FLOWTRANS 2015

International Conference on Flow in Transforming Porous Media

16-18 November 2015

University of Strasbourg

Nov. 16,17: IPGS, EOST, 5 rue Descartes

Nov. 18: Collège Doctoral Européen, 46 Bd de la Victoire

FLOWTRANS 2015 ABSTRACTS

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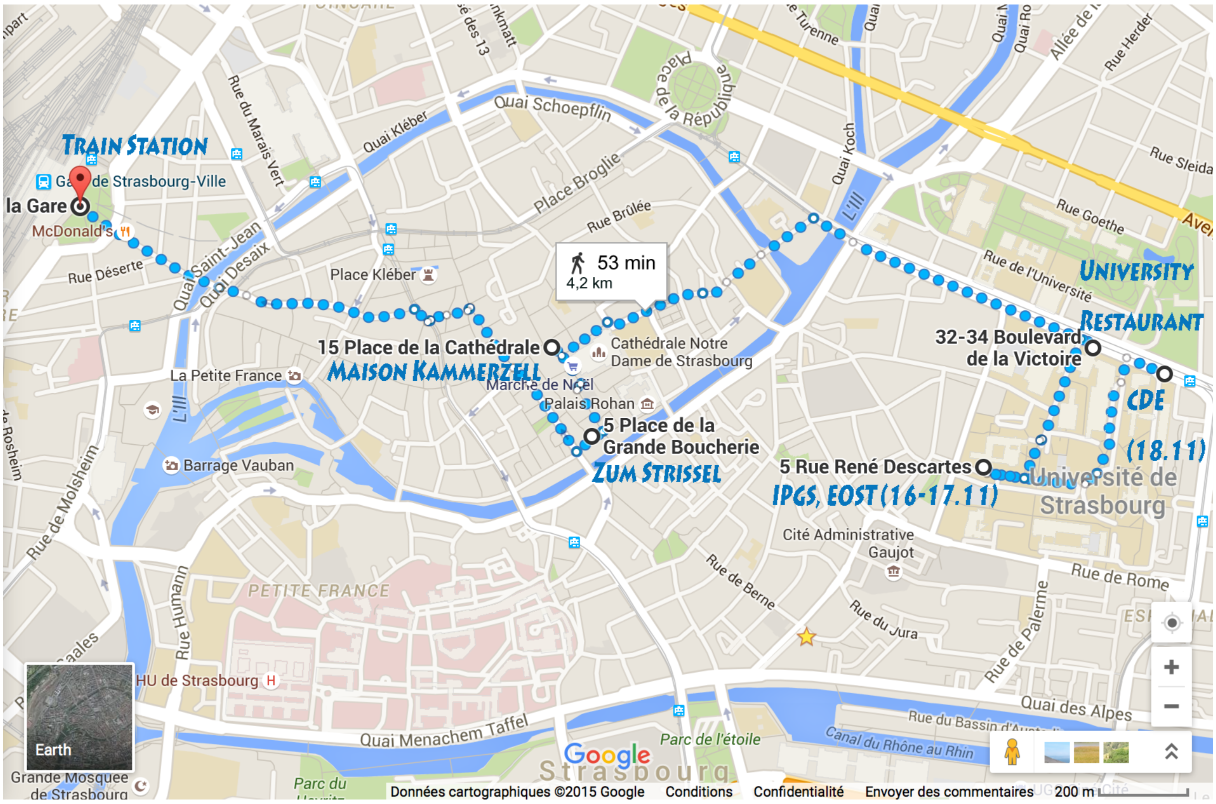
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General Motivation

The International Conference on Flow in Transforming Porous Media will be open to researchers presenting their results about coupled fluid and solid flow in natural rocks, soils, granular media and porous media. The changes happening can be due to fast processes, with force exchange between fluid and solids, or slow processes, as during chemical reactions with dissolution and precipitation, during seismic cycles in faults or during diagenesis, or thermal processes, as in volcanic phenomena. The conference welcomes contributions from experimental, numerical and theoretical approaches.

Sessions

Coupling between solid/fluid reactions and rock deformations
Conveners: Francois Renard, Piotr Szymczak
Invited Speakers: Andrew Putnis, Håkon Austrheim, Manolis Veveakis

Changes of porosity and transport properties due to physico-chemistry of porous media
Conveners: Christine Putnis, Knut-Jørgen Måløy
Invited Speaker: Oliver Plumper

Fracture - mechanics and physics of critical and subcrtical processes
Conveners: Joachim Mathiesen, Daniel Koehn
Invited Speakers: Alex Hansen, Stéphane Santucci, Knut Jørgen Måløy

Fluids and fault physics
Conveners: Einat Aharanov,Luis Rivera, Guillaume Daniel
Invited Speakers: Stephen Miller, Ziyadin Cakir

Fluids in granular media and soils, morphogenesis and instabilities
Conveners: Renaud Toussaint, Jan Ludvig Vinningland
Invited Speakers: Bjørnar Sandnes

Monitoring fluids in the Earth crust
Conveners: Eirik Flekkøy, Laurence Jouniaux, Pascal Sailhac
Invited speakers: Steve Pride, Damien Jougnot

Committees

semi-local organizing committee:

Renaud Toussaint, Wendy Louise Smith, Dilek Karayigit, Semih Turkaya, Fredrik Eriksen, Binta Mesmacque

Scientific committee: ITN FlowTrans board:

Einat Aharonov, Guillaume Daniel, Dag Dysthe, Eirik Flekkoy, Bjorn Jamtveit, Daniel Koehn, Joachim Mathiesen, Knut Jorgen Maloy, Andrew Putnis, Christine Putnis, François Renard, Piotr Szymczak, Renaud Toussaint

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Fracture - mechanics and physics of critical and subcritical processes

Local dynamics of a randomly pinned crack front during creep and forced propagation: An experimental study

Ken Tore Tallakstad[1], Renaud Toussaint[2], Stephane Santucci[3], Jean Schmittbuhl[2] and Knut Jørgen Måløy[1].

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ABSTRACT

We have studied the propagation of a crack front along the heterogeneous weak plane of a transparent poly(methyl methacrylate) (PMMA) block using two different loading conditions: imposed constant velocity and creep relaxation. We have focused on the intermittent local dynamics of the fracture front for a wide range of average crack front propagation velocities spanning over four decades. We computed the local velocity fluctuations along the fracture front. Two regimes are emphasized: a depinning regime of high velocity clusters defined as avalanches and a pinning regime of very low-velocity creeping lines. The scaling properties of the avalanches and pinning lines (size and spatial extent) are found to be independent of the loading conditions and of the average crack front velocity. The distribution of local fluctuations of the crack front velocity are related to the observed avalanche size distribution. Space-time correlations of the local velocities show a simple diffusion growth behavior. We further studied the fluctuations of the global velocity $V_l(t)$, computed at various length scales l, during the intermittent mode-I propagation of a crack front. The statistics converge to a non-Gaussian distribution, with an asymmetric shape and a fat tail.

Intermittent crack dynamics in heterogeneous materials

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ABSTRACT

The dynamics of a planar crack propagating within a brittle disordered material is investigated. We perform experiments where a crack is made propagated at the interface between a thick PDMS layer and a rigid substrate patterned with heterogeneities of controlled size, density and strength. The large velocity fluctuations of the front shown on the spatio-temporal diagram of lower panel of Fig. 1 are investigated at the scale of the material heterogeneities. They are shown to be reminiscent of the pinning/depinning evolution of a long-range elastic line driven in a random array of defects. The critical comparison between experiments and theoretical predictions evidences the central role played by the overhangs present along the front (see the top panel of the Fig. 1) that significantly alter the nature of the intermittency emerging from the collective pinning of the crack. Our results also shed light on the statistics of velocity fluctuations measured in other experiments of crack propagation in disordered materials.

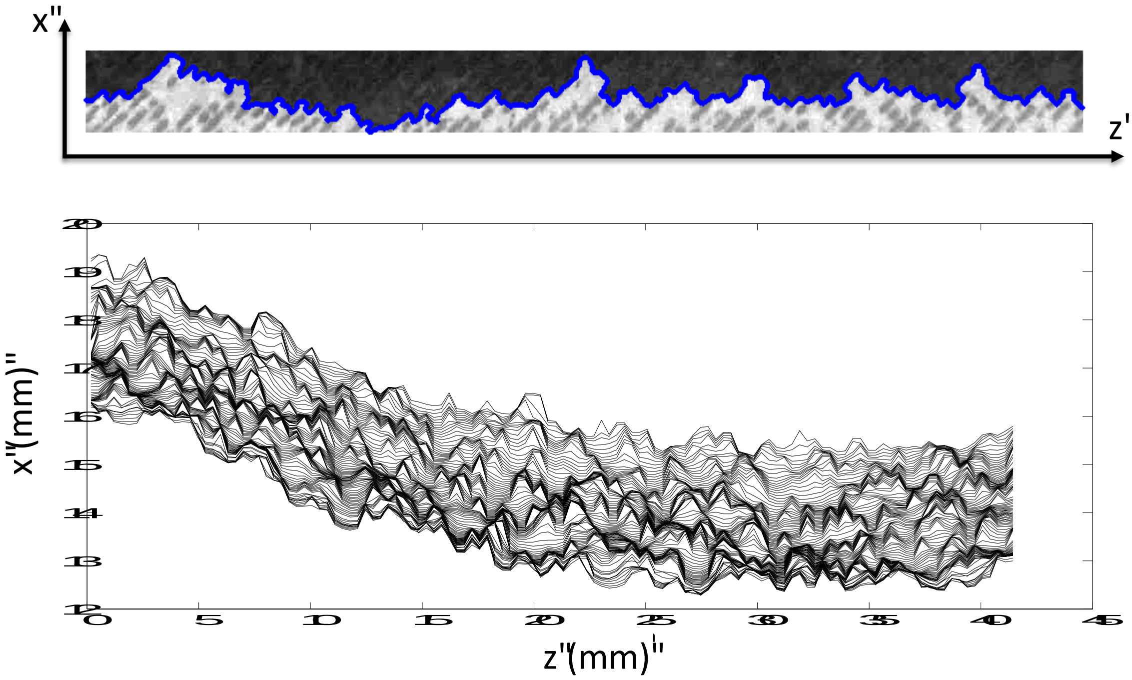

Fig. 1: The top panel represents a typical snapshot of the crack front (in blue) pinned by randomly located heterogeneities (in grey). The lower panel shows the spatio-temporal evolution of the front in the fractured plane. The dark regions correspond to a large waiting time, respectively a low velocity, while the light grey regions correspond to the low waiting time, respectively a low crack speed.

Tectonic Stylolites As Reliable Paleopiezometers

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ABSTRACT

Understanding the numerous effects of tectonic stress on rocks during long-term contraction is challenging and requires tools that reliably reconstruct both stress orientation and magnitude. At sub-seismic scale, few structures have been successfully used to reconstruct paleostress tensor so far, these structures being striated fault planes (to access paleostress orientation) and calcite twins (that also give an access to the maximum magnitude of the differential stress). Recent understandings of the morphogenesis of stylolites - pressure-solution features commonly linked with fracture networks in sedimentary rocks - stated that a stylolite can fossilize the stress field during its growth [1]. This stress signature is due to the competition of small-scale surface energy and large-scale elastic fluctuation regime that control the roughness of the stylolite. Consequently, a frequency analysis of the roughness signal shows the length scale for which the switch from small-scale to large-scale energy regime occurs: the crossover length, which is linked to the applied stress [1]. So far, this property has mainly been applied to bed-parallel isotropic stylolite populations in order to reconstruct maximum burial depth in shallow strata.

This contribution presents for the first time a natural case study where an anisotropic tectonic stylolite population described in deeply deformed strata is used to access the principal stress magnitude that prevailed in rocks during distinct tectonic stages. The Monte Nero Anticline (Northern Apennines, Italy) is a fault-related arcuate anticline where a fracture-stylolite network extensively developed, mainly related to the stress field that led to the folding. Five successive fracture sets and three related tectonic stylolite sets were discriminated in the microstructure population, and were used as a tectonic relative calendar for the area. The 3-D roughness of the stylolites was analysed and reconstructed based on 2-D profiles and periodicity properties [2] and principal stress magnitude were calculated for several steps of the deformation. In order to better understand the results of this inversion process, a paleostress study has been carried out on the fracture population using the established calcite twinning paleopiezometer. Results highlight that the tectonic stylolite roughness inversion is a reliable and user-friendly way to access paleostress. Used in combination with calcite twinning paleopiezometry it adds great details when reconstructing the natural evolution of stress during deformation, which is promising to better illustrate and so understand the interplay between stress and rock during deformation.

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Scale selection in polygonal fracture patterns

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ABSTRACT

Many natural fracture systems are characterized by a single length scale, which is the distance between neighboring fractures. Examples are mudcracks and columnar joints. In columnar jointing the origin of this scale has been a long-standing issue. Here we show that the diameter of columnar joints is a non-trivial function of the elastic and thermal parameters of the system. From a model of fracture propagation in a thermally contracting elastic material, we determine the shape of this function analytically and show that it is in agreement with numerical and physical experiments in a parameter range relevant for columnar jointing in igneous rock as well as in model systems such as corn starch and stearic acid.

Fig. 1: Exposed columnar joint formation at Svartifoss, Iceland.

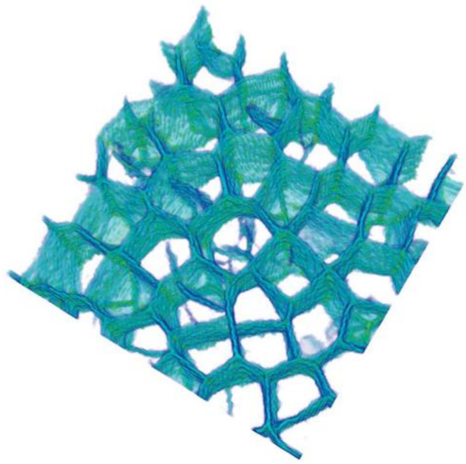

Fig. 2: Discrete element simulation of columnar jointing.

High Frequency Monitoring Reveals Aftershocks in Subcritical Crack Growth

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ABSTRACT

By combining direct imaging and acoustic emission measurements, the subcritical propagation of a crack in a heterogeneous material (sheets of paper) is analyzed. Both methods show that the fracture proceeds through a succession of discrete events. However, the macroscopic opening of the fracture captured by the images results from the accumulation of more-elementary events detected by the acoustics. When the acoustic energy is cumulated over large time scales corresponding to the image acquisition rate, a similar statistics is recovered. High frequency acoustic monitoring reveals aftershocks responsible for a timescale dependent exponent of the power law energy distributions. On the contrary, direct imaging, which is unable to resolve these aftershocks, delivers a misleading exponent value.

