaturated porous media.

For the fluid flow, the nonlinear Richard's equation is also discretized in space using the CR method which is equivalent to the Lumped Raviart-Thomas Mixed Finite Element Method developed in Younes et al. (2006). The time discretization of the obtained system is performed using high-order integration methods and an efficient adaptive time stepping scheme with the DASPK time solver.

Numerical results in saturated and unsaturated conditions are presented to validate the new model and to show the effectiveness of the model to overcome nonphysical pressure oscillations.

Keywords: Poroelasticity, Biot model, Unsaturated porous media, Richards equation, Nonconforming Finite Elements

References

[1] Miller, Cass T., Abhishek, C., Farthing, M.W. A Spatially and Temporally Adaptive Solution of Richards' Equation. Advances in Water Resources., 29, no. 4: 525–45 (2006).

[2] Hansbo, P., Larson, M.G. Discontinuous Galerkin and the Crouzeix–Raviart element: Application to elasticity. ESAIM Math. Model. Numer. Anal., 37 (1), pp. 63-72 (2003)

[3] Younes, A., Ackerer, P., Lehmann, F. A new mass lumping scheme for the mixed hybrid finite element method. Int. J. Num. Meth. Eng., 67, 89-107 (2006).

Uncertainty analysis for rainfall-induced landslide models

Rashad Abbasov[1], Marwan Fahs[1], Anis Younes[1], Hossein Nowamooz[2], Knut Jørgen Måløy[3], Renaud Toussaint[1,3]

[1]*Université de Strasbourg, CNRS, ENGEES, Institut Terre et Environnement de Strasbourg UMR 7063, F-67000 Strasbourg, France*

[2]*ICUBE, UMR 7357, CNRS, INSA de Strasbourg, 24 boulevard de la Victoire, 67084 Strasbourg, France*

[3]*PoreLab, The Njord Centre, Department of Physics, University of Oslo, Oslo, Norway.*

Intensive rainfall events are one of the crucial factors in slope destabilization. Hydromechanical modeling with slope stability indicators is an efficient tool to predict the risk of landslides. Input parameters of these models are prone to uncertainty due to imperfect knowledge of system conditions and inaccurate calibration with insufficient data during measurements. These uncertainties can propagate through the model and affect the model predictions. The uncertain model outputs can lead to unreliable warning information. The main objective of the work is to investigate how uncertainty propagates through the model and how we can quantify uncertainties of the outputs.

Implementing the screening technique in the initial stage aims to eliminate the insignificant input parameters. Screening technique helps to reduce CPU time and deal with the high dimensionality challenge. Then, the Polynomial Chaos Expansion surrogate modeling strategy is used to replace time-consuming simulations. This surrogate modeling technique allows forward estimation of Sobol indices. These indices are used as a sensitivity metric to rank the parameters by order of importance.

In the last stage, we utilize the verified surrogate modeling technique to quantify uncertainties in the model outputs. Uncertainty quantification analysis is performed via stochastic simulations. We use the remaining significant parameters as input parameters, selecting the area of the failure-prone zone as a relevant metric. Selecting parameters randomly with a 10% uncertainty across their range of variability results in an approximate 20% probability of inaccurate prediction regarding landslide occurrence.

The proposed strategy for uncertainty propagation and quantification analysis is generic. Its effectiveness extends to future applications, particularly in predicting and assessing the potential risk of landslides.

Keywords: Rainfall-induced landslide models; slope stability; Local factor of safety; uncertainty quantification analysis

Joint Inversion of electromagnetic and electrical data

A. Mohand-Said[1], G. Marquis[1], JF. Girard[1]

[1] *ITES, Université de Strasbourg, 5 rue René Descartes, Strasbourg France*

The Athabasca Basin is a world-class uranium mining province with several high-grade and high-tonnage deposits. The development of mineralization is driven by hydrothermal fluid flow, at the unconformity between basin sediments and basement's metamorphic and magmatic rocks. This massive fluid flow is channelized by crustal faults in which graphite later precipitated. Graphite-bearing faults are highly conductive, and their host-rock is resistive, thus they are a good target for electromagnetic (EM) inductive methods. Fluid flow also led to the alteration of basin and basement rocks modifying their petrophysical properties, including resistivity. The resistivity contrast between fresh and altered rocks is recorded in the signal of galvanic direct-current (DC) resistivity methods.

Exploration of Uranium deposits in the Athabasca Basin therefore relies on localizing graphitic conductors and alteration halos, as they are closely related to mineralization, using EM and DC methods.

We are working on the development of a methodology for joint inversion of EM and DC data. We are aiming for a resistivity model reproducing the measurements obtained in the field with both methods. Inversion of EM data alone succeeds in identifying the location of graphitic conductors, while inversion of DC data alone is not able to recover information of resistivity contrasts close to the unconformity. Indeed, the signature of the graphitic conductors overprints the signal from alteration. Joint inversion should allow to get benefits from the specific sensitivities of each method to obtain resistivity models with constrained extensions of graphitic conductor allowing to identify contrasts related to alteration halos.

Keywords: Inversion, Athabasca, Electromagnetic, Electrical, Uranium

Vp/Vs tomography in South-East Asia using SOLA-Backus-Gilbert inversion

E. Serra[1], C. Zaroli[1], S. Lambotte[1], P. Koelemeijer[2,3]

[1] *Institut Terre et Environnement de Strasbourg, Université de Strasbourg, France*
[2] *Department of Earth Sciences, University of Oxford, Oxford, UK*
[3] *Department of Earth Sciences, Royal Holloway University of London, Egham, UK*

The ratio of seismic velocity variations (R=dlnVs/dlnVp) is an important physical parameter to study the thermochemical properties of the subsurface. When obtained through the division of two independent models of Vs and Vp variation, a few issues emerge. Firstly, the two models must share the same local resolution. Secondly, the division itself must be possible. For a given location in our tomography models, the division involves 4 parameters: dlnVs, dlnVp and their uncertainties (if assumed gaussian). However, the probability function describing the division of these two Gaussian distributions, the Hinkley distribution, does not necessarily resemble a Gaussian distribution itself and it is likely very different compared to the direct division of dlnVs and dlnVp.

Thanks to a SOLA-Backus-Gilbert inversion approach, performed in the South-East Asia region, we are able to develop models of dlnVs and dlnVp with similar local resolution. We propose a method to use the Hinkley distribution to determine better estimates of the R value, bonded with a "quality parameter" that indicates the confidence of the dlnVs/dlnVp value. Thanks to the Hinkley function, we are also able to obtain an estimate of the uncertainty on the dlnVs/dlnVp division. In a similar way, we also investigate the dlnVp/dlnVs (1/R) ratio. We show that, in most cases, either R or 1/R is relevant (i.e. Gaussian). Thus, the two ratios are complementary, and worth being both considered in physical interpretations. In conclusion, with the SOLA-Backus-Gilbert approach, we are able to generate four models (dlnVp, dlnVs, dlnVs/dlnVp and dlnVp/dlnVs), with their respective uncertainties, each having similar local resolutions.

Keywords: Velocity ratio, Uncertainties, Resolutions, Hinkley probability function

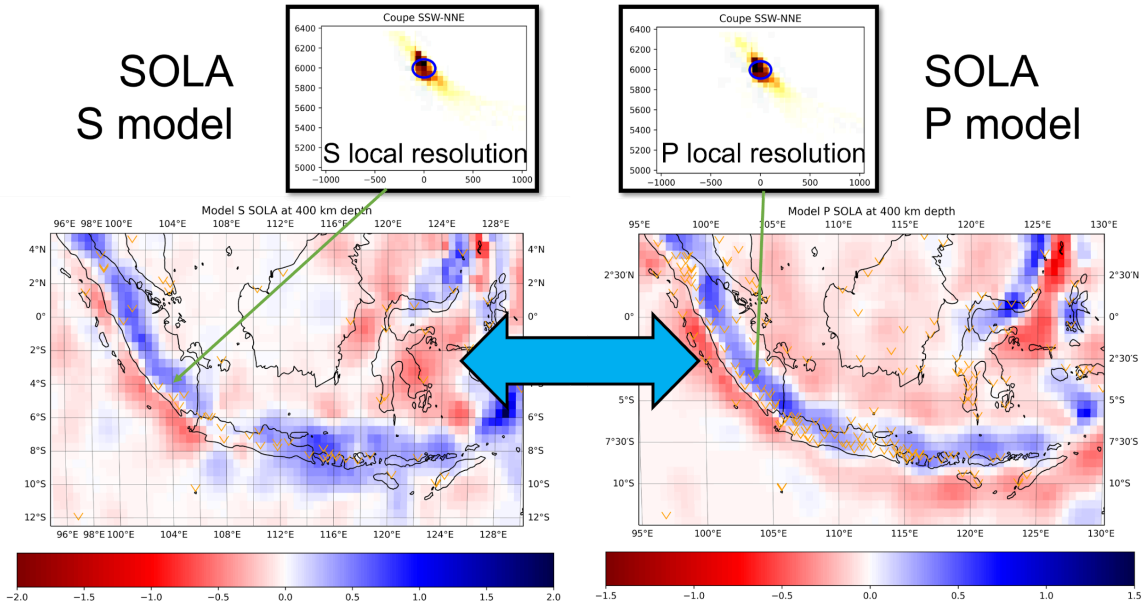


Figure: dlnVp (right) and dlnVs (left) tomography of the South-East Asia using SOLA. In the top, the local resolutions of the dlnVp and dlnVs of the cell shown with the arrow. The goal is to get the R(=dlnVs/dlnVp) ratio of the cells with similar local resolutions
(E. Serra, 2024)