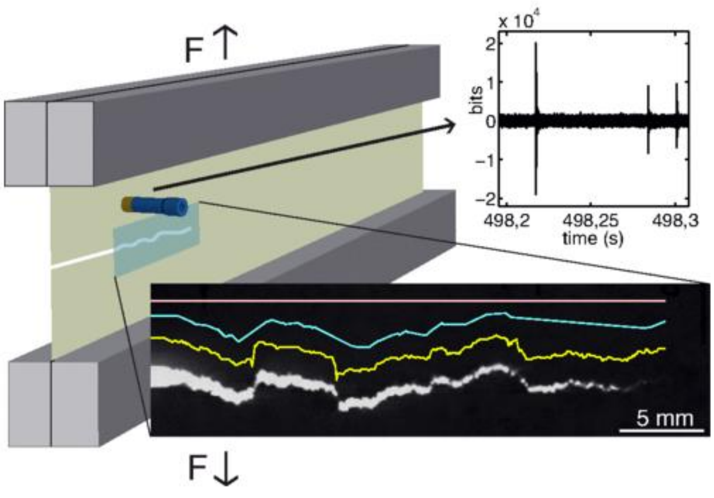

Fig. 1: Scheme of the experimental set-up

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How cool are cracks: a burning issue for paper

Renaud Toussaint[1,2*] , Olivier Lengliné[1,2], Stéphane Santucci[3,2], Tom Vincent-Dospital[1], Muriel Naert-Guillot[1], Knut Jørgen Måløy[4,1]

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ABSTRACT

Material failure often involves important heat exchange, sometimes with high temperature -- thousands of degrees -- reached at crack tips. Such temperature may subsequently alter the mechanical properties of the material and finally facilitate their rupture. Thermal runaway weakening processes could sometimes explain stick-slip motions and even be responsible for deep earthquakes. To understand and prevent catastrophic rupture events, it is thus crucial to establish an accurate energy budget of fracture propagation through measurement and assessment of the various energy dissipation mechanisms. Here, sheets of paper are torn apart under tension at slow imposed speed in a controlled mechanical setup, while the temperature is monitored using and infrared camera. Taking into account the thermal diffusion and the energy losses towards the surrounding atmosphere, we formulate a simple analytical solution linking the temperature field to the Joule heating during crack propagation. Combining calculations and numerics, we relate the temperature field around a moving crack tip to the part α of mechanical energy converted into heat. Monitoring the slow crack growth in paper sheets with an infrared camera, we measure a significant fraction α =12% +/- 4%.
In addition, we show that chemically released heat accumulation could weaken our samples with microfibers combustion, and lead to a fast crack (dynamic failure) regime triggered by the exothermal reaction. We show how the velocity of the crack during this fast stage is selected by heat diffusion through the process zone.

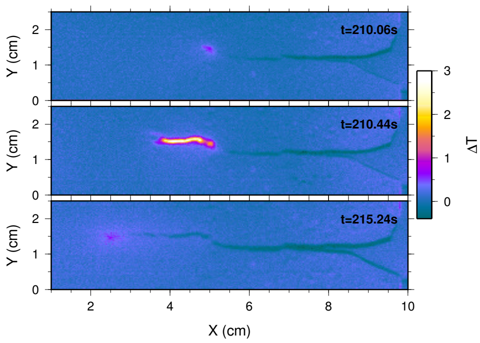

Fig. 1 Experimental IR measurements of temperature (in K) along a crack propagating in paper.

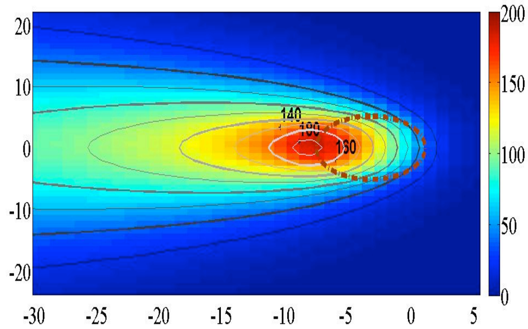

Fig. 2 Numerical model of closeup of the temperature excess (in K) generated along the process zone. Length units are in microns.

The Fiber Bundle Model

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ABSTRACT

The fiber bundle model is deceptively simple. First suggested and studied in 1926 by Peirce,[1] it is now established as a model that both is used for theoretical studies of the mechanisms behind brittle fracture, and as the starting point for numerical models used in the engineering of fiber-reinforced materials.[2,3] In its simplest form, the fiber bundle model consists of two parallel planes separated by some distance. Elastic fibers connect the two planes. The fibers are placed at the nodes of some regular lattice parallel to the planes. Each fiber has a maximum load it may sustain without irreversibly failing. When a fiber fails, the load it carried is transferred to the surviving fibers according to the elastic response of the two parallel plates.

We will in this talk present a number of new results concerning correlations between the failing fibers as the breakdown process proceeds. We will in particular discuss the surprising fact that a model where only the neighbors of the failing fibers absorb their load may under certain circumstances be more stable than a model where the load is evenly distributed among all surviving fibers. In a surprising way, this stability is related to a localization transition in the breakdown process where all failures from a given point on appear in a well-defined neighborhood.

We will also discuss the behavior of a one-dimensional version of the fiber bundle model, where one of the planes – now lines – is infinitely rigid whereas the other has a finite bending elasticity. With this model, we explore the different classes of behavior that may be found in one-dimensional fiber bundle models.

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Seismic Attenuation Due To Wave-Induced Fluid Flow In Heterogeneous Rocks Containing Fractures

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ABSTRACT

When a seismic wave travels through a fluid-saturated porous rock that contains heterogeneities in the mesoscopic scale range, that is, heterogeneities that are much larger than the typical pore size but much smaller than the predominant seismic wavelengths, local gradients in the pore fluid pressure arise. These fluid pressure gradients, which are due to the uneven response of the heterogeneities to the stresses associated with the passing seismic wavefield, induce viscous fluid flow and thus energy dissipation through internal friction. Due to the large compressibility contrast typically observed between fractures and their embedding background, fractured rocks represent a particularly prominent scenario where attenuation due to wave-induced fluid flow (WIFF) is expected to be predominant [1].

In some cases, the backgrounds of fractured rocks are highly heterogeneous. In particular, it is well known that permeability can vary orders of magnitude in relatively short distances [2], thus affecting the oscillatory fluid flow between the fractures and the background in response to the propagation of a seismic wave. Even though these features are expected to significantly modify the seismic responses of such media, this topic remains, as far as the authors know, largely unexplored in the literature. In this work, we apply numerical oscillatory relaxation tests [3] based on the quasi-static poroelastic equations [4] to study seismic attenuation and velocity dispersion in heterogeneous fluid-saturated porous rocks containing fractures. The fractures are modelled as very thin, highly compliant and highly permeable layers embedded in a stiffer and less permeable background [5]. We perform an exhaustive sensitivity analysis to understand how the presence of heterogeneities in the embedding background modifies the seismic response of the probed medium. In particular, we analyze the influence of different heterogeneous permeability fields in these WIFF effects. This kind of study may have important implications with regard to the estimation of effective hydraulic properties from seismic data.

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Hydraulic fracturing and the creation of hydraulic breccias

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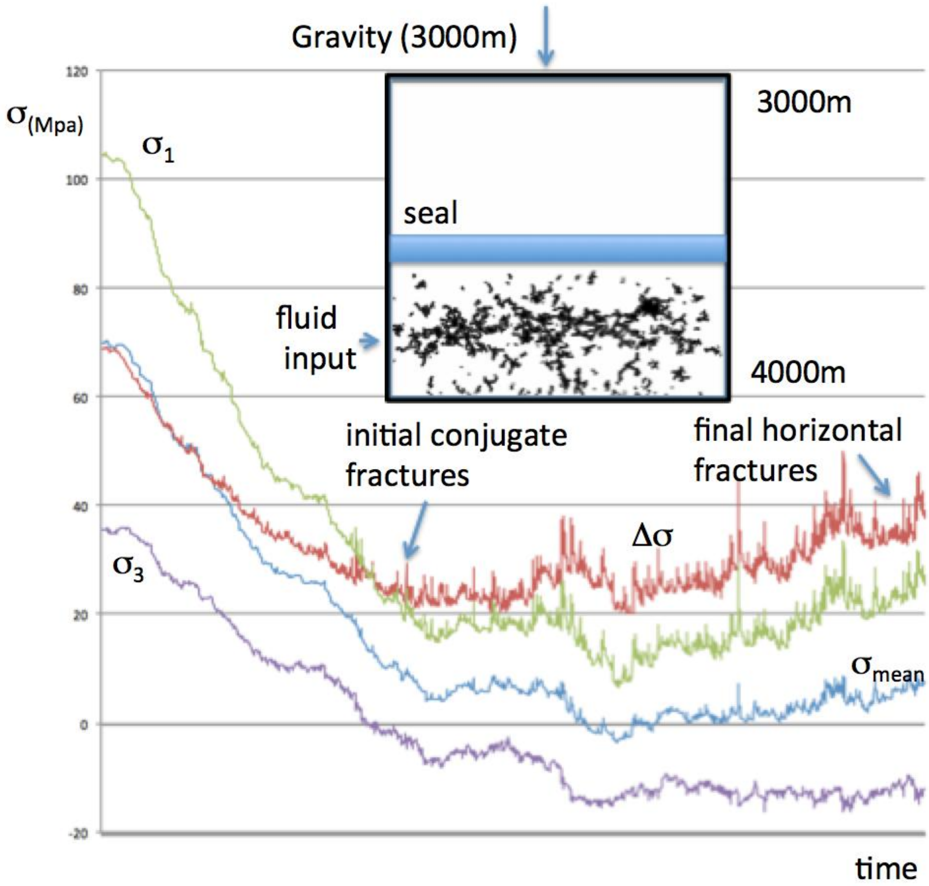
ABSTRACT

Vein systems that indicate paleofracture geometries can be found in variable settings including typical layer perpendicular and layer parallel veins. Some natural examples show layer parallel and perpendicular veins that appear to form synchronously. Thin-section observations of these systems indicates that the veins formed at the same time. Layer parallel veins can form as a function of seepage forces that develop due to fluid pressure gradients in an over-pressurized system. In order to understand the interaction of fluid pressure, effective solid stress and fracturing we use a hydrodynamic numerical model. The solid in the numerical model is represented by elements connected with linear elastic springs with normal and shear forces and the fluid is represented by fluid pressure that evolves throughout the model as a function of time, permeability and boundary conditions. Fluid pressure gradients can exert forces on the solid network and the solid network defines the permeability and porosity for the fluid.

Overpressures in geological systems can produce anisotropic effective stresses that lead to a decrease of differential stress as well as the development of seepage forces and a switch in the orientation of the least principal stress. In a sedimentary basin resulting fractures can vary in direction, from an initial vertical to sub-vertical orientation to horizontal fractures. The resulting network shows either a switch between bedding perpendicular and bedding parallel fractures/veins or represents a hydraulic breccia with no distinct direction of fracturing.



Effective stress evolution (average of stress below blue seal) and final fracture pattern in the numerical model. Graph shows evolution of stress through time. Fractures are shown in black in the inset.

Changes in Porosity and transport properties due to physico-chemistry in porous media

Porosity and permeability generated during the experimental replacement of calcite by fluorite

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ABSTRACT

In the context of fluid-rock interaction, the study of how fluids move through low permeable rocks is of most importance. In natural rocks, fluids can permeate through grain boundaries and/or pre-existing fractures, but permeability can also be generated by chemical alteration. This is the case of coupled dissolution-precipitation reactions, characterized by the generation of porosity enhancing fluid mobility (Putnis et al., 2002). To the best of our knowledge, no attempt was made before to measure the porosity and/or permeability generated during such reactions.

In this study we reacted a number of calcite single crystals with fluoride containing fluids at 40°C during several reaction times (2, 4, 8, 16, 22, 32 days) resulting in the partial replacement of the samples by porous fluorite. Reacted samples were dried and the permeability (connected porosity) was measured using nitrogen adsorption. A parallel experiment was made at 200°C during 8 days resulting in the total replacement of a calcite single crystal by fluorite. This sample was dried and milled using broad ion beam (BIB) to prepare low-relief polished surfaces for high-resolution SEM imaging to extrapolate total porosity. All samples were analysed using SEM for characterization of the products reaction front and microstructure.

Nitrogen adsorption results show that there is a linear relationship between the permeability and the fraction of fluorite transformed, and a power law relationship of each with the reaction time. Pore diameter ranged between 31 and 310 Å. The concentration of pores was higher for three specific pore diameters in each sample: at the lowest diameter (~31 Å); at a middle diameter (between 100 and 160 Å, depending on the sample); and at the higher diameters (for samples reacted for more than 2 days, ranging from 216 to 310 Å). Results from total porosity extrapolation will be presented.

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Dispersion of Passive Tracers in Disordered Porous Media

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ABSTRACT

We here present a comprehensive statistical analysis of Lagrangian trajectories and the pair particles separation in flows inside (realistic) three dimensional porous media obtained in numerical simulations. The tracking of individual trajectories allows us to go beyond the mean square displacement (MSD) and single-point probability densities which are insufficient to fully describe the geometrically induced anomalous behavior of such stochastic processes [1, 2]. We determine the Finite-Size Lyapunov coefficients for the pair particles dispersion. We also discuss the effects of an external field (pressure gradient) on the Lagrangian velocity autocorrelation function and the mean square displacement. We then examine the applicability of continuous time random walks (CTRWs) to model the anomalous fluctuations of the passive tracers in such random environments. From these models an Einstein's fluctuation dissipation relation in the asymptotic regime is derived as observed in several numerical experiments.

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Experimental investigation of the dissolution of fractures. From early stage instability to phase diagram

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ABSTRACT

Dissolution of natural rocks is a fundamental geological process and a key part of landscape formation and weathering processes. Moreover, in current hot topics like Carbon Capture and Storage or Enhanced Oil Recovery, mastering dissolution of the host rock is fundamental for the efficiency and the security of the operation. The basic principles of dissolution are well-known and the theory of the reactive infiltration instability has been extensively studied. However, the experimental aspect has proved very challenging because of the strong dependence of the outcome with pore network, chemical composition, flow rate...

In this study we are trying to tackle this issue by using a very simple and efficient device consisting of a chip of pure gypsum inserted between two polycarbonate plates and subjected to a constant flow rate of pure water. Thanks to this device, we are able to control all parameters such as flow rate, fracture aperture, roughness of the walls... but also to observe in situ the progression of the dissolution thanks to the transparency of the polycarbonate which is impossible with 3D rocks. We have been using this experimental set-up to explore and investigate all aspects of the dissolution in a fracture, such as initial instability and phase diagram of different dissolution patterns, and to compare it with theory and simulations, yielding very good agreement and interesting feedbacks on the coupling between flow and chemistry in geological media

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Invariantly propagating dissolution fingers in finite-width systems

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ABSTRACT

Dissolution fingers are formed in porous medium due to positive feedback between transport of reactant and chemical reactions [1-4]. We investigate two-dimensional semi-infinite systems, with constant width W in one direction. In numerical simulations we solve the Darcy flow problem combined with advection-dispersion-reaction equation for the solute transport to track the evolving shapes of the fingers.

We find the stationary, invariantly propagating finger shapes for different widths of the system W, flow rates and reaction rates. Shape of the reaction front, turns out to be controlled by two dimensionless numbers – the (width-based) Péclet number $Pe_W = \frac{v\,W}{D\,\phi_0}$ and Damköhler number $Da_W = \frac{ksW}{v}$, where k is the reaction rate, s – specific reactive surface area, v - characteristic flow rate, D – diffusion coefficient of the solute, and ϕ_0 – initial porosity of the rock matrix. Length of the stationary finger L turns out to be proportional to $Pe_W W$. Velocity of propagating front in initial stages of finger formation as a function of system parameters is also calculated.

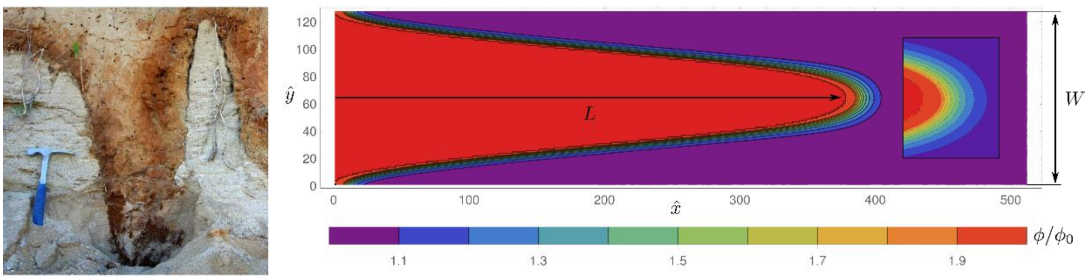

Fig. 1 Dissolution finger in the limestone quarry in Smerdyna (left) and porosity ϕ/ϕ_0 obtained in simulation for Péclet number $Pe_W = 128$ and Damköhler number $Da_W = 25.6$ (right). Inset shows close-up of the dissolution front.

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Microfluidic Tools for Reactive Transport In Porous Media

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ABSTRACT

Microfluidics is a fast growing platform of technologies for control of flow and chemical reactions at low Reynolds number. We describe some adaptations of the manufacturing and measurement techniques of microfluidics to the study of solid – liquid reactions relevant for geological processes in porous media: mineral dissolution and growth, wetting, clogging, gas absorption and force of crystallization.

Layer-controlled Stylolite Growth and the Creation and Destruction of Local Seals

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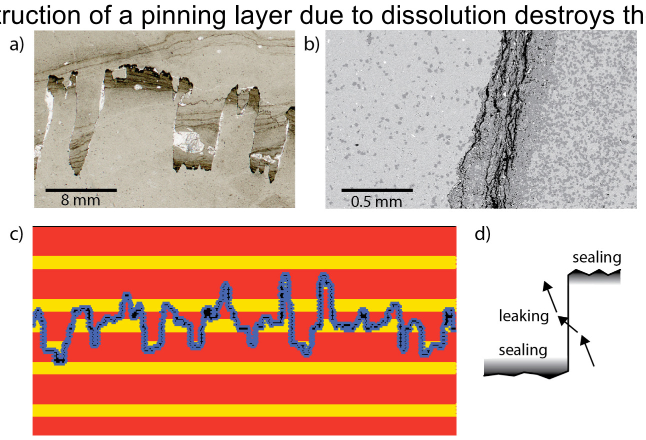
ABSTRACT

Cores of carbonate Zechstein sediments in the Lean Gas Field in northern Germany show a dense set of sedimentary stylolites. We studied these structures in detail using scans of cores, thin-sections, roughness analysis, SEM-EDS studies and a set of numerical simulations in order to understand timing and depth of stylolite growth, the development of varying stylolite patterns and their influence on fluid flow. The studied cores have a depth of about 4000m and it is expected that they experienced a minor inversion in the Cretaceous so that their original depth may have been up to 4500m. We studied the roughness of the stylolites and used a stress inversion technique to determine the depth at which they grew. The determined depth of growth is in the order of 4150m with an error of plus-minus 300m. This value represents the latest stylolite activity and indicates that they have been active until late in the burial history. SEM and EDS analysis on stylolite thin sections shows that the stylolites separate strongly dedolomitized sections from sections that still contain a large amount of dolomite. In addition stylolite seams capture or shield dolomitized parts of the rock. Dissolution holes are also partly linked to stylolite teeth indicating that fluid flow is significantly influenced by the presence of stylolites. Stylolite shapes and thus potentially their sealing capacity vary significantly throughout the cores from flat stylolites to small wavy ones all the way to stylolites showing extreme spikes and teeth. Quite often dark layers seem to control stylolite shapes. In order to understand the influence of layers on stylolite growth we use a numerical model that can treat the dynamics of the process linking elasticity with a dissolution routine. In this model we find that layers that dissolve slower can pin stylolite teeth and thus develop extremely long and spiky geometries. Growth typically happens in two to three stages depending on whether or not the pinning layer is destroyed. Stage one represents the nucleation of the stylolite in the layer and its initial growth until it reaches the boundaries of the layer. Typically the initial roughness development leads to a local variation of the position of the stylolite interface with respect to the upper or lower boundary of the layer. Stage two is represented by successive fast growth that is controlled by the pinning layer and the stylolite develops pronounced teeth. Stage three happens in cases where the layer disappears because it is also slowly dissolving. Once the layer is gone stylolite growth basically stops except for local variations in shape and rounding of teeth edges. The developing geometries influence the sealing capacity of stylolites significantly: collection of slow dissolving material in the stylolite does produce a potential seal, offset of a sealing layer due to pinning effects of that layer and the development of teeth can destroy the seal because of leakage across teeth sides and the destruction of a pinning layer due to dissolution destroys the seal completely.



Large stylolite teeth (a) showing layer offsets (potential seals), with tips of teeth influencing reactions (b) where de-dolomitized regions (light grey) are separated from dolomitized regions (dark grey) by stylolites. Modeling (c) shows that layers are offsets and thus seals may leak along flanks of teeth (d).

Nanoscale transient porosity controls large-scale reactive fluid flow

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ABSTRACT

The reaction of fluids with rocks is fundamental for Earth's dynamics as they facilitate heat/mass transfer and induce volume changes, weaknesses and instabilities in rock masses that localizes deformation enabling tectonic responses to plate motion. Fluid-rock interactions also play a key role in geothermal energy, hydrocarbon production, CO_2 sequestration and nuclear waste disposal industries. In all of these examples it is the ability of a rock to transmit fluid, its permeability, that dictates geological processes and the industrial use of geological formations. For nuclear waste storage an impermeable wall rock is vital. For anthropogenic CO_2 sequestration, however, impermeable rocks are detrimental. In natural systems some environments (sediments) are open to fluids, but the majority (e.g., oceanic lithosphere) are nearly impermeable. Surprisingly though, even in rocks that are nominally impermeable widespread fluid-rock interactions are observed leading to the question: How can fluids migrate through vast amounts of nominally impermeable rocks? Here we investigate on of the most wide-spread alteration processes in the Earth's crust, the albitization of granitic rocks and compare these to simple X-ray tomography experiments undertaken in the system KBr-KCl. We show that fluid flow and element mobilization during albitization is controlled by an interaction between grain boundary diffusion and reaction front migration through an interface-coupled dissolution-reprecipitation process. Using a combination of focused ion beam scanning electron microscopy (FIB-SEM)-assisted nanotomography combined with transmission electron microscopy (TEM) reveals that the porosity is dictated by pore channels with a pore diameter ranging between 20 to 100 nm. Three-dimensional visualization reveals that the pore channels must have been connected during reaction. Aspect ratio analysis shows a nearly normal distribution indicating that a Rayleigh-Taylor-type instability caused the disconnection of the pore channels. As the transport of fluids in nanometer-sized objects with at least one characteristic dimension below 100 nm enables the occurrence of phenomena that are impossible at bigger length scales we discuss the potential influence of nanofluidic transport phenomena for metamorphic systems and take first numerical approaches using molecular dynamics simulations.

A New Conceptual Model of Compaction Creep in Carbonate Rocks

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ABSTRACT

Rocks subject to compressional or shear stresses can deform slowly and irreversibly during time. In large scale this can be observed as compacting reservoirs due to fluid (hydrocarbon or water) production[1] and creeping faults at strike-slip plate boundaries[2].

We created a simple conceptual micromechanical model of compaction creep in rocks under hydrostatic conditions. This model combines microscopic fracturing and pressure solution and if scaled up to macroscopic scale by a statistical approach it can be used to predict strain rate at core scale. The model uses no fitting parameter and has few input parameters: effective stress, porosity, pore size distribution, temperature and water saturation. Internal parameters are Young's modulus, interfacial energy of wet calcite and the dissolution, diffusion and precipitation rates of calcite, all of which are measurable independently. We specifically investigated how to obtain good pore size distribution data from X-ray tomography and built a deep learning neural network to extract pore volume information from the tomography images.

The model was tested against existing long-term creep experiments and it was able to predict the magnitude of the resulting strain under largely different effective stress, temperature, water saturation and fluid chemistry conditions.

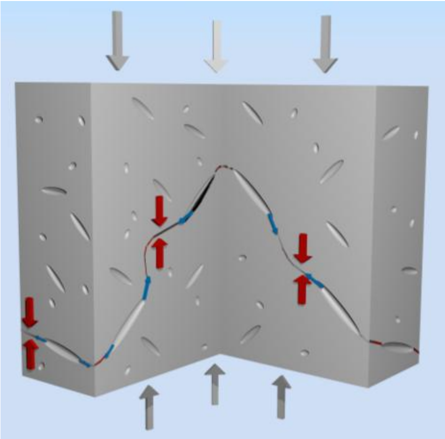

Fig. 1 The illustration of the micromechanical model of compaction creep

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Micro-fracturing induced by radioactivity of minerals: what consequences on the permeability of rocks?

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ABSTRACT

Some rocks may contain radioactive (U-Th) minerals (zircon, monazite, titanite, allanite, euxenite, uraninite…) ranging from micrometric to centimetric sizes (Figure 1). These minerals are therefore submitted to intense self-irradiation (i.e. α-decay of U and Th chains) that can lead to amorphization and also modify their environment by irradiating the host minerals.

Here, we focus ontwo examples of the effect of radiation damage within minerals and rocks from different localities. The first example[1]concernsuranothorianite (UTh) from theTranomarogranulitic skarns (SE-Madagascar). These structures consist of UTh grainssurrounded by both aluminous diopside(Figure 1 left) and calcite crystals. The second one[2]concerns accessory minerals (zircon, euxenite, xenotime) in rare-metal-rich pegmatites from southern Norway (Kragerø, Iveland-Evje); some of these minerals are rich in U (e.g. up to 15wt % for euxenite). In both cases similar features were described: presence of radiating cracks around the radioactive minerals and evidence of intense fluid circulation and elements transport through the fractures propagating inside rock.The conclusions of these observations are that irradiation (self and out), destroy the crystal lattice (amorphization) promoting the alteration of more or less destroyed parts. Amorphization induces volume increase, leading to the formation of cracks which eventually connected into a network through the rock. This fracturing allows fluid circulation, and promotes alteration of source minerals and dispersion of elements (e.g. Pb, Uand strategic metals like Nb, Ti, REE).These observations highlight the importance of understanding the impact of radiation damage on radioactive transport by fluids passing through such fractured rocks.

The next step is to determine the consequences of irradiation (amorphization, fracturing) of this radioactive minerals on key parameters (porosity, permeability, tortuosity) involved in the transport of elements (via fluid) within rock and also to determine how to take into account the transfer of scale to assess the significance of these effects at the macroscopic scale (Figure 1).

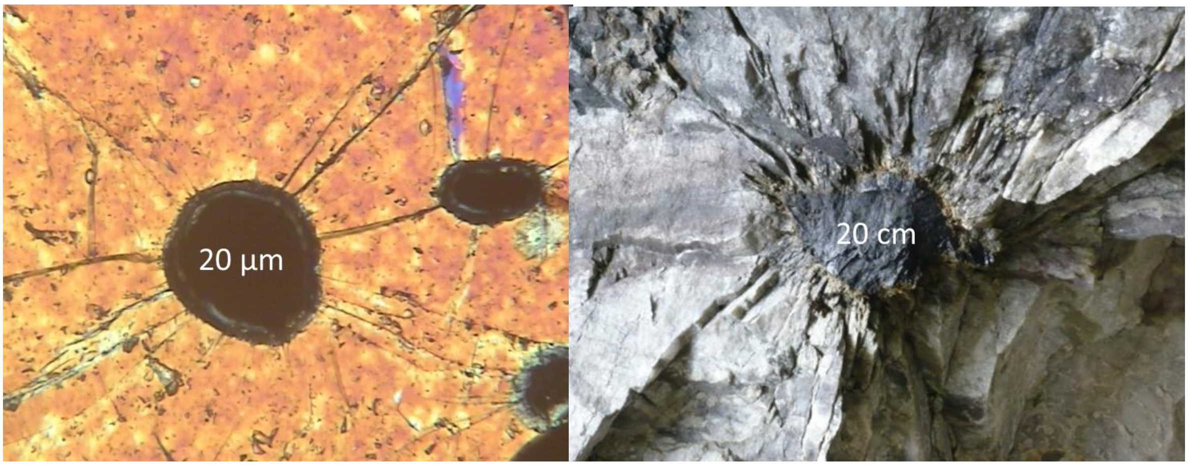

Figure1: U-Th-minerals micrometric (on the left urano-thorianiteinside diopside) and centimetric (on the right allanite in pegmatite).

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Stress Distribution in Fluid-Saturated Porous Solids: Interactions Between Elasticity, Fluid Flow, and Microstructure

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ABSTRACT

Fluid flowing through the pore-space of porous rocks under non-hydrostatic stress significantly contributes to the deformation of such materials, leading either to the formation of fractures or to dissolution-precipitation processes that modify the pore space geometry. For quantitatively understanding this phenomenon, the stress distribution at the interface between the fluid and the solid is a key component. At the micron scale, regions of high stress become prone to dissolution and crack formation, and the advective transport of solutes through the pore-space leads to precipitation in regions of low stress. This, over time, alters the geometry of the pore space and its transport properties.

In this study, we investigate by numerical means the impact of a fluid steadily flowing through porous solids, considering the solid-fluid interface stress distribution on a timescale where the effect of chemical reactions is negligible. In this regime, a one-way stress coupling from the fluid flow to the elastic field in the solid is sufficient, rendering simulations feasible using the finite element method (FEM) for the solid, and comparing the unstructured lattice-Boltzmann method and FEM Stokes flow for the fluid phase. By varying the flow rate and the externally applied stress, we obtain the probability distributions of the various components of the stress tensor. This approach is validated by using simple 2D and 3D geometries such as a circular or a cylindrical pore embedded into an elastic solid. Then, the numerical method is applied to a digital 3D limestone rock sample scanned using X-ray microtomography and where the pores and the solid matrix could be segmented. The results show how the heterogeneous material distribution in a natural rock controls the stress distribution upon external loading and internal fluid flow and how close to fracturing the rock is when injecting fluid.