Self-Supervised Learning Strategies for Clustering Continuous Seismic Data

J. Rimpot[1], C. Hibert[1,2], J.-P. Malet[1,2], G. Forestier[3], J. Weber[3]

[1] *Institut Terre et Environnement de Strasbourg, CNRS UMR 7063, Université de Strasbourg – 5 Rue René Descartes, 67084 Strasbourg*
[2] *Ecole et Observatoire des Sciences de la Terre, CNRS UAR 830, Université de Strasbourg – 5 Rue René Descartes, 67084 Strasbourg*
[3] *Institut de Recherche en Informatique, Mathématiques, Automatique et Signal, UR 7499, Université de Haute-Alsace – 12 rue des Frères Lumière, 68093 Mulhouse Cedex*

Continuous seismological datasets offer insights for the understanding of the dynamics of many geological structures (such as landslides, ice glaciers, and volcanoes) in relation to various forcings (meteorological, climatic, tectonic, anthropic) factors. Recently, the emergence of dense seismic station networks has provided opportunities to document these phenomena, but also introduced challenges for seismologists due to the vast amount of data generated, requiring more sophisticated and automated data analysis techniques. To tackle this challenge, supervised machine learning demonstrates promising performance; however, it necessitates the creation of training catalogs, a process that is both time-consuming and subject to biases, including pre-detection of events and subjectivity in labeling. To address these biases, manage large data volumes and discover hidden signals in the datasets, we introduce a Self-Supervised Learning (SSL) approach for the unsupervised clustering of continuous seismic data. The method uses siamese deep neural networks to learn from the initial data. The SSL model works by increasing the similarity between pairs of images corresponding to several representations (seismic traces, spectrograms) of the seismic data. The images are positioned in a 512-dimensional space where possible similar events are grouped together. We then identify groups of events using clustering algorithms, either centroid-based or density-based.

The processing technique is applied to two dense arrays of continuous seismological datasets acquired at the Marie-sur-Tinée landslide and the Pas-de-Chauvet rock glacier, both located in the South French Alps. Both datasets include over a month of continuous data from more than 50 stations. The processing technique is then applied to the continuous data streams from either a single station or from the whole station network. The clustering products show a high number of distinct clusters that could potentially be considered as produced by different types of sources. This includes the anticipated main types of seismicity observed in these contexts: earthquakes, rockfalls, natural and anthropogenic noises as well as potentially yet unknown sources. Our SSL-based clustering approach streamlines the exploration of large datasets, allowing more time for detailed analysis of the mechanisms and processes active in these geological structures.

Keywords: Environmental Seismology, Clustering, Self-Supervised Learning, Deep Learning, Landslide, Glacier

Toward exhaustive instrumental catalogs from massive seismological data and machine learning : application to the European Alps

C. Groult[1], C. Hibert[1], J.P. Malet[1], F. Provost[1]

[1] Ecole et Observatoire des Sciences de la Terre/Institut Terre et Environnement de Strasbourg, CNRS, EOST, 5 rue Descartes, F-67084 Strasbourg

---

Recent large landslides in many parts of the World (Nuugaatsiaq, Greenland, 2017; Culluchaca, Peru, 2021) as well as the increase in the frequency of mass movements in the European Alps (e.g. collapse of the Drus, Mont Blanc Massif, France; Piz Cengalo, Switzerland) question the effect of climate change on landslide occurrences. Seismology provides continuous recordings of landslide activity at long distances. The objective of this work is to present a method to identify and construct instrumental landslide catalogs from massive seismological data. The method will be developed and applied for the period 2000-2022 at the scale of the European Alps (~ 900 x 300 km). This new type of instrumental landslide catalog provides an unprecedented spatio-temporal resolution over a long time period allowing to explore possible correlations between landslide activity and forcing factors (meteorology, tectonic).

The detection method applied to the seismological observations consists of computing the energy of the signal between 2 and 10 Hz on which the short term average over the long term average method (STA/LTA) is applied forward and backward. The detection is performed on the sum of the two STA/LTA. Then, a supervised Random Forest classifier, trained on known events, is used to identify the source of natural events recorded at regional scale (earthquakes/landslides). To reject noise detections, a post-processing chain is implemented based on signal-to-noise ratio, number and spatial distribution of stations involved in the detection and the probability scores given by the Random Forest. To localize all events, we compute travel times from seismological stations to all points of the area with a fast marching method and we perform the inversion with the NonLinLoc software.

First application on continuous data on 2017 and on the whole network containing 336 seismic stations allowed finding 40 new landslides including 10 over 11 reference events. The model is retrained with these events and applied on year 2018. From this processing chain, a catalog with 100 possible new landslides has been compiled. The derived instrumental catalog will be presented.

Keywords: environmental seismology, landslides, machine learning

The Po river-mouth in the 1st millennium BCE: comparative reconstruction of morpho-sedimentary dynamics with archaeological and historical chronologies

Joé Juncker[1]

[1]*Laboratoire Image Ville Environnement*

During the first millennium BCE, the main river mouth of the Po was located at the central part of the delta in the area of Comacchio (Province of Ferrara). The river mouth formed a wave-built delta with several beach-ridges well fossilised and visible on aerial photographs. The fortuitous discovery of the Etruscan site of Spina in the first part of the 20th century raises many questions about resilience in a context of high environmental mobility. This geomorphological configuration makes it a privileged commercial hub with the connection between the Mediterranean basin, the Po Valley and the mountains (Alps and Apennines). For several decades, the issue of proximity to the river and the coast has been central to understanding its commercial dynamism but also the risks that may lead to the decline of this short-lived city (6th-3rd century BCE). This ancient deltaic lobe has been little explored regarding the Late Holocene and offers limited dates except for major trends obtained by interpolation. The chronology of the local succession of the ancient coastline transmitted by the literature is based on tangible archaeological evidence providing a coastline in the archaeological sense and a *terminus ante quem*. However, geochronological tools have never been used to date these deposits. A French-Italian core drilling campaign was conducted as part of a project called "EOS-Etruscan on the Sea" (2020-on) in 2022. This new sedimentary drilling, based on an innovative sampling strategy, will be studied by a multivariate approach combining diverse dating techniques (^{14}C, OSL, and portable OSL) with various sedimentological analyses. We propose an exploration of the complex relationship between the morphologies of the river mouth, their dynamics through time and their relationship with the city thanks to high resolution chronologies. This case study is the first proposal for a systematic approach of deltaic sediment in Mediterranean basin.