Numerical Simulation of Fluid Flow and Local Thermal Non-Equilibrium Heat Transfer in Fractured Porous Media

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ABSTRACT

Geothermal power is a potential alternative energy resource for the future, because of its sustainable, effective and environmentally friendly nature. Due to high costs of drilling and deep exploration, it is beneficial to estimate the heat extraction of a geothermal system in advance. Despite numerous studies in this area, heat production estimation of such a system is still a challenge. There are two main models describing heat transfer between a hot rock and a flowing fluid. One is based on an immediate thermal equilibrium between the rock and the circulating fluid. The other one computes the heat flow in fluid and rock separately but coupled with a fluid-rock heat transfer term. The former is known as local thermal equilibrium model (LTE) and the latter as local thermal non-equilibrium (LTNE).

The previous numerical researches are typically using the LTE assumption; however, studies show the validity of this model only under restricted conditions [1][2]. We present a comparison between these two models using a two-dimensional numerical simulation of coupled fluid flow and heat transport in a porous medium. In order to validate the numerical model, the results of Zhao (2014) are used [3].

Different parameter studies are done to investigate the role of permeability, porosity and fluid injection rate. It is assumed that cold water is flowing through a hot porous medium with a single fracture, while the porosity and permeability of rock and fracture zone are constant. Fluid and rock temperatures are computed over time and the differences between LTE and LTNE model predictions are analyzed. The results show that porosity and water injection rate do not have a large impact on the differences between the model approaches; however, the differences rise extremely as fracture permeability increases. Our results show that transient heat transfer between matrix and fluid should be explicitly accounted for in coupled fluid flow and heat transport models since the assumption of local thermal equilibrium can lead to significant overestimation of the heat transport rates in particular along permeable pathways.

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Determining Pore Size Distribution Data from X-ray Tomography Images by Neural Networks

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ABSTRACT

X-ray tomography is an efficient way of getting insight into a rock sample without destroying it. During the measurement density map slices are obtained from which a 3-dimensional dataset can be obtained by conventional algorithms (e.g. as implemented in the commercial software Avizo).

Conventional image segmentation algorithms work very well with tomography data where structures are significantly larger than the resolution of imaging[1], however they give less reliable results if structures have similar size than the resolution. Analyzing tomography data we found the chalk contains a large amount of microporosity difficult to extract by conventional image segmentation algorithms.

We created a learning algorithm based on the concept of deep learning neural networks to identify pore space in the tomography data. The method was earlier applied to biological tomography data and gives an improved segmentation accuracy compared to standard segmentation methods[2].

Here we present initial results of this new approach which is then used to update results for predicting strain rates in compaction experiments by a theoretical model[3].

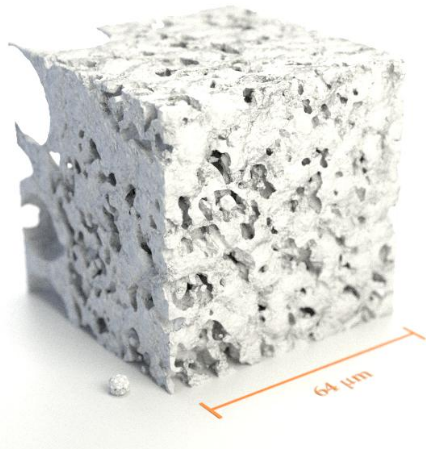

Fig. 1 Tomography data of a Liège chalk sample

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Removal of dissolved textile dye from aqueous solutions by natural clay under dynamic flow conditions

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ABSTRACT

This work deals with the cleanup of textile effluents using natural clay, which is less expensive and easier to handle than traditionally used adsorbent [1]. It reports new findings on the physisorption of Foron Blue 291 (FB) on natural bentonite under dynamic flow conditions of the aqueous solution (Figure 1), that may important when using adsorption technique for wastewater treatment. Two major aspects were studied: (i) impact of dynamic mass transfer on removal efficiency of clay minerals: advective-dispersive mass transport versus heterogeneous reaction (adsorption-desorption process), (ii) comparison of quantity of dye retained by the solid matrix under both ideal exchange conditions between dye and adsorbent given in a batch reactor and a pulse injection of dissolved azo dye in a soil column composed of a mixture of mean grain-sized sand and bentonite at different flow rates and various mass fractions of bentonite. Prior to the experiments of reactive mass transport, column experiments using a non-reactive tracer (Fluorescein) were performed to study the hydrodynamic behavior of the 11 cm-thick clay/sand mixture. It was shown that advective-dispersive transport across the clay/sand mixture may be characterized by a double-porosity medium having mobile and immobile zones. The results obtained on the reactive transport of FB underline that adsorption of FB depends strongly on the fraction of clay in the clay/sand mixture (Figure 2). With a percentage of 30% of mass of clay, 77% of dissolved FB mass were removed by the adsorbent. At low flow rates, the removal rates obtained in the dynamic reactive system were similar to the ones obtained in previous batch (static) experiments [2].

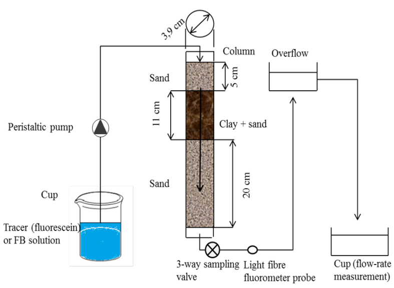

Fig. 1 : Scheme of the experimental set up

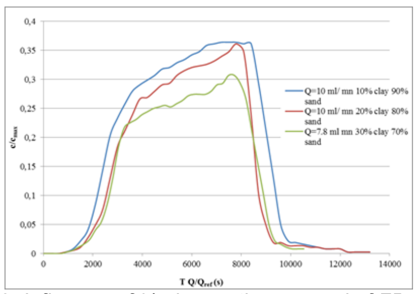

Figure 2: Influence of % clay on the removal of FB azo dye from water

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Fluids and Physics of Faulting

Onset and Mechanism of Surface Creep On Strike Slip Faults: Clues From The North Anatolian Fault, Turkey

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Aseismic surface slip was first reported over forty years ago along some major strike slip faults such as the San Andreas fault in California and the North Anatolian fault (NAF) in Turkey. Yet its origin and timing on active strike slip faults and underlying physical processes still remain subjects of debate today. Recent studies based on space geodesy and geological observations howerver are now providing new insights in to the mechanism, characteristics, and initiation of fault surface creep. Using the persistent scatterer InSAR (PS-InSAR) and GPS techniques we investigate both the creeping section of the NAF at Ismetpaşa that had ruptured during the 1944 earthquake, and the postseismic deformation of the 1999 İzmit Earthquake. The results reveal that the central segment of the 1999 Izmit Earthquake rupture has been creeping for over for the past 16 years since the earthquake, becoming the longest lasting afterslip ever recorded. The slip pattern of ongoing surface creep on the İzmit rupture supports the idea that stable fault creep may commence as postseismic afterslip, a mechanism proposed previously but could not be confirmed due to the lack of pre- and post-earthquake observations on creeping faults such as the Ismetpaşa segment of the NAF and the central section of the SAF. Geological maps along the Ismetpaşa and Izmit creeping segments show that both fault zones run through ophiolitic and calcareous rocks that are known to facilitate aseismic creep due to their weak mineral contents. Observations of creeping faults suggest that following a large earthquake, a stable surface creep can be triggered on a section of a mature fault if it has evolved in to simple geometry and is located within weak rocks.

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High strain rate behavior of saturated and non-saturated sandstone: implications for earthquake mechanisms.

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ABSTRACT

Damage zones of active faults control their resistance to rupture and transport properties. Hence, knowing the damage's origin is crucial to shed light on the (paleo)seismic behavior of the fault. Coseismic damage in the damage zone occurs by stress-wave loading of a passing earthquake rupture tip, resulting in the dynamic (high strain rate) loading and subsequent dynamic fracturing or pulverization. Recently, interest in this type of damage has increased and several experimental studies were performed on dry rock specimens to search for pulverization-controlling parameters. However, the influence of fluids during dynamic loading needs to be constrained.

Hence, we have performed compressional loading experiments on water saturated and oven dried Vosges sandstone samples using a Split Hopkinson Pressure Bar apparatus. Due to the high porosity in these rocks, close to 20 %, the effect of fluids should be clear. Afterwards, microstructural analyses have been applied on thin sections.

Water-saturated samples reveal dynamic mechanical behavior that follows linear poro-elasticity for undrained conditions: the peak strength of the sample decreases by 30-50% and the accumulated strain increases relative to the dry samples that were tested under similar conditions. The mechanical behavior of partially saturated samples falls in between.

Microstructural studies on thin sections show clear compressive deformation features in all samples: Intra-granular fractures are formed that are restricted to some quartz grains while other quartz grains remain intact, similar to co-seismically damaged sandstones observed in the field. Also, inter-granular fracturing is observed, thereby appointing an important role to the cement in the matrix in between grains. For saturated samples, this phase of compressional deformation is followed by a phase of tensile deformation related to the presence of fluids.

The presence of pore fluids in the rocks lower the dynamic peak strength, especially since fast dynamic loading does not allow for time-dependent fluid dissipation. Thus, fluid-saturated rocks would show undrained mechanical behavior, creating local overpressure in the pore that breaks the intra-granular cement. This strength-decreasing effect provides an explanation for the presence of pulverized and coseismically damaged rocks at depth and extends the range of dynamic stress where dynamic damage can occur in fault zones.

A Fluid-Driven Earthquake Cycle

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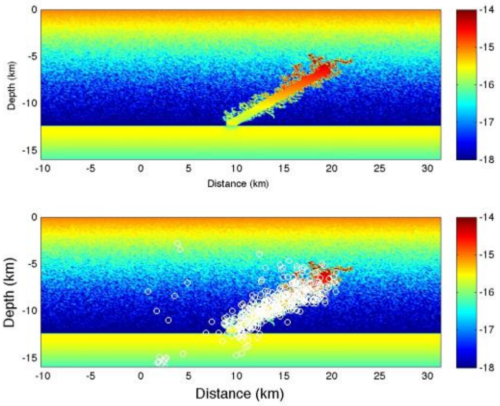
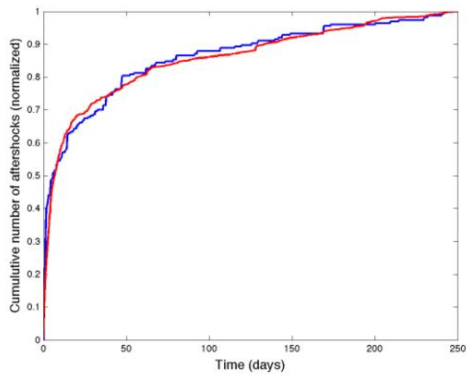
ABSTRACT

Increasing evidence suggests that fluids play an integral role in tectonics and the earthquake cyclef, including the 1997 Colfiorito earthquake sequence [*S. A. Miller et al.*, 2004] that showed the aftershock sequence was driven by degassing of a deeply sourced and overpressured reservoir of CO_2. Subsequently, it was demonstrated that high-pressure fluids (presumably also CO_2) played an important role in the 2009 L'Aquila earthquake [*Terakawa et al.*, 2010]. That CO_2 played a role in these Apennine earthquakes is not surprising considering the ubiquity of CO_2 degassing observed in Italy [*Chiodini et al.*, 2011].

The non-linear diffusion model used to simulate the Colfiorito earthquake sequence also successfully modeled the Basel fluid injection experiment [*S.A. Miller*, 2014] with the caveat that permeability was allowed to increase by a factor of about 500 when the failure condition was reached. Recently, this model was combined with a model that mimics precipitation by requiring the permeability to decrease exponentially with time, consistent with a distance from equilibrium type relationship. This addition to the model produces exciting results because the combination of the physically reasonable exponential dependence of permeability on the effective normal stress with the exponential decrease in permeability with time due to precipitation produces Omori's Law.

The model was applied to the 1994 Northridge thrust earthquake, using a high pressure source at depth and an initially high fluid pressure within a model slip zone. The well-constrained hypocenter data from Northridge earthquake was compared to the evolved permeability (Figure 1a), and Figure 1b compares the (normalized) cumulative number of aftershocks between observation and model, and demonstrates convincingly that this simple mechanistic model reproduces Omori's Law.





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Fault interaction and stress transfer along the Algerian plate boundary zone

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Abstract

We address the rôle and distribution of stress transfer that may trigger destructive earthquakes in the Central Tell Atlas (Algeria). A sequence of historical events reaching M 7.3 and related stress tensor with thrust faulting mechanism illustrates the Coulomb Failure Function (CFF) modeling. We explore here the physical pattern for a stress transfer along the Tell thrust-and-fold belt taking into account an observed northeast trending earthquake migration from 1891 to 2003. An effective friction coefficient μ'=0.4 shows stress loading lobes on targeted coseismic fault zone and location of stress shadow across other thrust-and-fold regions. Jaumé and Sykes (1992) suggest that one explanation for this apparently low value of μ' would be the presence of high fluid pressure. The Computation integrated the seismicity rate in the CFF computation, which is in good agreement with the migration seismicity.

The CFF calculation provides the critical value of 2 bars sufficient to trigger the largest earthquakes as for instance (Mw 7.3 El Asnam earthquake), The CFF values for other moderate earthquakes being 0.1-0.8 bar. Recent InSar studies and aftershocks of the 2003 Zemmouri earthquake (Mw 6.8) are integrated in the post-seismic stress loading reach some selected faults by a value of 1bar with the same co-seismic fluid effect. The presence of fluid and related poroealstic deformation can be considered as decisive topics of debate for the occurrence of majors earthquakes in the western Mediterranean regions.

Localization Of Lamb Waves: Technique Based On The Inverted Source Amplitude Comparison

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ABSTRACT

Signal localization is a complex problem having a wide range of application. We propose a new localization method on plates which is based on energy amplitude attenuation and inversed source amplitude comparison. This inversion is tested on synthetic data using lamb wave propagation direct model and on experimental dataset (recorded with 4 Brüel & Kjær Type 4374 miniature piezoelectric shock accelerometers, 1 - 26 kHz frequency range). We compare the performance of this technique to the classical source localization algorithms, arrival time localization, time reversal localization, localization based on energy amplitude.

Furthermore, we measure and compare the accuracy of these techniques as function of sampling rate, dynamic range, geometry and signal to noise ratio with a conclusion that this technique, which is very versatile, works better than conventional techniques over a range of sampling rates 10 kHz – 1 MHz. Thus, using this proposed energy based localization method, it is possible to have a decent resolution using a very cheap equipment set.

The experimental setup consist of a glass/plexiglass (Figure 1) plate having dimensions of 80cm x 40cm x 1 cm equipped with four accelerometers and an acquisition card. Generated signals over the glass plate due to a wooden hammer hit or a steel, glass or polyamide ball hit (with different sizes) are captured by sensors placed on the plate on different locations with the mentioned sensors.

The numerical simulations are done using a dispersive far field approximation of the plate waves. The signals are generated using a hertzian loading over the plate. By using the imaginary sources outside the plate boundaries, the effect of the reflections is also included.