Keywords: Po delta, River mouth, Spina, Beach-ridges, Geoarchaeology

Low Flow Comparison from 1956 to 2022 in the transboundary River Lauter and an Adjacent Station on the River Rhine (France/Germany)

Xiaowei Liu [1], and Carmen de Jong [1]

[1] *CNRS UMR 7362 Laboratoire Image Ville Environnement (LIVE), Faculty of Geography and Spatial Planning, University of Strasbourg, Strasbourg 67000, France*

Climate change is increasing air temperatures and altering the precipitation regime on a global scale. Challenges arise when assessing the impacts of climate change on the local scale for water resources management proposes, especially for low mountain headwater catchments that not only serve as important water towers for local communities, but are also have distinct hydrological characteristics. Until now, no low flow or hydrological drought studies have been carried out on the Lauter River. This study is unique in that it compares the Lauter River, a transboundary Rhine tributary with a nearby station on the River Rhine just below its confluence at the French-German border. The Lauter catchment is a mostly natural, forested catchment but is strongly influenced by past and present cultural human activities. Climate change disturbances cascade through the hydrologic regime right down to the local scale. As we are expecting more low flow events, the decrease in water availability could cause conflicts between different water user groups in the Lauter catchment. However, the choice of different methods for identifying low flow periods may cause confusion for local water resources management. Using flow rate time series of the Lauter between 1956 and 2022 we compare for the first time three low flow identification methods: the variable threshold method (VT), the fixed threshold method (FT), and the Standardized Streamflow Index (SSI). Similar analyses are also applied to the adjacent Maxau station on the Rhine River for the same time period. This study aims at 1) interpreting the differences amongst the various low flow identification methods and 2) revealing the differences in low flow characteristics of the Lauter catchment compared to the Rhine River. It appears that the FT reacts faster to direct climate or anthropogenic impacts whereas VT is more sensitive to indirect factors such as decreasing subsurface flow which is typical for small headwater catchment, such as the Lauter where flow dynamics react faster to flow disturbances. Abnormal flow conditions such as very low flow during the early spring time in tributaries such as the Lauter can help predict low flow conditions of the Rhine river during the following half year. The results could facilitate in Early Warning of Hydrological Droughts and drought management for water users in the Lauter catchment.

Keywords: Low flow; Hydrological drought identification; Low mountain catchment, Rhine

Van der Zon - Macrophyte metacommunities in man-made pond networks

Abstract for ED413 Doctoral Students Congress 20 March 2024

To compensate for the loss and degradation of wetlands, and subsequent decline of wetland species, pond networks can be created. Ponds are surprisingly rich in species and host rare and protected animals and plants. Furthermore, ponds in a pond network differ from one another in the species they host and together the ponds in a network contribute to regional biodiversity.

We investigated two pond networks that were created to provide habitat for the European pond turtle, a threatened wetland species, and declining amphibians. One of the networks is located on the French-German border and the other in Lativa. Here results on the plant communities in the ponds will be presented.

Plants are of key importance for aquatic biodiversity. They maintain waterbodies in a clear state and provide food and shelter for animals that live in the water. Since they fulfil these roles that are indispensable to the good ecological status of aquatic ecosystems, it is important to understand which processes structure plant communities.

Our results show that one pond network is very rich in plant species while the other network is much poorer. There are different theoretical perspectives that could explain the structuring of communities in pond networks. Analyses showing if the same perspectives apply to the two different pond networks will be presented.

Sedimentological control on permeability heterogeneity, and its effects in fluid-flow modelling: a case study of the Middle Buntsandstein sandstones, Upper Rhine Graben, Eastern France

L. Bofill[1], G. Schäfer[1], G. Bozetti [1], M. Schuster [1], J. Ghienne [1], P. Ackerer [1], C. Scherer [2], E. Souza [3], G. Armelenti [2]

[1] *Institute Terre et Environnement de Strasbourg, Université de Strasbourg, Strasboug, 67000*
[2] *Instituto de Geociencias, Universidade Federal do Rio Grande do Sul, Porto Alegre, Brazi*
[3] *Universidade Federal do PAMPA, Caçapava do Sul, Brazil*

Sedimentary processes govern fluid-flow heterogeneities in porous media in several scales, therefore, their understanding is a common practice in the petroleum industry. However, hydrogeologists have lagged behind when it comes to discretising porous sedimentary aquifers in flow, heat and transport models. At the Upper Rhine Graben, in Eastern France, the Lower Triassic Buntsandstein Group serves as an important reservoir for groundwater and lithium-rich geothermal brines. The main objective of this study is to assess the architecture of the Lower Grès Vosgien Formation (LGV), Middle Buntsandstein, and how sedimentological processes, at different scales, generate significant permeability heterogeneities. It is implemented a high-resolution sedimentological characterisation, through vertical profile descriptions, digital outcrop model, and petrographic analysis. Subsequently, permeability measurements are coupled with sedimentological data, to identify different scales of sedimentary controls on permeability distribution. Finally, a realistic 2D hydrostratigraphic conceptual model is generated as a reference, allowing the evaluation of how different scenarios of heterogeneity simplification impact fluid-flow modelling, concerning particle residence time, macro-dispersivity, and upscaled anisotropy.

Results indicate that 93% of the LGV is composed of sandstones deposited by a braided fluvial system, with evidence suggesting that discharge variability was a main depositional controlling factor of sedimentary facies and heterogeneity distribution. The LGV stacking pattern reveals periods when fluvial processes were absent, and aeolian processes dominated sediment transport and deposition, comprising 7% of the total LGV thickness. The aeolian deposits record signs of persistent water in the system, either due to water table rise, or ephemeral floods, primarily contributing to the sedimentary facies association with the lowest permeabilities of the LGV, exceeding 3 orders of magnitude lower than the fluvial deposits. Despite representing only 7% of the LGV total thickness, the aeolian deposits exhibit lateral extensions that extrapolate outcrop scales (hundreds of metres), representing significant vertical flow baffle zones.

Fluid-flow simulations demonstrate that model simplifications, whether through assigning deterministic permeability values (mean), or stochastically distributing permeabilities, unconstrained by realistic sedimentary architectures, have a direct impact on macro-dispersivity (both vertical and horizontal), vertical mean residence time, and upscaled anisotropy results. Nevertheless, the results for horizontal mean residence time show no significant effect when simplifying the observed sandstone heterogeneities.

Keywords: Sedimentology, Permeability, Groundwater, Heterogeneity, Fluid-flow

Unravelling the drainage divide migration of a mid-altitude mountain range in a low-deformation context: Integrating morphometry and cosmogenic nuclides in the Vosges Mountains (NE France)

Bastien Mathieux[1], Jérôme van der Woerd[1], François Chabaux[1], Philippe Steer[2], Julien Carcaillet[3], Thierry Perrone[1].

[1]ITES, UMR 7063, CNRS/ENGEES, Univ. Strasbourg, 67084 Strasbourg, France, b.mathieux@unistra.fr
[2]Géosciences Rennes, UMR 6118, CNRS, Univ. Rennes, 35000 Rennes, France
[3]ISTerre, UMR 5275, CNRS/IRD/IFSTTAR, Univ. Grenoble Alpes, Univ. Savoie Mont Blanc, 38000 Grenoble, France

The Vosges massif, a mid-altitude mountain range in northeast France, stretches 250 km north of the Alps, displaying significant north-south and east-west topographic, geological, and geomorphological gradients, from Paleozoic exhumed basement culminating at 1400 m asl in the south to Mesozoic sandstone in the north, with summits ranging between 400 and 700 m asl. Its formation is linked to the Eocene-Oligocene development of the Rhine graben followed by a general flexure of the lithosphere induced by the Jura thrust in the Mio-Pliocene. The present-day slow deformation rates in the Rhine graben, coupled with the region's moderate seismicity dominated by strike-slip mechanisms, raise questions about the current driving forces behind the Vosges topographic evolution.

The evolution of drainage divides provides a window into the complex interrelations among tectonic forces, surface erosion processes and climatic influences that contribute to shaping a mountain range. Morphometric analysis reveals an instability of the Vosges' main drainage divide suggesting a migration away from the Rhine graben. In order to quantify this migration, in-situ cosmogenic nuclides (^{10}Be and ^{26}Al isotopes) have been measured in river sands collected across various segments of the divide. Cosmogenic nuclide analysis reveals a robust set of ^{10}Be/^{26}Al ratios falling within the steady-state denudation curve and an eastward trend in denudation corroborating with the morphometric gradient. The denudation rates range from 30 to 90 mm/kyr in the south and 40 to 70 mm/kyr in north, with corresponding westward migration rates of 20-70 mm/kyr and 3-30 mm/kyr, respectively. To gain further insights, we assessed the relationship between the calculated denudation rates and the hilltop curvatures derived from high-resolution (1m) DEMs. A linear relation was observed in the south, while no significant correlation was found in the north, suggesting additional complexities in controlling morphogenetic processes. This allowed us to use the hilltop curvature as a proxy for denudation rates, particularly within mono-lithologic soil-mantled basins, to get a glimpse of the southern drainage divide migration at the mountain range scale unravelling the dynamics at play in the highest relief of the Vosges Mountains.

Keywords: *Morphometric analysis, Cosmogenic nuclides, Denudation rates, Mid-altitude mountains, Drainage divide migration, Vosges*

ACTIVE DEFORMATION IN TUNISIA FROM GNSS MEASUREMENTS

H. Kristou[1,2], F. Masson[1], N. Bahrouni[3], M. Meghraoui[1], P. Ulrich[1]

[1] *ITES, University of Strasbourg and CNRS - France*
[2] *Faculty of sciences of Bizerte - Tunisia*
[3] *National Office of Mines - Tunisia*

Tunisia lies at the centre of the East-West trending convergence zone between the Nubian and Eurasian plates, at the eastern end of the large tectonic structures of the Atlas and Tell mountains and to the west of the Pelagian block and Sicily. As a result, its complex tectonics along the plate boundary show N-S to NW-SE oblique convergence expressed by E-W- to WNW-ESE-trending right-lateral strike-slip faults associated with E-W- to NE-SW-trending thrust faults that affect the Neogene and Quaternary units of the Tell and Sahara Atlas of Tunisia. Although this region is generally characterized by moderate seismicity, it is known for its historical and instrumental seismic activity that has resulted in human and materiel losses, such as in Utique 408 AD, Kairouan 859 AD, Tozer 1997 and recently in March 2018 an earthquake felt between Tunis and Bizerte and in April 2023 an earthquake felt in Metlaoui, both earthquakes registered (Mw 5).

A partnership between the National Office of Mines ONM-Tunisia and ITES-Strasbourg is being set up to develop spatial geodesy work using GNSS measurements to characterize and quantify the active deformation of Tunisia alongside previous tectonic and seismotectonic works. A network of already existing 21 GNSS stations spread over the Tunisian territory is managed by OTC (Office of topography and cadaster) so in the framework of this project 6 days/year of records from 2012 to 2019 has been purchased. To improve the resolution of the acquired data and fill the gaps between the OTC stations, a national network consisting of 24 mobile stations is set up and three campaigns of 3 days of records in 2019, 2021 and 2023 have already been carried out. Between 2022 and 2023, five more permanent stations have been installed to provide a continuous flow of data. Two target areas, Gafsa and Kairouan have been chosen to install regional networks consisting of 16 sites each around active faults. Three campaigns in 2021, 2022 and 2023 have been carried out and one more is planned in 2024 to detect the deformation in those areas.

All these data allowed the calculation of a precise velocity field of Tunisia based on GPS trends and the establishment of the strain rate distribution across continental Tunisia. These new data will be analyzed in the light of existing knowledge, in particular the recent seismotectonic and paleoseismological work carried out as part of our project.

Keywords: GNSS, Active deformation, Strain, Tectonics, Seismotectonic

Generation of High-Resolution Seismic Catalog Associated With the Production Phase 2021 - 2022 at the Balmatt Geothermal Site

R. Gautam[1,3,4], J. Kinscher[3], J. Schmittbuhl[1,2], M. Broothaers[4], Ben Laenen[4]

[1] *EOST/ITES - University of Strasbourg – 1 Cr des Cigarières, 67000 Strasbourg*
[2] *EOST/ITES - University of Strasbourg/CNRS – 1 Cr des Cigarières, 67000 Strasbourg*
[3] *INERIS – 82 Rue Sergent Blandan, 54000 Nancy*
[4] *Flemisch Institute of Technological Research (VITO) - Boeretang 200, 2400 Mo,l Belgium*

The Balmatt geothermal doublet, developed and managed by the VITO (Flemisch Institute of Technological Research), targets the fractured Lower Carboniferous Limestone reservoir in the Campine Basin at the depth of 3000 m to 4000 m. The development of the project started in 2015 and the operation began in 2018. The geothermal plant consists of two active wells, one injection well and one production well. The geothermal production had to be suspended after the occurrence of a stronger M_L 2.2 event on the 23rd of June 2019 which triggered a red alert status on the local traffic light system (TLS). Production was then resumed in April 2021, following an extension of the seismic monitoring network and an update of the TLS. Activities were suspended again in November 2022 after another strong M_L 2.1 event was induced. Thanks to the network extension, current investigations aim at understanding in detail the main structural features (active faults) and hydromechanical processes involved in the generation of such larger events which will contribute to improving seismic forecast possibilities for future monitoring operations. Here we present insights into ongoing data processing to create a high resolution unbiased (complete) seismic catalog providing the basis for future interpretation of the spatio-temporal and energetic behaviour of seismicity towards different production settings. Our current work focuses in particular on the development of an automatic detection routine based on continuous data of the deep borehole sensor (installed at the depth of 2052 m) by combining a machine learning based automatic events detection algorithm and template matching method. The events detection in the continuous data is complicated by the periodic malfunctioning of the sensor and the presence of aseismic noise which leads to the large number of false events detection. To address this issue and to minimize the number of false detections, we employ frequency and amplitude analysis of the seismic data. Afterwards, we will analyse the source attributes of the detected events which involve source mechanism inversion and source parameter determination as well as clustering analysis and constraining source location for noisy small magnitude events. Furthermore the comparison between the production data (injection pressure, temperature, volume etc.) with the results from the seismic analysis will provide us with better constrain on the hydromechanical characteristics of the reservoir and the relation between the geothermal operations and seismicity at Balmatt geothermal site.

Keywords: Deep Geothermal Energy, Geothermal Reservoir, Induced Seismicity

A COMPLETE FEATURE SET FOR CLASSIFICATION OF SEISMIC SOURCES WITH DISTRIBUTED ACOUSTIC SENSING (DAS) IN THE CONTEXT OF LONG-RANGE MONITORING

C. Huynh[1,2], C. Hibert[1,3], C. Jestin[2], J-P. Malet[1,3], V. Lanticq[2]

[1] *Institut Terre et Environnement de Strasbourg (ITES) ; CNRS UMR 7063 ; Université de Strasbourg – 5 rue René Descartes, 67084 Strasbourg*
[2] *FEBUS Optics – 2 Av. Du Président Pierre Angot, 64000 Pau*
[3] *Ecole et Observatoire des Sciences de la Terre (EOST) ; CNRS UAR 830 ; Université de Strasbourg – 5 rue René Descartes, 67084 Strasbourg*

Distributed Acoustic Sensing (DAS) exploits Rayleigh light backscattering to extract images of seismic wave propagation along a fiber optic in time and distance. The spatial distribution of virtual point sensors represents an opportunity to develop innovative methods for seismic event sources detection and identification. We develop in this study a method based on Machine Learning solutions for events classification.

This method relies on the development of features which translate the characteristics of the signals we observe into quantities that can be processed by machine learning algorithms to achieve the source classification. Three families of features investigating temporal and spatial characteristics and similarity of the signal are proposed, such as spatial and temporal analysis of the standard deviation, kurtosis or skewness of the signal or cross-correlation and dynamic time warping characterization and enables to quantify their individual contribution. Then we use a supervised machine learning model named XGBoost to perform classification based on these developed features. We tested this approach with a dataset recorded along a 91 km-long fiber optic deployed in the Pyrenees in France. The data acquisition has been achieved using a FEBUS A1-R DAS interrogator and with the support of TotalEnergies, from August 30 to September 20, 2022. During this period, 11 earthquakes and 6 quarry blasts have been recorded.

The trained model is validated using cross-validation techniques. Our Machine Learning processing chain successfully detect and classify 13 regional events from continuous background noise made by natural and anthropogenic activities. In particular, spatial features help to reduce the contribution of moving vehicles, whose presence is unavoidable along existing long-distance telecommunication fiber sections installed alongside roads. In the continuity of this study, we investigate the potential of transfer learning from geophones deployed along the studied cable to DAS data or to another fiber optic cable installed in the same area.

Keywords: Distributed Acoustic Sensing, Machine Learning, Time-series analysis, Spatial analysis, Earthquake hazards, Seismic noise

Multidisciplinary approach (geology, satellite imaging, geophysics) to evaluate the geothermal potential of the Alols Lakes region, Republic of Djibouti

H.Ousman[1,2] , C.Doubre[1], M.A.Daoud[2], F.Masson[1]

[1] *Institut Terre et Environnement Strasbourg, Université de Strasbourg, ITES/CNRS, 5 Rue René Descartes, 67000, Strasbourg, France*
[2]*Centre d'Etude et de Recherche de Djibouti, CERD, Republic of Djibouti*

The Alol basin, located in western Djibouti, is characterized by the presence of several hydrothermal manifestations along the major faults bounding the depression. So far, a few studies have been conducted on this area and a low amount of data is available to better constrain the structure and the activity of the geothermal reservoir together with the tectonic features. Following a multidisciplinary and multi-scale approach, I investigate the relationships between the tectonics and the fluid circulation at depth. The first part of the project is dedicated to study the role of this basin in the regional tectonic context, by the quantification of the Quaternary deformation using high resolution topographic data. The location and the extent of the hydrothermal sources will be precisely mapped using optical satellite images. In addition, ASTER satellite data is being used to identify and locate specific alteration mineral deposits on the surface that could be linked to local hydrothermalism.