This proposed method, can be modified for the application in 3d environments, to monitor industrial activities (e.g boreholes drilling/production activities) or natural brittle systems (e.g earthquakes, volcanoes, avalanches).

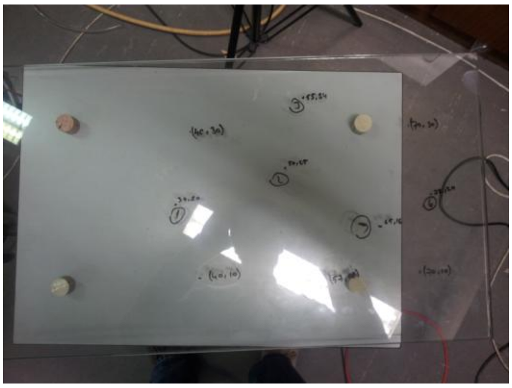

Fig. 1 Glass plate with marked source locations.

Rupture and seismic signals of hydrofracture networks

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ABSTRACT

Hydrofracturing is becoming one of the most discussed and controversial topics in the modern oil and gas industry. Significant effort is put towards investigating safeness of such engineering endeavor. One of the largest issues associated with the safety concerns is induced seismicity and possibility of triggering larger seismic events. As a part of larger project, the aim of which is to model the hydrofracturing process itself and to forward model synthetic seismograms, we present a numerical model which, while it simulates the hydrofracturing process, also analyzes movement of individual particles during rapture of the rock. By calibrating this model to the representative values for the real world, we were able to obtain the seismic moment for the fracturing and, thus, calculate moment magnitude of the seismic events. Furthermore, as we analyze the individual movement of the particles, it is possible to evaluate the ratio between mode I and mode II components in each individual fracturing event. One aim of this experiment is to see if there is a correlation between relatively larger seismic events and the presence of greater element of shear (mode II). Preliminary results have shown that the model is well calibrated, as moment magnitude range is coherent with the values observed in the real world. The model shows a correlation between greater proportion of mode II in the fracturing process and the moment magnitude. We will explore the effects of hydrofracturing on seismic signals and statistical distributions of events.

Fluids in granular media and soils, morphogenesis and instabilities

Bubbles trapped in a fluidized bed: trajectories and contact area

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ABSTRACT

We report the experimental study of gas injection at constant flow-rate at the bottom of an immersed granular layer confined in a vertical Hele-Shaw cell. In the stationary regime, a central fluidized zone formed by two granular convection rolls is observed [1-2]. We point out that the bubbles trapped inside the liquid-saturated bed follow different dynamics: either the bubbles are initially formed outside the fluidized zone, and remain trapped in the system permanently; or they are located inside the fluidized zone where they are attracted by the central air channel. By image analysis we can follow their trajectories in time.

We investigate the dependence of the air volume trapped inside the fluidized zone, the bubble size and the three-phase contact area on the gas injection flow-rate and grains diameter. Contrary to the intuition, the gas-liquid-solid contact area decreases when increasing the flow-rate. We find that the volume fraction of air trapped inside the fluidized zone is roughly constant and of the order of 3-4% when varying the gas flow-rate and the grains size.

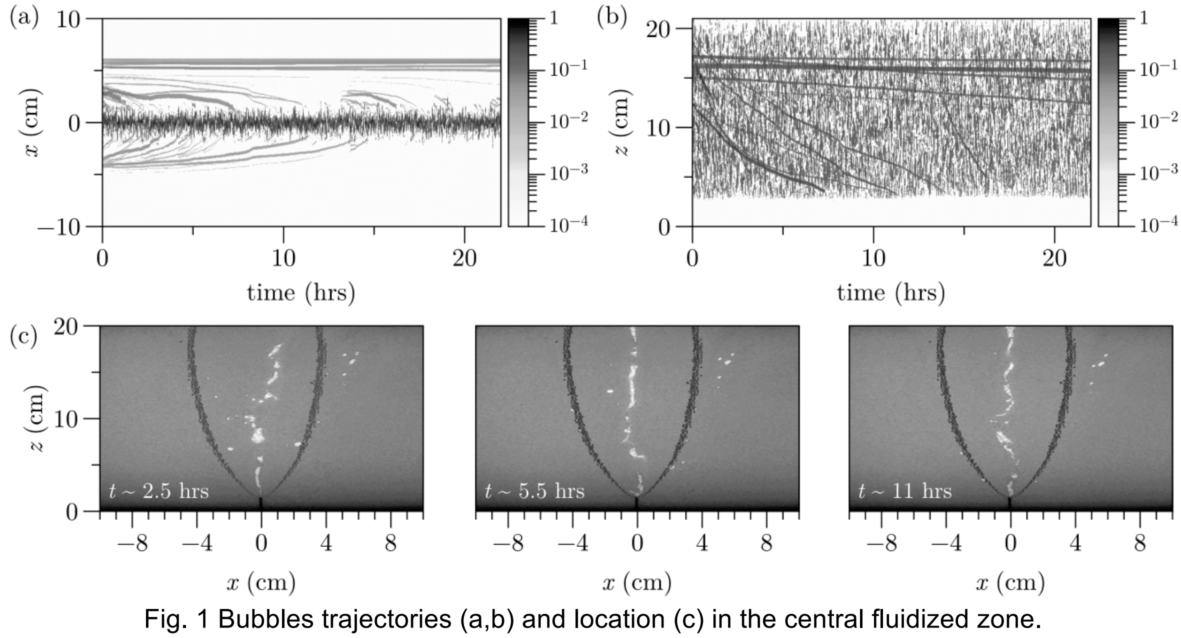

Fig. 1 Bubbles trajectories (a,b) and location (c) in the central fluidized zone.

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Three-Phase Flow and Fracturing of Wet Granular Media

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ABSTRACT

Gas driven fracturing of soil and rock is a key process in pneumatic fracturing for enhanced contaminant remediation, stimulation of sensitive hydrocarbon reservoirs and CO_2 injection and sequestration in the subsurface. Fracturing also governs natural processes such as soil drying and outgassing of crystal rich magmas. We study a simple model system: fracturing of unconsolidated wet granular material by forced injection of a gas. An in-depth analysis of both pore-scale phenomena and overall pattern formation is presented. We find that the fractures grow in an intermittent, stick slip fashion, where growth is impeded by local compaction of the deformable granular medium. The effects of material properties (grain size/shape) and injection rate are quantified, and the system is found to undergo a series of transitions in terms of observed dynamics and pattern formation. The overall shape of the fracture pattern and the spatial distribution of fracture branches are important parameters in terms of targeting mass transport in or out of the bulk formation. We propose a simple analytical model that predicts the fracture density from basic granular medium properties, and also demonstrate a transition from fracturing to viscous fingering beyond a critical injection rate.

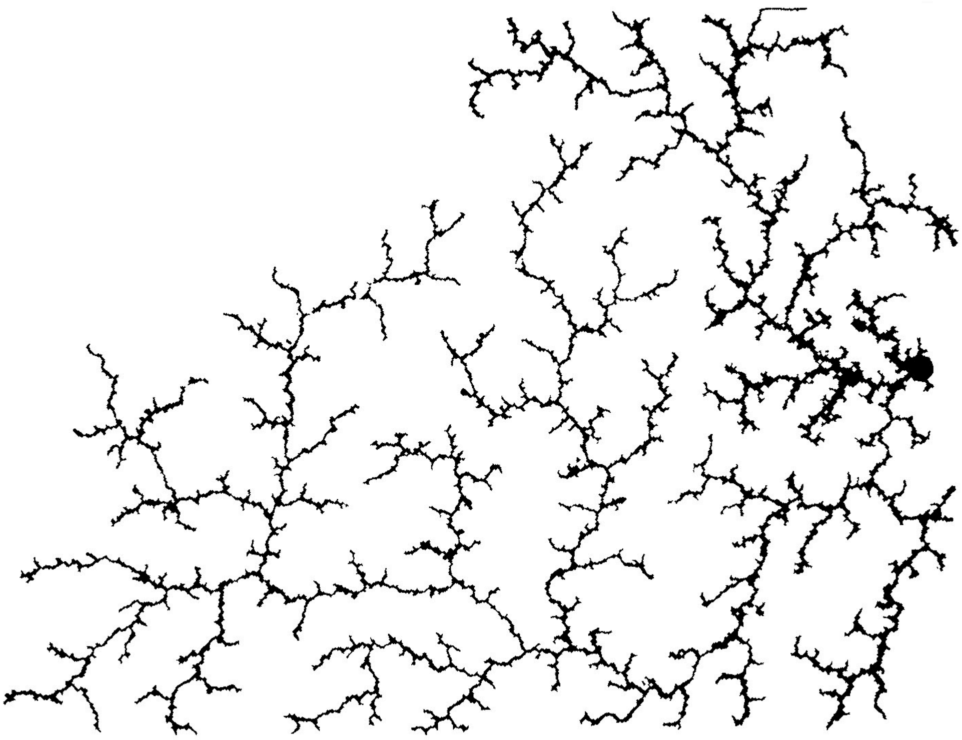

Fig. 1 Gas fractures in a wet granular packing.

Invasion Patterns During Two-phase Flow In Deformable Porous Media

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ABSTRACT

We will present our study of the viscous fingering and fracturing patterns that occur when air at constant overpressure invades a circular Hele-Shaw cell containing a liquid-saturated deformable porous medium [1] -- i.e. during the flow of two non-miscible fluids in a confined granular medium at high enough rate to deform it. The resulting patterns are characterized in terms of growth rate, average finger thickness as function of radius and time, and fractal properties. Based on experiments with various injection pressures, we identify and compare typical pattern characteristics when there is no deformation, compaction, and/or decompaction of the porous medium. This is achieved by preparing monolayers of glass beads in cells with various boundary conditions, ranging from a rigid disordered porous medium to a deformable granular medium with either a semi-permeable or a free outer boundary. We show that the patterns formed have characteristic features depending on the boundary conditions. For example, the average finger thickness is found to be constant with radius in the non-deformable system, while in the deformable ones there is a larger initial thickness decreasing to the non-deformable value. Then, depending on whether the outer boundary is semi-permeable or free there is a further decrease or increase in the average finger thickness. When estimated from the flow patterns, the box-counting fractal dimensions are not found to change significantly with boundary conditions, but by using a method to locally estimate fractal dimensions, we see a transition in behavior with radius for patterns in deformable systems; In the deformable system with a free boundary, it seems to be a transition in universality class as the local fractal dimensions decrease towards the outer rim, where fingers are opening up like fractures in a paste.

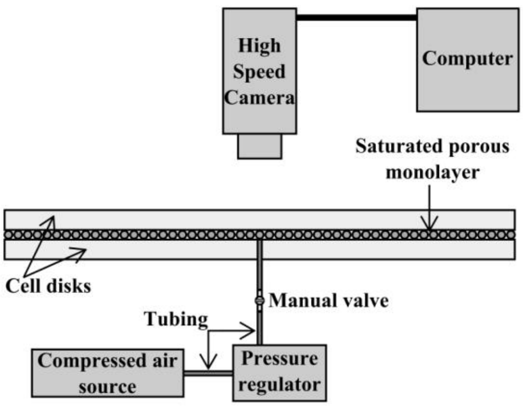

Fig. 1 : Experimental setup. *Cross-sectional skecth, side view.*

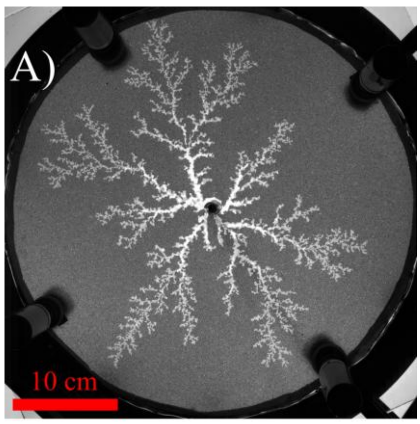

Fig.2 : Top-down view of an experiment.

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Long Runout Landslides: A Solution from Granular Mechanics

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ABSTRACT

Large landslides exhibit surprisingly long runout distances compared to a rigid body sliding from the same slope, and the mechanism of this phenomena has been studied for decades. This paper shows that the observed long runouts can be explained quite simply via a granular pile flowing downhill, while collapsing and spreading, without the need for frictional weakening that has traditionally been suggested to cause long runouts. Kinematics of the granular flow is divided into center of mass motion and spreading due to flattening of the flowing mass. We solve the center of mass motion analytically based on a frictional law valid for granular flow, and find that center of mass runout is similar to that of a rigid body. The spreading of the mass is estimated based on the shape of deposits observed in experiments with collapsing granular columns and numerical simulations of landslides. The spreading leads to a deposit angle much lower than the angle of repose or the dynamic friction angle, and is shown to be an important, often dominating, contribution to the total runout distance. The combination of the predicted center of mass runout and the spreading length gives the runout distance in a very good match to natural landslides.

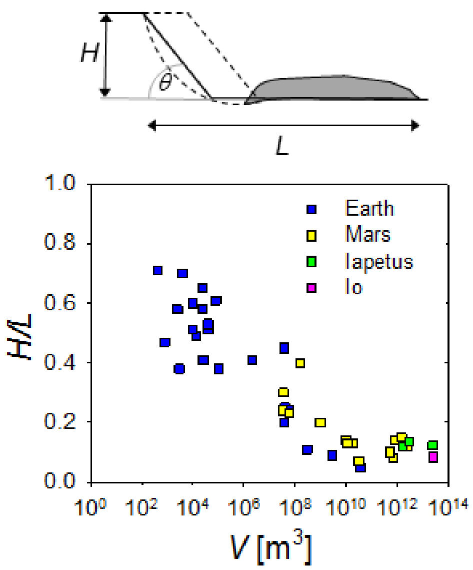

Fig. 1 Heim's ratio *H/L* as a function of landslide volume *V*, based on field data taken from Ref. [2]. Note that Heim's ratio for long runout landslides can reach values as low as 0.1, *i.e.* much lower than that for a rigid body.

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Two-phase Flow in a Quasi-2D Porous Medium: Influence of Boundary Effects in the Measurement of Pressure-Saturation Relationships

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ABSTRACT

We have performed two-phase flow experiments and simulations to analyze the drainage from a quasi-2D random porous medium [1]. The medium is transparent, which allows for the visualization of the invasion pattern during the flow (Figure 1) and is initially fully saturated with a viscous fluid (a dyed glycerol-water mix). As the capillary pressure (pressure difference between the non-wetting and wetting phases) is gradually increased, air begins to penetrate from an open inlet, thus displacing the fluid which leaves the system from the outlet in the opposite side.