The second part of the project focuses on the quantification of active deformation within the basin using the combination of the InSAR data resulting from the automatic processing of Sentinel-1 images realized by the FlatSIM projet (ForM@ter) and the seismic data acquired during a period of high density of stations in the region. The former data will allow the identification of the zones of active surface deformation and the estimation of the surface millimeter/centimeter displacements (transient and/or stationary slip on faults, vertical motion of the inner floor of the basin...). The latter data will be processed using Artificial Intelligence (EQtransformer) to automatically detect and localize the seismic events in the area (using additional techniques, such as double-difference locations), and eventually determine their focal mechanisms to characterize the rupture mechanisms along the faults. Finally, a local tomography will be processed to access to the crustal structure within and around the basin, and will be compared to other geophysical data (EM and MT) already acquired in this region.

Keywords: Central Afar, Remote sensing, Active deformation, Artificial intelligence, Geothermal Energy

Analyzing and Modeling the Geothermal Operations-Triggered Seismic Crisis in Strasbourg City

Arezou Dodangeh[1]; Renaud Toussaint[1,2]; Marwan Fahs[1]; Eirik Flekkøy[2]; Knut Jørgen Måløy[2]

[1]*University of Strasbourg, CNRS, ENGEES, Institut Terre et Environnement de Strasbourg UMR7063, Strasbourg, France*

[2]*SFF PoreLab, Njord, Physics Department, University of Oslo, Norway*

Geothermal energy, a renewable and green energy source, faces drawbacks, notably seismic risks, including induced and triggered seismicity during well operations.

Alsace, one of the most important regions for geothermal resources in Europe, housed the Geoven pilot plant, which was located in Vendenheim, north of Strasbourg, and aimed to exploit geothermal energy along the Robertsau fault.

In 2019–2020, two seismic clusters have been observed near the Geoven site and at the Robertsau area (5km to the south). This sparked discussions about a potential connection between the earthquakes and the plant's operations. Debates ensued between scientists and the company operating Geoven due to the considerable distance between the injection well and the southern seismic cluster.

The study aimed to assess the potential link using an approach based on coupled hydro-mechanical modeling. It consists of the following three steps:

1. Identifying fault geometry by extracting angles and tectonic stresses along major faults.
2. Modeling pressure perturbation due to water injection through a quasi-2D pressure diffusion equation with injection parameters, permeability, and porosity.
3. Evaluating fault stress and earthquake-triggering risk using the Mohr-Coulomb failure criterion and activation by fluid pore pressure rise.

The results of this analysis revealed that:

- In the northern cluster, the fault is strong and has potential to resist to high activation pressure. This is why the risk of sliding and micro-earthquake stimulation is reduced.
- Around the southern cluster, the fault is weak. Thus, a small pressure can cause slip and making it prone to triggering earthquakes with minor pressure increases.
- The fault's resistant orientation between the clusters prevents sliding despite pressure increases, maintaining a 5km earthquake-free zone.

The study concludes that the fault configuration around the southern cluster necessitates less activation pressure for sliding, making it susceptible to pressure perturbations from Geoven operations, even at a distance, potentially triggering earthquakes in that area.

Keywords: Geothermal operation, Triggered seismicity, Pore pressure, Mohr-Coulomb, Pressure diffusion equation

PARTIAL MELTING AND REFERTILIZATION AT LITHOSPHERIC BREAK-UP: INSIGHTS FROM THE DIAMANTINA ZONE (SW AUSTRALIA)

M. Ballay[1,2], M. Ulrich[1], G. Manatschal

[1] *Institut Terre et Environnement de Strasbourg – ITES/Géols- UMR 7063 CNRS*
[2] mballay@unistra.fr

How continents break, separate, and how, when, and where magma is produced during breakup is yet little understood. Studies of exhumed mantle rocks from the N-Atlantic and the fossil-Alpine Tethys ocean-continent transitions (OCT) show that partial melting, percolation and refertilization of inherited mantle are intimately related to lithospheric thinning and tectonic exhumation during final rifting. Here we present new petrological and geochemical data from mantle peridotites dredged along the Diamantina OCT (SW Australia), show modelling results of mineral-melt exchange, discuss element partitioning related to refertilization and partial melting and compare results with those described from the OCTs in the Alps.

The major and trace element concentrations of minerals composing spinel and plagioclase-lherzolites were measured by µ-XRF and LA-ICP-MS. Clinopyroxenes show two distinct populations that, consistently with those observed in the Alpine-Tethys ophiolites, are representative of two mantle domains: the inherited-subcontinental mantle, with higher content of Na_2O ; and the refertilized domain characterized by lower Na_2O content and higher equilibration temperatures (1100°C±100°C) highlighting the entrapment of melts in the plagioclase stability field (~5kbar). Interestingly, few spinels found in inclusions in large orthopyroxene-porphyroclasts in samples from the refertilized domain display the same chemical compositions as those from the inherited domain. This observation enables to establish, for the first time, a direct genetic link between inherited and refertilized domains.

Geochemical modeling and pyroxene thermo-barometry suggest that lithospheric break-up in this region is preceded by exhumation of subcontinental mantle from the spinel to the plagioclase stability field in the presence of a high geothermal gradient, similarly to the observations previously documented from the Alpine Tethys. Thus, despite of the different pre-rift evolution and inheritance, the exhumation process and related magmatic evolution may be similar at the Diamantina and Alpine Tethys margins, which is in line with the observed magma-magma poor evolution of both margins.

Keywords: Magma-poor rifted margin, Ocean-Continent transition, refertilization.

Present-day crustal deformation of the Caucasus and Northern Iran: observations from semi-automatic seismic catalog and InSAR time series

Z. Bayramov[1,2], R. Viltres[1], C. Doubre[1], A. Maggi[1], F. Masson[1], B. Zamani[1], M.P. Doin[4]

[1]*ITES Université de Strasbourg, CNRS, ITES UMR 7063, F-67084, Strasbourg, France*

[2]*French-Azerbaijani University, Baku, Azerbaijan*

[3]*Department of Earth Sciences, University of Tabriz, Tabriz, Iran*

[4]*University Grenoble Alpes, University Savoie Mont Blanc, CNRS, IRD, IFSTTAR, ISTerre, Grenoble, France*

The Caucasus and North-Western Iran lie within the central part of the Alpine-Himalayan belt, where the Arabian and Eurasian plates started colliding over 100 My ago and caused the building of mountain chains associated with complex tectonic structures. Investigations of the few publicly available seismic catalogs of the region have been insufficient to understand the seismo-tectonic behavior of the regional structures due to sparse existing seismic networks and high magnitude of completeness (M_c=2.0). Therefore, to obtain a robust and detailed picture of current deformation and dynamics of these structures we process both seismological and geodetic raw data.

On the seismological side, we built the seismic catalog using the artificial-intelligence picking algorithm (EQTransformer) for a six-month period using newly installed seismic stations in Azerbaijan (since mid-2022) where we checked each AI-detected pick to maximize accuracy of location and magnitude of seismic events. We were able to produce clusters of seismic events along the southern slope of the Greater Caucasus belt and the local seismogenic fault near the Georgian-Armenian border. Additionally, we identified mining explosions and possible mining-induced events in the Lesser Caucasus mountains, as well as hydroelectric reservoir-induced events, and regional events in Khoy, Northern Iran, and the South Caspian basin.

On the geodetic side, we performed Synthetic Aperture Radar Interferometry using the NSBAS processing of Sentinel-1 imagery archive along a descending track for 9-years (2015 to 2023) from the NE Caucasus (mainly within the Republic of Azerbaijan) to NW Iran. We produced a regional-scale interseismic velocity map that highlighted crustal motions of the large-scale tectonic structures. Moreover, we have identified co-seismic deformation due to the 5.2 ML Shamakhi earthquake in the SE Caucasus mountains (05.02.2019) and the 5.9 Mw Torkamanchay earthquake in the Bozgush mountains of NW Iran (07.11.2019). Our results can also be used to study the local deformation of mud volcanoes in the Eastern part of Azerbaijan.

Keywords: Caucasus, Northern Iran, seismicity, InSAR time series, ground deformation

Assessing And Understanding The Potential Of High Spatial Resolution Time Series For Monitoring Urban Tree Phenology

C. BRESSANT[1], P-A. HERRAULT[1], A. PUISSANT[1]

[1] *LIVE UMR 7362 CNRS*

Urban trees were originally intended for visual aesthetic amenities in heavily built-up areas. Today, the scientific community has been able to highlight the many other benefits provided by these trees, including mitigation of the heat island effect, reduction of rainwater runoff, carbon storage, shading, or pollutant filtering. In this way, greening cities appears to be an effective local-level strategy for addressing climate change and act as an inhibiting factor on the ongoing urbanisation phenomenon. The study of urban tree phenology becomes particularly relevant: monitoring and providing knowledge about urban tree appear essential for their sustainable management.

The phenology is the study of periodic events occurrence, linked to seasonal variation, of vegetation. It is built on techniques and methods that keep evolving over decades. To ensure greater convenience in tracking phenological changes, for long-term valuations, remote sensing and the use of optical satellite imagery is an effective approach. It captures reflectance that depends on the vegetation properties, and the overall context of the surrounding environment and climate. Several studies involve Sentinel-2 and PlanetScope satellites data. These constellations have an interesting spectral range, a high temporal frequency and a spatial resolution that is particularly well-suited to study trees in urban area.

The aim of this research is to assess the discrepancies in derived phenological metrics based on in-situ and remote sensed data, while limiting the disparities in methodology and acquisition, to achieve a better understanding of the urban environment. Using objective observations on homogeneous objects, considering the intrinsic parameters of the sensors used, and with a temporal perspective, we propose a reflective reading of what is actually seen when urban trees are studied using remote sensing.

Keywords: urban trees, phenology, HR SITS, Sentinel-2, PlanetScope

ON-SITE AND OFF-SITE ARCHIVES: CHRONOLOGICAL COUPLING OF THE MONTMAURIN MULTI-LEVEL CAVE SYSTEM WITH LANDSCAPE EVOLUTION OF THE LANNEMEZAN MEGAFAN (SW FRANCE)

Coraline Fuchs[1], Claire Rambeau1, Jean-Luc Ponche[1,2], Gilles Rixhon[1], Damien Ertlen[1], Christian Perrenoud[3], Amélie Vialet[3]

[1] *Laboratoire Image, Ville, Environnement (LIVE UMR 7362), Université de Strasbourg*
[2] *Institut de Chimie de Strasbourg (IC UMR 7177), Université de Strasbourg*
[3] *Museum National d'Histoire Naturelle (MNHN UMR 7194)*

The Montmaurin multi-level cave system is located in the French Pyrenean foreland. It has become famous since 1949 when archaeological excavations unearthed a human mandible attributed to Homo heidelbergensis. A new research program starting in 2020 aims to study chronologically constrain sedimentary infills of this multi-level cave system, mostly focusing on the Coupe-Gorge cave and its 7m-thick sequence which bears human remains, such as a well-preserved humerus discovered in Summer 2022. The field campaign and analyses carried out over the last three years included high-resolution topographic measurements (laser), Uranium/Thorium dating of flowstone, clay mineralogy and fauna characterisation. However, understanding the caves' sedimentary infills requires an integration into landscape evolution at a broader spatial scale.

Against this background, this new project aims to establish a link at different spatial scales between human occupation at Montmaurin and the geomorphological evolution of the surrounding valleys incised into the Lannemezan megafan. Integrating both subaerial and underground markers, it accordingly focuses on reconstructing (1) the terrace staircase of fluvial valleys around the Montmaurin caves, i.e. Seygouade and Save Rivers, (2) the evolution of karstic networks over time in response to base-level variations, and (3) the caves' sedimentary history, including origin of material, filling phases, as well as post-depositional lateral and vertical movements. This project is based on a multidisciplinary approach which usefully combines complementary methods. The latter include geomorphological mapping, sedimentological analyses (i.e. granulometry, micromorphology, clay mineralogy, magnetic susceptibility), source tracking (i.e. SMIR), and relative (i.e. portable luminescence reader, weathering rind analysis) as well as numerical (OSL, cosmogenic nuclides) dating. Expected results will bring new insights into the fluvial landscape evolution, i.e. phases of base-level stability and incision, as well as into sediment movements within the karstic network and between the cave's occupation phases. It will ultimately provide a better timeframe for the presence of Homo heidelbergensis at Montmaurin.

Keywords: Geoarchaeology, geomorphology, numerical dating, mid-infrared spectroscopy

Birth and death of a triple junction: The example of the Bay of Biscay

Roxane Mathey[1], Julia Autin[1], Gianreto Manatschal[1], Daniel Sauter[1], Marc Schaming[1], Luis Somoza[2]

[1] *Institut Terre Environnement Strasbourg, Université de Strasbourg, Centre National de la Recherche Scientifique : UMR7063, Centre National de la Recherche Scientifique - Strasbourg*
[2] *Instituto Geológico y Minero de España - Madrid*

The Bay of Biscay fossil triple junction was separating three tectonic plates: North America, Europe and Iberia. It is defined by three pairs of conjugate margins: Armorican-North Iberian margins, the Goban Spur-Flemish Cap margins, and the West Iberia-Newfoundland margins. In this area, although it is proposed that steady-state spreading started in Aptian/Albian times and ceased around 80 Ma (Verhoef et al., 1986), the timing and opening directions during rifting and spreading remain uncertain. Indeed, oceanic magnetic isochrones are badly constrained. Moreover, exhumed mantle is exposed, so the Ocean-Continent Transition (OCT) of the three conjugate margins is difficult to localized (Boillot et al., 1988; Sibuet et al., 2007; Thinon, 1999; Tugend et al., 2015). As a result, there is no consensus in kinematic reconstructions.

This work, in the context of my PhD thesis, is part of the ANR project "*FirstMove"*. It is based on a multidisciplinary approach using geological data (wells, dives) and geophysical data (seismic reflection, magnetic, gravity and bathymetry data). Notably, we integrate the *Breogham* seismic reflection profiles which cross the fossil spreading ridge. We aim to redefine, map and date the different rift domains (necking, hyperextended, exhumed mantle and oceanic domains), in order to better constraint the evolution of the Bay of Biscay triple junction. Indeed, the Iberia plate kinematic is a keystone to understand the global kinematic of the whole Atlantic-Tethys system.

Boillot, G., Winterer, E. L., & et al. (Eds.). (1988). *Proceedings of the Ocean Drilling Program, 103 Scientific Results* (Vol. 103). Ocean Drilling Program. https://doi.org/10.2973/odp.proc.sr.103.1988

Sibuet, J., Srivastava, S., & Manatschal, G. (2007). Exhumed mantle‐forming transitional crust in the Newfoundland‐Iberia rift and associated magnetic anomalies. *Journal of Geophysical Research: Solid Earth*, *112*(B6), 2005JB003856. https://doi.org/10.1029/2005JB003856

Thinon, I. (1999). *Structure profonde de la Marge Nord Gascogne et du Bassin Armoricain.* Ifremer-IUEM, Brest, France.

Tugend, J., Manatschal, G., Kusznir, N. J., & Masini, E. (2015). Characterizing and identifying structural domains at rifted continental margins: application to the Bay of Biscay margins and its Western Pyrenean fossil remnants. *Geological Society, London, Special Publications*, *413*(1), 171–203. https://doi.org/10.1144/SP413.3

Verhoef, J., Collette, B. J., Miles, P. R., Searle, R. C., Sibuet, J.-C., & Williams, C. A. (1986). Magnetic anomalies in the northeast Atlantic Ocean (35°-50° N). *Marine Geophysical Researches*, *8*(1), 1–25. https://doi.org/10.1007/BF02424825

Keywords: Geology, Geophysics, Geodynamics, Rift, Spreading ridge, Bay of Biscay.

Passive monitoring of a deep geothermal reservoir in the Strasbourg area by interferometric approaches using ambient seismic noise.

Flavien Mattern[1], Jérôme Vergne[1], Jean Schmittbuhl[1], and Dimitri Zigone[1]

[1] *Institut Terre et Environnement de Strasbourg, UMR7063, Université de Strasbourg/EOST, CNRS, F-67084 Strasbourg, France*

We present preliminary results of ambient seismic noise monitoring near the deep geothermal reservoir at the Vendenheim site north of Strasbourg in France. From November 2019 to mid 2021, various operations led to an intense induced seismic swarm with several events of magnitudes above 3.0Mlv. This crisis is also characterized by the presence of an isolated swarm ~5km south of the geothermal site as well as the occurrence of the maximum magnitude event (3.9Mlv) 6 months after the cease of injection tests. Understanding these remote and delayed triggering mechanisms is essential for the successful development of future deep geothermal projects. We use ambient seismic noise correlations between pairs of sensors from a composite network of 137 permanent and temporary stations in the area. In particular, we intend to monitor the evolution of the upper crust around the reservoir by studying velocity variations and coda waveforms decorrelation in different frequency bands.