A feedback mechanism was devised to control the experiment: the capillary pressure is continuously increased to be just above the threshold value necessary to drive the invasion process. This mechanism is intended to keep the invasion process slow, in the so-called capillary regime, where capillary forces dominate the dynamics. Pressure measurements and pictures of the flow are recorded and the pressure-saturation relationship is computed. The effects of boundary conditions to this quantity are verified both numerically and experimentally by repeatedly performing the analysis using porous media of different sizes. We show that some features of the pressure-saturation curve are strongly affected by boundary effects. The invasion close to the inlet and outlet of the model are particularly influenced by the boundaries and this is reflected in the phases of pressure building up in the pressure-saturation curves, in the beginning and end of the invasion process respectively. Conversely, at the central part of the model (away from the boundaries), the invasion process happens at an essentially constant capillary pressure, which is reflected as a plateau in the pressure-saturation curve.

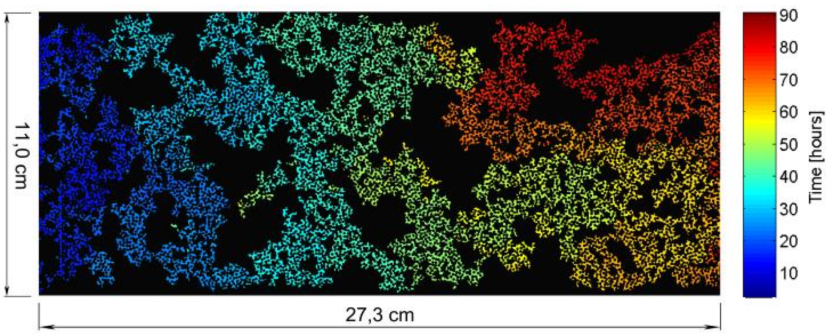

Figure 1: Experimentally measured spatiotemporal evolution of the drainage process.

References

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Secrets Of Aero-fractures: A Dual (Optical/Microseismic) Study

Semih Turkaya[1], Renaud Toussaint[1], Fredrik Kvalheim Eriksen[1,2], Megan Zecevic[3], Guillaume Daniel[3], Eirik G. Flekkøy[2], Knut Jørgen Måløy[2]

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ABSTRACT

In this work, analogue models are developed (similar to the previous work of Johnsen [1]) in a linear geometry, with confinement and at lower porosity to study the instabilities developing during fast motion of fluid in dense porous materials: fracturing, fingering, channeling (Figure 1). We study these complex fluid/solid mechanical systems using two imaging techniques: optical imaging using a high speed camera (1000 fps) and high frequency resolution accelerometers and piezoelectrical sensors. Additionally, we develop physical models rendering for the fluid mechanics (similar to the work of Niebling [2,3]) in the channels and the propagation of microseismic waves [4] around the fracture (Figure 2). We then confront a numerical resolution of this physical system with the observed experimental system.

The experimental setup [5] consists in a rectangular Hele-Shaw cell with three closed boundaries and one semi-permeable boundary which enables the flow of the fluid but not the solid particles. During the experiments, the fluid is injected into the system with a constant injection pressure from the point opposite to the semi-permeable boundary. At the large enough injection pressures, the fluid also displaces grains and creates channels, fractures towards the semi-permeable boundary.

In the analysis phase, power spectrum of different timewindows (5 ms) obtained from the recorded signal are calculated. Then, the evolution of the power spectrum is compared with the optical recordings. The power spectrum initially follows a power law trend and when the channel network is developed, stick-slip events generating peaks with a characteristic frequency can be seen. These peaks are strongly influenced by the size and branching of the channels, compaction of the medium, vibration of air in the pores and the fundamental frequency of the plate. Furthermore, the number of these stick-slip events, similar to the data obtained in hydraulic fracturing operations, follows a Modified Omori Law decay with an exponent p value around 0.5. Using direct simulations of acoustic emissions due to the air vibration in developing fractal cavities the evolution in the power spectrum is investigated.

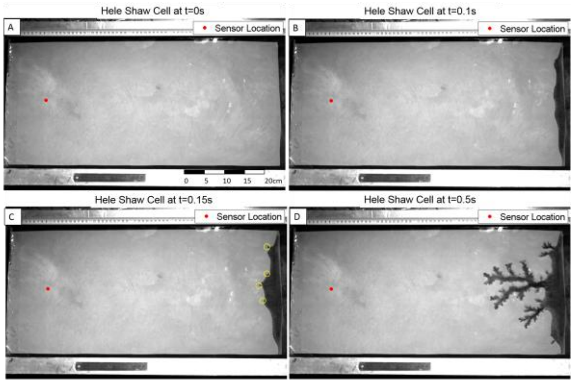

Fig. 1 Aerofractures in a Hele-Shaw cell during air injection.

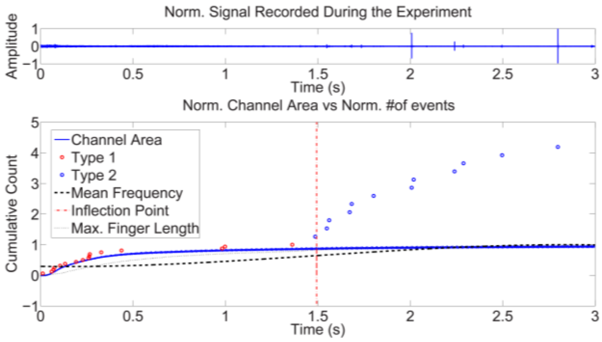

Fig. 2 Top: Signal during air injection inside the cell. Bottom: Number of acoustic events compared with carved area, maximum finger length and mean frequency.

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Dynamics of an unconfined aquifer

Adrien Guérin, Olivier Devauchelle, Eric Lajeunesse

October 5, 2015

Abstract

Rainwater infiltrates into the ground to join a groundwater reservoir, where it flows slowly towards a river. We use a tank filled with glass beads to simulate this process in a simplified laboratory experiment. A sprinkler pipe simulates rain, which infiltrates into the porous material. Groundwater exits this laboratory aquifer through one side of the tank. The resulting water discharge increases rapidly during rainfall, and decays slowly after the rain has stopped.

A theory based on Darcy's law and the shallow water approximation reveals two asymptotic regimes. At the beginning of a rain event, the water discharge increases linearly with time, with a slope proportional to the rainfall rate at the power of 3/2. Long after the rain has stopped, it decreases as the inverse time squared, as predicted by Polubarinova-Kochina (1962). These predictions compare well against our experimental data.

These asymptotic regimes depend on the geometric configuration of the flow. However, field measurements from two distinct catchments exhibit the same asymptotic behaviours as our experiment. This observation suggests that these results could be extended to a broader class of groundwater flows.

Two phase granular transport in cylindrical confinement

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In this study we have experimentally studied the displacement structure that emerge by the slow injection of an air phase into a granular mixture, confined by an horizontally oriented capillary tube. The tube diameter is 1.8 mm and is filled with a granular mixture, consisting of glass beads with an average size of 0.23 mm immersed in a 50/50 solution of water/glycerol. As the density of the grains is greater than that of the solution, the beads sediment to the bottom, forming a sedimented layer.
The moving air-liquid interface is observed to structure the sedimented layer into a pattern, characterized by its series of granular plugs and gaps. The preceding dynamics of the interface is identified to either be in a state of accumulation/compaction, of the region in front of the interface, or to be invading the very same region. These observations were made by capturing images and measuring the pressure in the air phase.

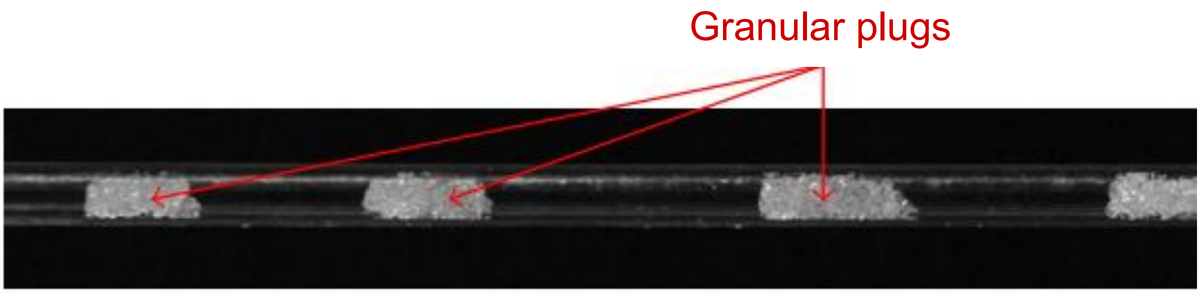

Fig.1: A side-view of the displacement pattern, where granular plugs are followed by gaps

Stabilizing effects of tip-splitting in fingered growth

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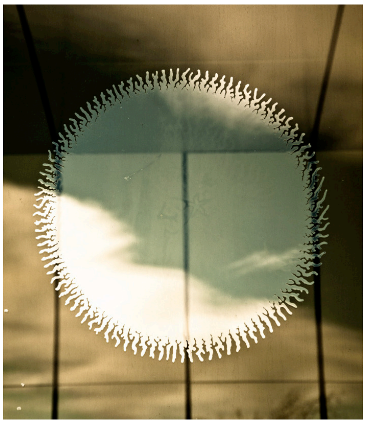
ABSTRACT

Pattern-forming processes, such as electrodeposition, dielectric breakdown or viscous fingering are often driven by instabilities. Accordingly, the resulting growth patterns are usually highly branched, fractal structures. Interestingly, however, in some of the unstable growth processes, the envelope of the structure seems to grow in a highly regular manner, with the perturbations smoothed out over the course of time. A nice example of such a regular growth can be observed on the windows of Vienna underground stations in the vicinity of the EGU conference venue (see the photo on the left).



In this communication, we show that the regularity of the envelope growth can be connected with small-scale instabilities leading to the tip-splitting of the fingers at the advancing front of the structure. Whenever the growth velocity becomes too large, the finger splits into two branches. In this way the system can absorb an increased flux and thus damp the instability. Thus, somewhat counterintuitively, the instability at a small scale results in a stability at a larger scale. The quantitative analysis of these effects is provided by means of the Loewner equation, using which one can reduce the problem of the interface motion to that of the evolution of the conformal mapping onto the complex plane. This allows us for an effective analysis of the multi-fingered growth in a variety of different geometries. We show how the geometry impacts the shape of the envelope of the growing pattern and compare the results with those observed in natural systems.

Aerofractures In Confined Granular Media

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ABSTRACT

We will present our ongoing study of the granular fracturing patterns that form when air flows into a dense, non-cohesive porous medium confined in a Hele-Shaw cell - i.e. into a packing of dry 80 micron beads placed between two glass plates separated by ~1mm. The cell is rectangular and fitted with a semi-permeable boundary to the atmosphere (blocking beads but not air) on one short edge, while the other three edges are impermeable. The porous medium is packed inside the cell between the semi-permeable boundary and an empty volume at the sealed side where the air pressure can be increased and kept at a constant overpressure (1-2 bar). Thus, for the air trapped inside the cell to release the overpressure it has to move through the solid. At high enough overpressures the air flow deforms the solid and increase permeability in some regions along the air-solid interface, which results in unstable flow and fingering patterns. These patterns are thought to be an analogue to hydrofractures, and an advantage of performing such experiments in a Hele-Shaw cell is that the fracturing process can be optically observed in the lab. Our experiments are recorded with a high speed camera with a framerate of 1000 frames per second. In the analysis, by using various image processing techniques, we segment out and study the fracture patterns over time, looking at growth dynamics, fractal dimension and characteristics such as average finger thickness as function of depth into the solid. In addition, by performing image correlation on two subsequent frames, we estimate displacement fields to investigate the displacement- and strain fields in the solid surrounding the fractures. Several experiments are performed with varying overpressure, and we compare the results. In a directly related project [1], acoustic emissions from the cell plate are recorded during experiments, where we aim to correlate acoustic events and observations.

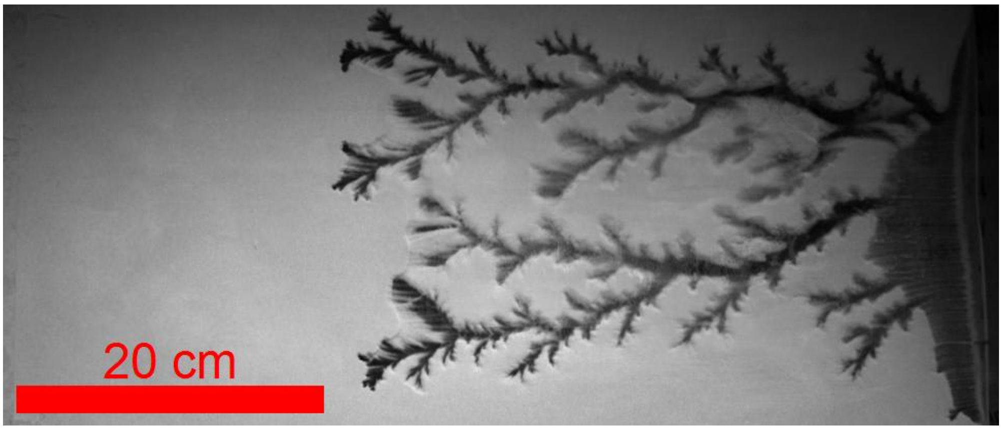

Fig. 1 : Top-down view of aerofractures in the Hele-Shaw cell

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Convective drying of a mixed wet porous medium bounded with a gas purge channel

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ABSTRACT

A fundamental understanding of drying processes in porous media is of great importance to not only the scientific research but also the industrial applications. In proton exchange membrane fuel cells (PEMFCs), dry gas is usually flowed into the gas channel (GC) to remove liquid in the gas diffusion layer (GDL) through the evaporation mechanism after the cell shutdown, Fig. 1. The GDL shows mixed wet characteristics, i.e., hydrophobic and hydrophilic pores coexist. The hydrophobicity of the GDL reduces as the cell operates. Hence, it is needed to understand the drying processes in the GDLs with various wettabilities. In this contribution, a pore network model is developed to understand how the GDL wettability influences the drying processes in the GDL with a gas purge channel. The developed model, which considers the capillary valve effect induced by sudden geometrical expansion and the effect of the liquid viscosity, is validated by comparing the numerical results with the experimental data. Based on this developed model, the drying processes in the GDL are revealed, Fig. 2.