At high frequencies (1-3Hz), velocity variations appear to be correlated with fluctuations of the water table elevation. Strong decorrelations in waveform coda are also observed during holidays, suggesting changes in anthropogenic noise sources illumination. At low frequencies (3-6s), apparent variations of velocity and decorrelation with mainly an annual periodicity are observed, but could be associated with seasonal variations in the position of the sources of the second microseismic peak.

This study shows that in order to observe temporal variation in the properties of deep geothermal reservoirs with ambient noise coda wave interferometry, it is necessary to understand and model variations in the subsurface layers and in the sources of ambient seismic noise.

Keywords: Monitoring, Ambient noise, Interferometry, Geothermal energy

The Aseismic Creep Modulation along the Izmit Segment of the North Anatolian Fault observed by InSAR Data

E. Neyrinck[1], B. Rousset[1], C. Doubre[1], C. Lasserre[2], M.P. Doin[3], P. Durand [4], FLATSIM team

[1] *ITES, CNRS, Université de Strasbourg, Strasbourg, France*
[2] *LGL-TPE, CNRS, Univ Lyon, ENSL, Lyon, France*
[3] *ISTerre, CNRS, Université Grenoble Alpes, Grenoble, France*
[4]*CNES, Toulouse, France*

Improving the detections and analysis of the transient aseismic slip events on major seismogenic faults may enable a better understanding of the seismic cycle and give constraints on the associated seismic hazard. In this study we focused on the aseismic creep dynamics of the Izmit segment, the last ruptured segment of the North Anatolian Fault (NAF) during the two large Izmit and Düzce earthquakes in 1999, with Mw 7.6 and Mw 7.2 respectively. Since then, two slow slip events have been detected modulating the creep in 2015 (Özarpaci et al., [2020]) and 2016 (Aslan et al., [2019]), more than 20 years after the earthquake. To complete these studies and analyze the creep dynamics over a longer period, we used Interferometric Synthetic Aperture Radar (InSAR) time series from 2016 to 2021, automatically processed in the framework of the FLASTIM project (CNES/Form@Ter), using Sentinel-1 images and following the NSBAS approach. We extracted the tectonic deformation from the time series by removing an annual seasonal signal, and projecting our ascending and descending displacements into horizontal (East-West) and vertical ones. By using an Independent Component Analysis (ICA) on the E-W residual signals within the Izmit sedimentary basin, we corrected our data from a non-tectonic high frequency signal. After post-processing the time series, we are able to detect three main transient slip events affecting the Izmit segment: in December 2016 (previously detected by Aslan et al., [2019]), in March 2018 and in November 2019. We computed the total displacements due to each transient event, and used an inversion method based on a layered elastic half space to compute 2D-fault interface slip models. The slip patches are located between 1 and 3 km-deep, below the interface sediments-bedrock. The succession of transient slip events reveals creep heterogeneity along the segment, with 50% of the total aseismic creep on the central part during the ~20 days of the slow slip events, and only 25-30% for the edges of the segment. This type of aseismic creep made by the successions of cycles composed of two phases of (i) slow slip events and (ii) apparent continuous creep, observed on some segments of continental strike slip faults like the Izmit and Ismetpasa segments of the NAF, challenges the common logarithmic decay of the afterslip during the postseismic phase.

Keywords: Aseismic, Creep, InSAR, SSE, Afterslip

Dissipation of micropollutants in an agricultural river under the influence of organic matter

Popp Jakob [(1)]; Masbou Jérémy [(1)]; Imfeld Gwenaël [(1)]

[(1)] *Institut Terre et Environnement Strasbourg (ITES) UMR 7063 - Ecole et Observatoire des Sciences de la Terre (EOST) - Université Strasbourg; Ecole Nationale du Génie de l'Eau et de l'Environnement de Strasbourg (ENGEES); Centre national de la recherche scientifique (CNRS), France*

Micropollutants are frequently detected in surface waters, posing ecotoxicological threats and compromising water quality. The dissipation of micropollutants in surface water involves diverse transformative and non-transformative processes. These processes are influenced by quantity and quality of dissolved organic matter (DOM), a heterogeneous mixture derived from living matter, its remnants and decomposition products. This study examines the fate of *S*-Metolachlor and Sulfamethoxazole in rivers, representing pesticides and pharmaceuticals, the two most prevalent categories of micropollutants in European rivers. Conventional field observations, relying solely on quantitative analyses, prove inadequate in capturing the simultaneous occurrence of transformative and non-transformative processes, often yielding similar effects. To assess the influence of DOM on micropollutant transformation, Compound-Specific Isotope Analysis (CSIA) was combined with quantitative analysis and spectrophotometric characterization of DOM.

Preliminary biotransformation experiments revealed rapid degradation of Sulfamethoxazole (DT50 = 43 ± 7 h) in microcosms containing sediment from the heavily agriculturally and wastewater impacted river Souffel. *S*-Metolachlor in the same microcosms exhibited slower biodegradability (DT50 62 ± 24 d). However, both compounds degraded more extensively and at a faster rate than in microcosms without sediment, highlighting the crucial role of additional carbon sources, such as DOM, in putatively co-metabolic degradation, especially of Sulfamethoxazole. Preliminary stable carbon isotopic fractionation indicates greater isotope enrichment factors (ε = -1.1 ± 0.3 ‰) than previously reported for aerobic biodegradation of Sulfamethoxazole.

This investigation of micropollutant transformation in rivers using CSIA will be expanded through bio- and photodegradation experiments, encompassing various concentrations and types of DOM. Subsequent river channel experiments will further elucidate the effect of a dynamic sediment-water interface. To validate the suitability of the combined approach under environmental conditions, sampling and analysis of micropollutants in the river Souffel is ongoing. This approach will contribute to a more comprehensive understanding of micropollutant dissipation and may have practical application in future field surveys.

Keywords: Sulfamethoxazole, S-Metolachlor, degradation, dissolved organic matter, CSIA

Factors limiting participatory approaches in environmental consultation processes: case of natural reserves.

B. Schaffner[1]

[1] *Université de Strasbourg, LIVE*

Natural protected areas are the result of a social and political construction of the nature, which has evolved over time. In the past, they were created exclusively and top-down, without any real local population's involvement, in order to guarantee the protection of the nature. Protected areas creation is now part of a territorial strategy, involving multiple interests and issues.

Participation in environmental decision-taking processes has become an almost inseparable part of environmental politics. It aims at several objectives, including social acceptance of the project. However, recent examples of population involvement in consultation processes have shown limited effects in terms of acceptance. In fact, they rejected the project to create protected areas.

In 2017, for example, Ivorian government launched a project to create an ecological corridor with a natural reserve status, in order to strengthen connectivity between two national parcs. After two years of consultation, local residents of only one study area (of three) accepted the project.

My research aims at discussing the causal link between participatory approaches and acceptance. It aims too at assessing the factors that have limited the success of these approaches.

Keywords: participatory approaches, protected areas, natural reserve.

Revisiting the exhumed mantle at the Iberia margin to get new insight about break-up processes

H. Suire[1], M. Ulrich[1], G. Manatschal[1]

[1] *Institut Terre Environnement Strasbourg, Université de Strasbourg, ITES/CNRS, 5 Rue René Descartes, 67000 Strasbourg, France*

Previous studies from the Western Iberia magma-poor rifted margin enabled to describe the evolution of the mantle lithosphere during rifting and breakup based on the study of dredged and drilled magmatic and mantle samples. These data together with those from the present-day Australia-Antarctica and the fossil Alpine Tethys rifted margins and Pyrenean hyperextended basins provide insights about the role of the mantle processes and inheritance on the tectono-magmatic evolution of rift systems during rifting and breakup. However, key questions remain in understanding lithospheric breakup such as when, where, and how much magma is produced during breakup; how first magma interacts with the percolated subcontinental mantle and how these mantle-melt processes interrelate with the extensional processes operating during breakup.

This study focuses on samples drilled during ODP Legs 103, 149, 173 and 210 from the conjugate Iberia-Newfoundland margins and included also previously little studied dive-recovered samples from the Galicia Bank (Galinaute I and II). Bulk-rock, in-situ chemical and isotopic analysis of ultramafic rocks are used to constrain mantle dynamics during final rifting and breakup along the southern North Atlantic margins. Major and trace-element concentrations of primary minerals like olivine, pyroxenes and spinel are used to distinguish between different mantle domains, i.e., depleted oceanic or refertilized and/or inhertited subcontinental mantle. Thermo-barometry calculations are applied to define rates and thermal conditions during mantle exhumation.

Preliminary results from textural observations and geochemical data from Galinaute ultramafic rocks show two mantle types: subcontinental and refertilized mantle (T1/T2 mantle types). Indeed, plagioclase texture in corona around spinel together with spinel compositions are consistent with lherzolite formation by sub-solidus re-equilibration, similar to those of subcontinental mantle exposed in the Alps (Tasna and Malenco). However, some clinopyroxene compositions show evidence of low pressure mantle-melt interaction, which may indicate a refertilization process by ascending MORB-type melts. Diffusion modeling of sub-solidus major element and REE re-equilibration between OPX and CPX from Galinaute peridotites show that the exhumed mantle along the Galicia Bank cooled at rates between 10^{-6} and 10^{-4}°C/yr across the sp-pl peridotite facies transition, slower than cooling rates determined for samples from the Alpine Tethys and the present-day Australia-Antarctica magma-poor rifted margins.

Keywords: Iberia rifted margin, mantle-melt interaction, refertilization, mantle rocks

Dreissenids as biofouling organisms – colonization dynamics and management options in nuclear power plants

N. Trunfio[1.2.3], J.N Beisel[1.2], G. Nogaro[3]

[1] *Université de Strasbourg, CNRS, LIVE UMR 7362, 67070 Strasbourg, France*
[2] *Ecole Nationale du Génie de l'Eau et de l'Environnement (ENGEES), 1 Cour des cigarières, 67070 Strasbourg, France*
[3] *EDF R&D, Laboratoire National d'Hydraulique et Environnement (LNHE), 6 quai Watier 78401 Chatou, France*

The functioning of nuclear power plants can be disrupted by the development of biofouling organisms in cooling circuits and filtration devices, which can lead to significant performance losses. These organisms (plants or animals), which grow on humid or submerged surfaces, are known as biofouling organisms. Dreissenids (*Dreissena polymorpha*/zebra mussel, *Dreissena rostriformis bugensis*/quagga mussel) are freshwater bivalves native from the Ponto-Capsian basin and considered as invasive species in Europe and North America. With their ability to attach themselves to almost any submerged substrate and to develop massive populations, they are particularly impactful in industrial equipments. Several nuclear power plants have already been affected by the presence of dreissenids, and there is every reason to believe that this phenomenon will increase in the coming years. In order to respond to EDF's urgent need to combat the development of dreissenids in nuclear power plants, this thesis, in partnership with that company, has 3 objectives: (1) to determine the species and their life cycle in the natural environment and in nuclear power plants; (2) to understand the hydrodynamic conditions that favor/disfavor the attachment and development of dreissenids; and (3) to test in laboratory potential management methods adapted to nuclear power plants.

Keywords: Invasives species, Biofouling, Dreissenids, Nuclear Power Plants

Geothermal Reservoir Deformation Monitoring Based on Coda Wave Interferometry

Y. Wang[1], J. Azzola[1, †], D. Zigone[1], O. Lengliné[1], V. Magnenet[2], J. Vergne[1], J. Schmittbuhl[1]

1 ITES UMR 7063, Université de Strasbourg/CNRS, Strasbourg, France.
2 ICube UMR 7357, Université de Strasbourg/CNRS, Strasbourg, France.
† Karlsruhe Institute of Technology (KIT), Institute of Applied Geosciences (AGW), Karlsruhe, Germany.

Monitoring of geothermal reservoir deformation is essential for the normal development of the Enhanced geothermal system (EGS). Ambient noise interferometry (ANI) that is based on coda wave interferometry (CWI) is regarded as an effective and low-cost monitoring technique and draws more and more attentions. But the connection between the obtained ANI measurements and the undergoing physical changes of deep reservoir is still not so clear. In this study, we take Rittershoffen geothermal system (France) as a case study and conduct a series of forward simulations regarding the propagation of scattered wavefield through the deformed model considering acoustic-elastic effect based on Code_ASTER (mechanical loading) and SPECFEM2D (wave propagation). The simulations are based on a two-dimensional numerical model with a scale of 12km (width)×20km (height), in which the upper reservoir model contains 8 layers to mimic Rittershoffen geothermal reservoir, the lower sub model with multiple circular inclusions is set to scatter the waves emitted from point source at bottom and produce scattered wavefield; two seismic stations are located at the top of the model. The model is first verified by reproducing the seasonal variation of relative wave velocity changes obtained from ambient noise cross-correlation functions (ANCCF) induced by the underground water table elevation changes. Based on the validated model, we study the effect of in-situ reservoir deformation on ANI measurements by modelling the hydraulic pressure increases on an open hole and the aseismic slip of an embedded fault which is based on the case of hydraulic injection of GRT-1 well, Rittershoffen. The result indicates the induced small reservoir deformation in both situations can be detected by ANI measurements, which helps us to have a better understanding about the connection between the obtained ANI measurements and the undergoing deformation of deep geothermal reservoir.

Keywords: Geothermal Reservoir, deformation monitoring, numerical simulation, acousto-elastic effect, coda wave interferometry

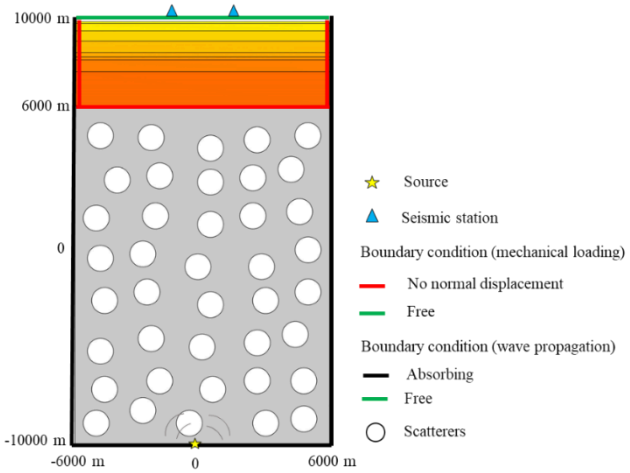


Figure 1: 2-Dimensional numerical multiple layered model of Rittershoffen subsurface (the top 4 km with 8 layers) and the sub-model (16km in depth), located below the subsurface model as a virtual scattering domain.

Time series of very-high resolution satellite imagery for landslide monitoring in practice

B. Wirtz[1,2], F. Provost[1,3], J.-P. Malet[1,3], O. Méric[2]

[1] *Institut Terre et Environnement de Strasbourg, CNRS UMR 7063, University of Strasbourg – 5 rue Descartes, Strasbourg, France*
[2] *Société Alpine de Géotechnique / SAGE – 2 rue de la Condamine, 38610 Gières, France*
[3] *École et Observatoire de Sciences de la Terre, CNRS UAR 830, University of Strasbourg – 5 rue Descartes, Strasbourg, France*

Monitoring landslides is an important challenge due to their high impacts on society. Using satellite imagery is an effective way to assess the challenge. Indeed, some studies already present methods to monitor landslides with optical imagery or InSAR, such as (Provost et al., 2022 ; Stumpf et al, 2017). These techniques are focusing on known catalogued events and quickly show limits due to the products they use. Their specifications and caracteristics inhibits the detection of small (< 100m²) and slow (< 0.5m/year) landslides. Access to high resolution optical satellite imagery may complement information on landslide activity by covering a larger spectrum of surface velocities and/or landslide sizes. The purpose of this work is to enhance the sensibility of Very High Resolution (VHR) imagery (<5 m) by applying a specific processing workflow to possibly reach detection accuracy of 0.05 m (Pléiades) and 0.30 m (Planet) of displacement in optimal conditions. The use of VHR imagery also provides the possibility to retrieve 3D information from stereo-processing, leading to the computation of 3D deformations and opening the possibility to study landslides physical properties from satellite imagery. This thesis aims at (1) adapting and automating methods to VHR imagery to obtain the most accurate deformation fields ; (2) combining different sensors data to ensure the most accurate deformation fields ; (3) exploiting 3D information to retrieve landslide physical properties.

References:

Provost F, Michéa D, Malet J-P, Boissier E, Pointal E, Stumpf A, Pacini F, Doin M-P, Lacroix P, Proy C and Bally P (2022) Terrain deformation measurements from optical satellite imagery: The MPIC-OPT processing services for geohazards monitoring. *Remote Sensing of Environment* 274, pp.112949.

Stumpf A, Malet J-P and Delacourt C (2017) Correlation of satellite image time-series for the detection and monitoring of slow-moving landslides. Remote Sensing of Environment 189, pp. 40-55

Keywords: VHR satellite imagery, Time series, Landslide monitoring, Correlation, Co-registration