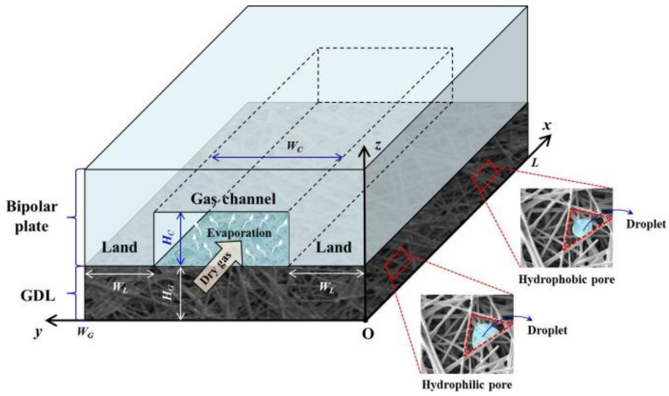

Fig. 1 Drying process in GDL

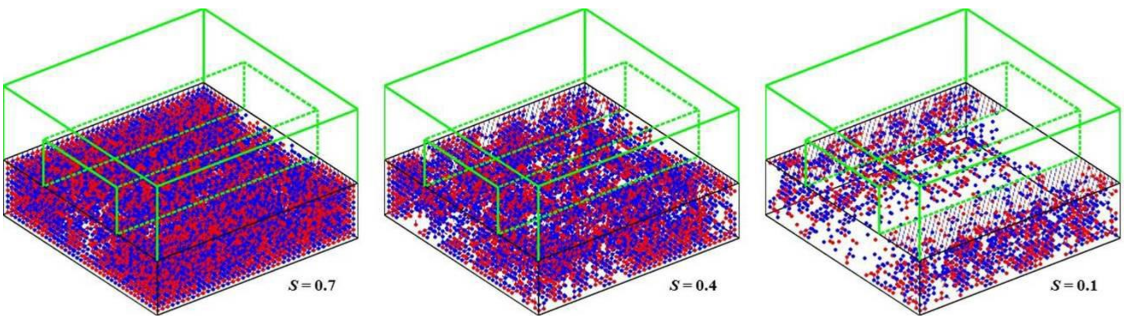

Fig. 2 Variation of liquid distribution in a mixed wet GDL during drying. The blue are the liquid filled hydrophilic pores, and the red are the liquid filled hydrophobic pores.

Soil Liquefaction Without Pressurization: A Simple Mechanism.

Numerical And Experimental Study, Consequences On The Range Of Field Earthquake-Triggered Events

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ABSTRACT

During earthquakes, certain soils can loose their ability to support shear and liquefy. This effect can cause buildings to sink into the soil. We aim to understand the behavior of object sinking into liquefied granular media : can we foresee the velocity of sinking and the final depth of driving in if it exists ? We run numerical simulations and laboratory experiments to study the behavior of a model system, namely the mechanics of an intruder above a shaken model soil, a sphere lying on the top of a (saturated or dry) granular medium shaken by horizontal movements at controlled frequency. The simulations are done with frictional elastic molecular dynamics models. The experiments are monitored using optical data and accelerometers.

Simulations and experiments show that the sphere displays three different ways to enter the granular medium : (1) rigid motion without deformations, (2) liquefaction, (3) convection. The peak ground acceleration (PGA) is the decisive parameter. The final depth of driving in depends on isostasy, and on the severity of shaking.

It can be entirely determined by isostasy, when the shaking entirely unjams the medium and suppresses the average friction around the intruder. For moderate shaking, the liquefaction is absent, or partial, and the sinking is subisostatic. The initial velocity of driving in of the sphere is often sufficient to determine in which of the three behavior the experiment takes place.

We show that the macroscopic response of the medium, once identified in the right regime, can be collapsed on a master curve, with a reduced depth as function of a reduced time. The adimensionalisation is done using an immersed volume determined by isostasy, and a time determined by the imposed frequency.

We also show that the liquefaction effect is maximum when the water table reaches the surface of the granular medium and when the PGA allows the small particles to slide the one on each other but is not strong enough to allow the intruder object to slide on small particles.

We next study the response of a dry granular medium, and how it evolves during liquefaction.

With numerical simulations we study the velocity field and a phase difference between the intruder velocity and the surrounding medium. On the other side with laboratory experiments we compare the accelerometric signals between one accelerometer fixed on the moving box

and one accelerometer inside the sphere. We find again a phase difference which can explain how the object can enter the granular medium. From the velocity field computed during numerical simulation, we can compute an excitation parameter allowing to understand vertical motion (Sanchez-Colina et al., 2014). Eventually the shape of the object has also a real effect, as shown in recent studies (Brzinski et al., 2013). Our experiments shows that cylinders lying on the granular medium are more stable under horizontal shaking than the same cylinder attached to a ring below burried into the medium as buildings foundations. We are currently modelizing this observation with numerical simulations.

Eventually, we show how the derived criteria for liquefaction can render for the field occurences.

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Coupled fluid reactions and deformations in rocks

The Implication Of Rock Transformation On Fault Creep: An Example From The North Anatolian Fault, Turkey

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ABSTRACT

Aseismic creep is found along several sections of major active faults at shallow depth, such as the North Anatolian Fault in Turkey, the San Andreas Fault in California (USA), the Longitudinal Valley Fault in Taiwan, the Haiyuan fault in China and the El Pilar Fault in Venezuela. Identifying the mechanisms controlling creep and their evolution with time and space represents a major challenge for predicting the mechanical evolution of active faults, the interplay between creep and earthquakes, and the link between short-term observations from geodesy and the geological setting.

Hence, studying the evolution of initial rock into damaged rock, then into gouge, is one of the key question for understanding the origin of fault creep. In order to address this question we collected samples from a dozen well-preserved fault outcrops along creeping and locked sections of the North Anatolian Fault. We used various methods such as microscopic and geological observations, EPMA, XRD analysis, combined with image processing, to characterize their mineralogy and strain.

We conclude that (1) there is a clear correlation between creep localization and gouge composition. The locked sections of the fault are mostly composed of massive limestone. The creeping sections comprises clay gouges with 40-80% low friction minerals such as smectite, saponite, kaolinite, that facilitates the creeping. (2) The fault gouge shows two main structures that evolve with displacement: anastomosing cleavage develop during the first stage of displacement; amplifying displacement leads to layering development oblique or sub-parallel to the fault. (3) We demonstrate that the fault gouge result from a progressive evolution of initial volcanic rocks including dissolution of soluble species that move at least partially toward the damage zones and alteration transformations by fluid flow that weaken the gouge and strengthen the damage zone.

Experiment of Dissolution in Radial Geometries in Porous Media and Fractures

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ABSTRACT

Dissolution is very important for the rock deformation. Reaction-infiltration instability refers to the morphological instability of a reactive fluid front flowing in a soluble porous medium. The medium is chemically dissolved in the fluid at an overall rate depending on the local permeability and the rate of flow. Locally, an increase in permeability augments the flow and thus the rate of dissolution. In that way a positive feedback loop is established between dissolution and permeability increase. This process is important for many natural occurring phenomena, such as the weathering and digenesis of earth rock, dissolution in salt deposits and melts extraction from the mantle etc.

My project is focused on experiment of dissolution in Radial Geometries in Porous Media and Fractures. In the experiment, we inject pure water into plaster sample in the Hele-Shaw Cell, taking advantage of the property of plaster slightly soluble in pure water[1][2]; we are able to see the dissolution patterns evolve with time. Here we firstly present the phase diagram of dissolution patterns with influence of Péclet and Damköhler number and the dynamic process of dissolution in 2D radial geometries in porous media and fractures. Péclet number $Pe = q/D$ where q is injection rate and D is diffusion constant and Damköhler number $Da=kh/q$ where k is reaction rate constant and h is characteristic length of system.

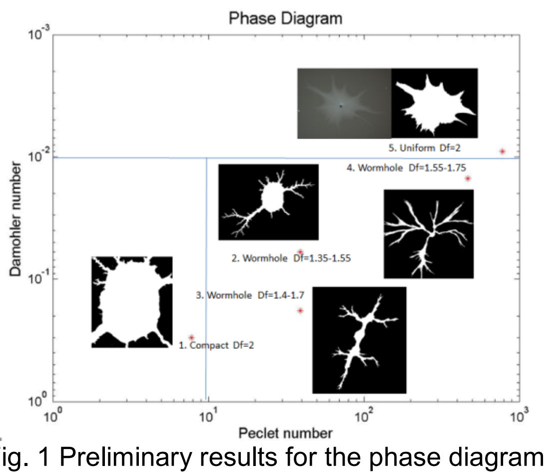

Fig. 1 Preliminary results for the phase diagram of dissolution patterns with influence of Péclet and Damköhler number.

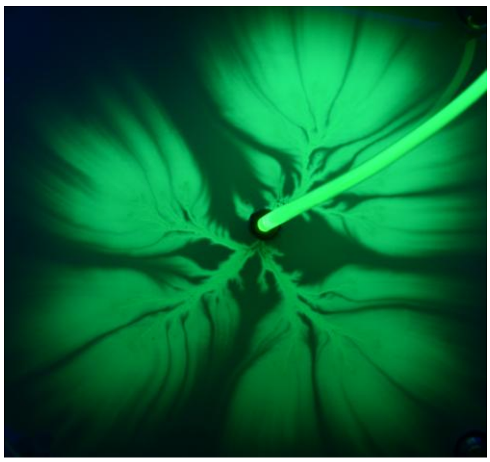

Fig. 2 Flow transport in dissolution pattern and porous media with fluorescence trace

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A review of the effects of coupled fluid/rock reactions in rock deformation at different geological environments

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ABSTRACT

Interactions and phase transitions between fluids and host rocks have been recently shown to govern the macroscopic response of rocks during deformation, in all geological settings (Poulet et al 2014b; Veveakis and Regenauer-Lieb 2015). Examples include fluid release reactions (Alevizos et al 2014; Poulet et al 2014a; Veveakis et al 2014), as well as fluid-assisted dry transitions (Peters et al, 2015). In this work a review of the methods used to tackle the effect of these reactions to deformation and vice versa is presented. The methods are then tested in a suite of case studies.

In particular, for the case of fluid-release reactions we present cases studies of (1) carbonate decomposition/precipitation and serpentine dehydration/hydration in thrusting environments, (2) smectite-to-illite transitions during shale diagenesis in gas reservoirs, (3) clay dehydration in major landslides and (4) K-Feldspar dissolution/precipitation in faulting environments.

For the case of fluid-assisted dry transitions, we present examples of solid rock-fluidised rock transition and grain size evolution in (1) compressive environments forming compaction bands, (2) large scale deformations during boudinage and folding and (3) the formation of zebra bands.

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Coupled mass transfer through a fluid phase and volume preservation during the hydration of granulite: an example from the Bergen Arcs, Norway

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The Precambrian granulite facies rocks of Lindås Nappe, Bergen Arcs, Caledonides of W. Norway are partially hydrated at amphibolite and eclogite facies conditions. The Lindås Nappe outcrops over an area of ca. 1000 km^2 where relict granulite facies lenses make up only ca. 10%. At Hillandsvatnet, garnetite displays sharp hydration fronts across which the granulite facies assemblage composed of garnet (55%) and clinopyroxene (45%) is replaced by an amphibolite facies mineralogy defined by chlorite, epidote and amphibole. The major element bulk composition does not change significantly across the hydration front, apart from the volatile components (loss on ignition, LOI) that increases from 0.17 wt.% in the granulite to 2.43 wt.% in the amphibolite. However the replacements of garnet and of clinopyroxene are pseudomorphic so that the grain shapes of the garnet and clinopyroxene are preserved evenwhen they are completely replaced. The textural evolution during the replacement of garnet by pargasite, epidote and chlorite and of pyroxene by hornblende and quartz in our rock sample conforms to that expected by a coupled dissolution–precipitation mechanism.

SEM and electron microprobe analysis coupled with the software XMapTools V 1.06.1 were used to quantify the local mass transfer required during the replacement processes. The element losses and gains in replacing the garnet are approximately balanced by the opposite gains and losses associated with the replacement of clinopyroxene. The coupling between dissolution and precipitation on both the grain andwhole rock spatial scale preserves the volume of the rock throughout the hydration process. However, the hydration involves reduction of rock density and mass balance calculations, together with volume preservation (isovolumetric reaction) require a significant loss of the mass of the rock to the fluid phase. This suggests a mechanism for coupling between the local stress generated by hydration reactions and mass transfer, dependent on the spatial scale over which the system is open where the fluid infiltration is pervasive along grain boundaries.

Pattern Formation In Mississippi Valley-Type Deposits

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ABSTRACT

One pattern which is frequently observed in the vicinity of economic Pb-Zn mineralization is the zebra dolomite (fig. 1). This rhythmic pattern consists of alternating dark and light dolomitic bands which also show a strong variation in the grain size between the layers. In addition to this grain size difference, a high density of second-phase material is present in the dark layers. The genesis of this structure and its association with the ore-forming processes is controversial

Our research approach is to study the pattern formation with a numerical model based on microchemical and microstructural analysis. The simulations are carried out in 2D at thin section scale and consist of two main processes, namely dolomitization and grain boundary migration affected my second-phase particle densities. The pattern evolving due to a redistribution of the initial second-phase particle scatter followed by grain growth influenced by the impurity densities is similar to those observed in the natural samples (fig. 2). Therefore we put forward a generic model of zebra dolomite formation based on the impurity redistribution by the dolomitizing front and grain growth affected by second-phase particle densities [1].

The crucial mechanism during the pattern formation in our model is the development of a layered impurity scatter. The redistribution process is likely to be related either to the dolomitization [2] or to the mechanics of the coupled fluid/solid system [3]. Which reorganization process is more likely to occur in the environment of zebra dolomites is currently the main research subject.

Fig. 1: Outcrop of zebra dolomite at the San Vicente mine, Central Peru.

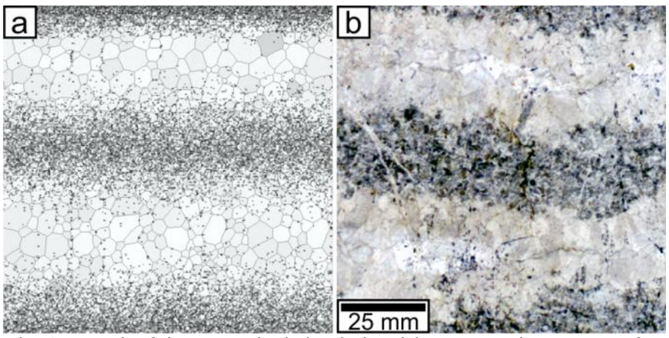

*Fig. 2: Result of the numerical simulation (**a**) compared to a scan of a thin section (**b**).*

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The Importance Of Displacive And Replacive Reactions For Transport Of Fluids And Matter Through Rocks

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Abstract

The Kongsberg-Bamble sectors of SE-Norway are known as classical high grade metamorphic terrains that have undergone extensive metasomatism with formation of albitites and scapolite rich rock and a number of previously economic important ore deposits including the Kongsberg Silver- and the Modum Cobalt mines. We demonstrate here that the central part of the Bamble sector (Kragerø area) has locally developed low grade metamorphic minerals (prehnite, pumpellyite, analcime and thompsonite) belonging to the prehnite pumpellyite and zeolite facies. Structurally the low grad minerals are found both as fracture fills and in the alteration selvages around fracture where the rock is albitised. The fracture fill and the alteration selvages vary from mm to 1 m in thickness and make a high angle with the regional foliation typically with a horizontal orientation. The fractures with low grade minerals are part of larger fracture systems. The low grade minerals are mostly formed in two textural settings or in a combination of these: 1) together with albite, k-feldspar, quartz, epidote and hydrogrossular as lenses along 001 faces in phlogopite and chlorite leading to bending of the sheet silicates through a displacive reaction mechanism 2) by numerous replacement reactions including the earlier minerals as well as the low grade minerals. As albite, k-feldspar, talc, quartz, actinolite, titanite, calcite and hydrogrossular are found in the same veins and in the same phlogopite grain as the classical low grade mineral it is suggesting that they belong to the low grade assemblage and that some of the albitisation in the region occurred at low grade conditions. Reconnaissance studies at east (Iddefjord terrain) and the northwest (Kongsberg sector) sides of the Oslo rift together with reports of low grad assemblages in south eastern Sweden along the continuation of the rift into Skagerak suggest that the low grade assembles occur in rocks adjacent to the Oslo rift along its full extent. Ar-Ar dating of K-feldspar from the low grade assemblage gave an age of 265.2 ± 0.4 Ma (MSWD = 0.514 and P = 0.766) suggesting that the low grade metamorphism is induced by fluids and heat from the magmatic activity of the Permian Oslo rift which require transport of fluid over distances of several kilometres. The displacive reactions created micro fractures in the adjacent minerals and porosity that enhance fluid flow and low grad minerals formation on a local scale. On a thinsection scale the displacive growth of albite in biotite results in a local volume increase of several 100 %.Whether the displacive reactions played an active role in the formation of the shoulder of the Oslo rift remainunknown.

Influence of layering on the formation and growth of solution pipes and cave conduits

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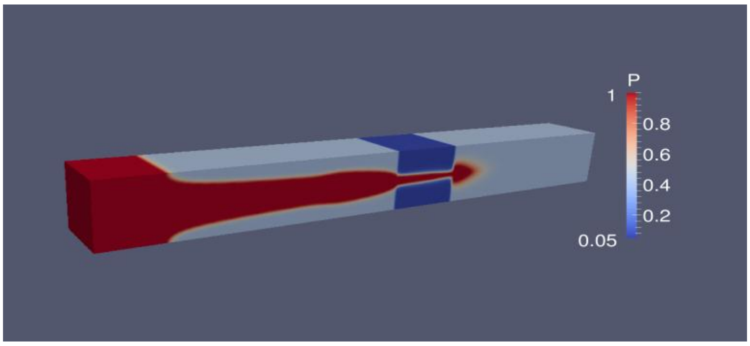
ABSTRACT

Karst systems are the product of the dissolution of carbonate rocks. Their formation are controlled by physical processes (gravitational flows), chemical erosion of the rocks CO_2-saturated water and hydrogeological conditions such as the stratigraphy of the porous medium. These processes are strongly coupled, which can lead to a number of different instabilities, resulting in the formation of dissolutional voids, caverns and conduits [1-2].

Arguably the simplest systems of this kind are solution pipes, in which gravitationally driven water movement carves long-and-thin vertical conduits in limestone rocks. In the homogeneous rocks these conduits are often cylindrical, with almost a constant diameter along their length. However, in a stratified medium, the presence of less porous layers leads to the appearance of the pipes with variable cross-sections – narrower in the tight layers and wider in more porous ones.

In this communication, we investigate numerically these effects with a goal of linking the characteristics of natural forms (such as their lengths, widths or aspect ratios) with the main physical parameters which control their formation (such as flow and dissolution rate and the stratigraphy of the system. We find that not only the shapes of the individual pipes are affected by stratification, but also the growth rates of the pipes and the interaction between them is altered by the presence of the tight layers in the rock [3].

Finally we comment on the possible link between these results and the morphologies of the cave conduits.



Porosity field correspoding to a hydraulic conduit penetrating a less porous layer.

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Effect of Stress on Chemically Induced Creep and Rock Transformation: Insights from Indenter Experiments

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ABSTRACT

In the Earth's upper crust, the slow deformation of rocks, also called creep, is commonly associated with development of mineralogical layering, leading to irreversible transformations of their microstructure. Moreover, active faults in the Earth's upper crust can slide either steadily by aseismic creep or abruptly causing earthquakes. Seismic and aseismic processes are closely related: earthquakes are often followed by transient afterslip creep, and rocks are transformed due to dissolution-precipitation mechanisms. To study these processes where stress is coupled to dissolution and precipitation, indenter experiments developed in the past ten years have been developed and are reviewed in this presentation. This experimental technique is very simple: an indenter is applied onto a rock sample, with controlled stress and temperature, and in the presence of various reactive aqueous solutions. This setup represents how stress is concentrated along grain contacts of a rock, leading to local non-hydrostatic loading conditions that may drive chemical transformations. This experimental technique can be used to study:

- Pressure solution creep laws relevant at upper to middle crustal conditions;
- The interactions between fracturing and comminution processes induced by dynamic stress loading and how they drastically accelerate the displacement rates accommodated by pressure solution creep, providing a mechanism for post-seismic creep;
- The development of differentiated mineralogical layering, similar to that observed in natural deformation in fault zones and sedimentary rocks.

All these indenter experiments share common properties: simplified geometry, high resolution time-lapse measurement of deformation, long-term rheology (some experiments last up to one year), and well-controlled stress. Several samples were also imaged using high-resolution X-ray microtomography to provide additional insights on the damage and geometry. In the past ten years, they have provided unique data sets that demonstrates that the Earth's upper crust is not only brittle, but also show slow aseismic deformations that are localized in space and time.

Coupled fluid-mineral reactions and rock deformation

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ABSTRACT

Fluid infiltration into dry, granulite rocks of the Bergen Arcs, western Norway results in deformation and the formation of shear zones on a range of spatial scales. These allow a detailed study of the relationships between fluid- mineral reactions, the evolution of microstructure and deformation mechanisms. A sequence of rocks from the relatively pristine granulites into a shear zone has been studied by optical microscopy, electron microprobe microanalysis (EMPA), scanning electron microscopy (SEM), electron backscatter diffraction (EBSD) and transmission electron microscopy (TEM), focusing on the progressive development of microstructure in the plagioclase feldspars, leading up to their deformation in the shear zone. At the outcrop scale, fluid infiltration into the granulites is marked by a distinct colourchange in the plagioclase from lilac-brown to white.This is associated with the breakdown of the intermediate compositionplagioclase (An50) in the granulite to a complex intergrowth of Na-rich and Ca-rich domains. EBSD analysis shows that this intergrowth retains the crystallographic orientation of the parent feldspar,but that the Ca-rich domains contain low-angle grain boundaries. Within the shear zone, this complex intergrowth coarsens by grain boundary migration, annihilating these grain boundaries but retainingthe Na-rich and Ca-rich zoning pattern. Analysis of nearest neighbourmisorientations of feldspar grains in the shear zone demonstrates that local crystallographic preferred orientation (CPO) is inherited from the parent granulite grain orientations. Random pair misorientation angle distributions show that there is no CPO in the shear zone as a whole, nor is there significant shape preferred orientation (SPO) in single grains. These observations are interpreted in terms of fluid-induced weakening and deformation by dissolution-precipitation (pressure solution) creep.

Precipitation of $CaCO_3$ in pressure solution experiments: the relative importance of damage and stress

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ABSTRACT

Pressure solution (PS) is a widespread phenomenon in the Earth's upper crust, which influences many important natural processes, including porosity evolution of sedimentary rocks and fault healing. PS is a creep process effecting porous rocks, involving microscale dissolution and precipitation reactions mediated by diffusion of solutes in the fluid phase. We present an experimental study in carbonates, aiming to advance basic understanding of the physical chemistry controlling PS. The experiments utilize a newly developed method which enables imaging the precipitation stage of PS with a confocal microscope, via a fluorescent marker that binds to precipitating carbonate. We use this method to study the relative role of the various driving forces and the dominant mechanisms controlling the amount and spatial distribution of precipitation in carbonates undergoing PS.

Using a clamping apparatus we performed dozens of experiments in which carbonate samples were indented by quartz grains in the presence of water. Carbonate precipitation was observed to occur relatively fast (hours), within and around all indented pits, irrespective of the imposed experimental conditions such as stress and fluid saturation, yet the amount and distribution of the precipitation varies between experiments. Two major factors were found to control the amount of precipitation: degree of damage inflicted by pitting and the application of stress. Fluid saturation was seen to affect the spatial distribution of precipitates. In light of these results, we reexamine the traditional chemical potential equations of PS in order to explain the comparable effects of damage and stress on precipitation.

Pattern Formation In Mississippi Valley-Type Deposits

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ABSTRACT

A rhythmic pattern which is frequently observed in the vicinity of Pb-Zn mineralization is the zebra dolomite. The structure consists of alternating dark and light dolomitic layers whereas the grain size is much larger in the light bands.

In this study, samples from the San Vicente mine in Central Peru were analyzed structurally with Petrographic- and Scanning Electron Microscopy (SEM). In addition to this, micochemical analyses were performed with Electron Microprobe (EMP), and Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS).

The Petrographic microscopy and SEM revealed a high density of impurities which tend to be lined up along grain boundaries. The geometry of the grain boundaries also shows a slight variation between the dark and light regions. During the EMP analysis, no variation in chemical composition of the two dolomite generation was detectable. Only in the central part of the light bands a difference in *Fe* and *Mn* content was observable. This correlates with luminescent structures revealed by Cathodoluminescence-microscopy. High resolution trace element analysis performed with LA-ICP-MS detected variations in different element concentrations between the light and dark layers. The findings observed with the different analytical techniques form the basis of a microdynamic simulation. This simulation will help to understand the fundamental processes which lead to the pattern formation.

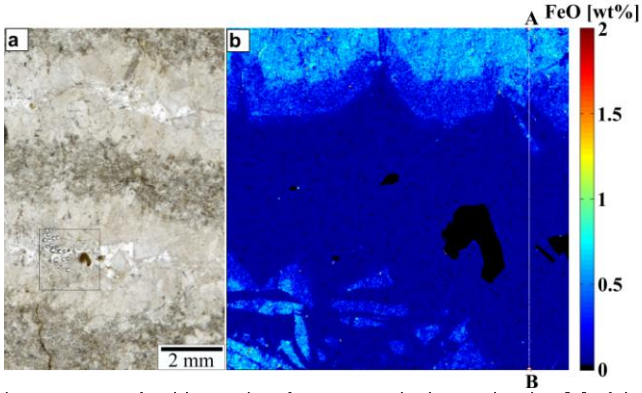

Fig. 1: ***a*** *scan of a thin section.* ***b*** *processed microprobe data[1] of the area indicated in* ***a****.*

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Monitoring Fluids in the Earth Crust

Geophysical investigations of the Salse di Nirano mud volcanic field, Italy, reveal a possible seismic precursory signal.

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ABSTRACT

Mud volcanoes are often characterised by elevated fluid pressures at depth deviating from hydrostatic conditions. This near-critical state makes mud volcanoes particularly sensitive to external forcing induced by natural or man-made perturbations. We used the Nirano mud volcanic field as a natural laboratory to test pre- and post-seismic effects generated by distant earthquakes.

We first characterised the subsurface structure of the Nirano mud volcanic field with a geoelectrical study. Next, we deployed a broadband seismic station in the area to understand the typical seismic signal generated at depth. Seismic records show a background noise below 2 s, sometimes interrupted by pulses of drumbeat-like high-frequency signals lasting from several minutes to hours. To date this is the first observation of drumbeat signal observed in mud volcanoes.

In June 2013 we recorded a M4.7 earthquake, approximately 60 km far from our seismic station. According to empirical estimations the Nirano Mud Volcanic Field should not have been affected by the M4.7 earthquake. Yet, before the seismic event we recorded an increasing amplitude of the signal in the 10-20 Hz frequency band. The signal emerged approximately two hours before the earthquake and lasted for about three hours. We attribute the precursory seismic signal to crustal pressure build up. This may have enhanced pore pressures at depth in the already critically pressurised environment leading to the measured seismic noise.

Effect of Salinity on Streaming Current Generation, Study Of The Effective Excess Charge Evolution

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ABSTRACT

The self-potential (SP) method is of interest in hydrology and environmental sciences because of its non-invasive nature and its sensitivity to water flow and transport processes in the subsurface. The contribution to the SP signal by water flux is referred to as the streaming potential and is due to the presence of an electrical double layer at the mineral-pore water interface. When water flows through the pore, it gives rise to a streaming current and a resulting measurable electrical voltage [e.g. 1]. Several approaches can be used to predict streaming potentials in saturated and partially saturated media. One approach conceptualizes the porous media as a capillary bundle and proposes a flux averaging upscaling procedure to determine an excess charge which is effectively dragged in the medium by the water flow [2]. The proposed model takes into account both the water saturation and the pore water salinity in the medium.

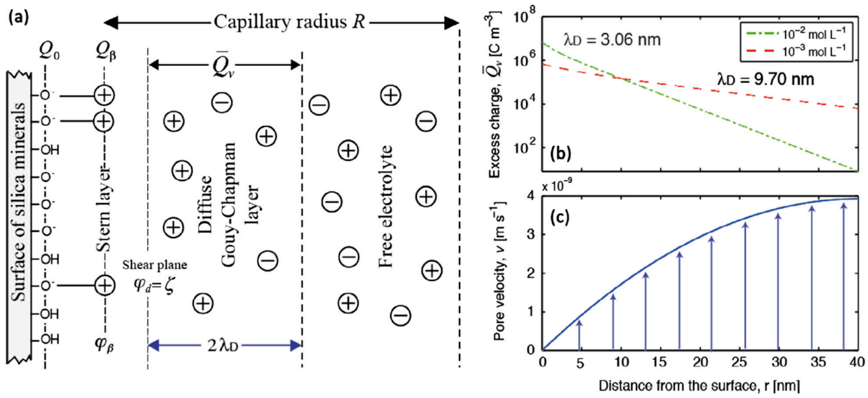

Figure 1: Effect of NaCl concentration on the excess charge distribution in the electrical double layer for a given capillary (modified from Jougnot et al. [3])

In this work we focus mainly on the impact of the pore water salinity on the effective excess charge, from an electrical double layer description at the mineral-solution interface (Fig. 1) to the coupling coefficient at macroscopic scale. The proposed model has been successfully tested against literature data [e.g. 1, 4] and clearly highlights the importance of considering salinity effects when using the effective excess charge approach.

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Monitoring water accumulation in a glacier using time lapse magnetic resonance surveys

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ABSTRACT

Since the catastrophic subglacial lake outburst flood in 1892, the risk of a new event in the glacier of Tête Rousse, in the Alps (close to the Mont Blanc) has been thoroughly studied until now (Vincent et al., 2010, 2012). In the last 5 years, the combination of several geophysical technics has provided valuable input for the glaciologists to better understand the structure and the evolution of sub-glacial liquid water (Garambois et al, 2015). Ground penetrating radar which has proven for long to be a very efficient tool in glacial environment has been used here, providing fine imaging of internal structures, bed rock depth estimate, crevasses and the top of the main cavity. In addition, Magnetic resonance has been performed in 2009, confirming the existence of the liquid water volume, and applied in 2010 along a tight array of loops to provide a 3 D image and an estimate of the total water volume. Indeed, this latter parameter is of major importance to evaluate the level of risk.

Fig. 1, The “Tete Rousse glacier” is located at 3200m altitude, the equipment is installed during 10 days in a tent, and the operators installed the 80x80 m loops generally on the snow.

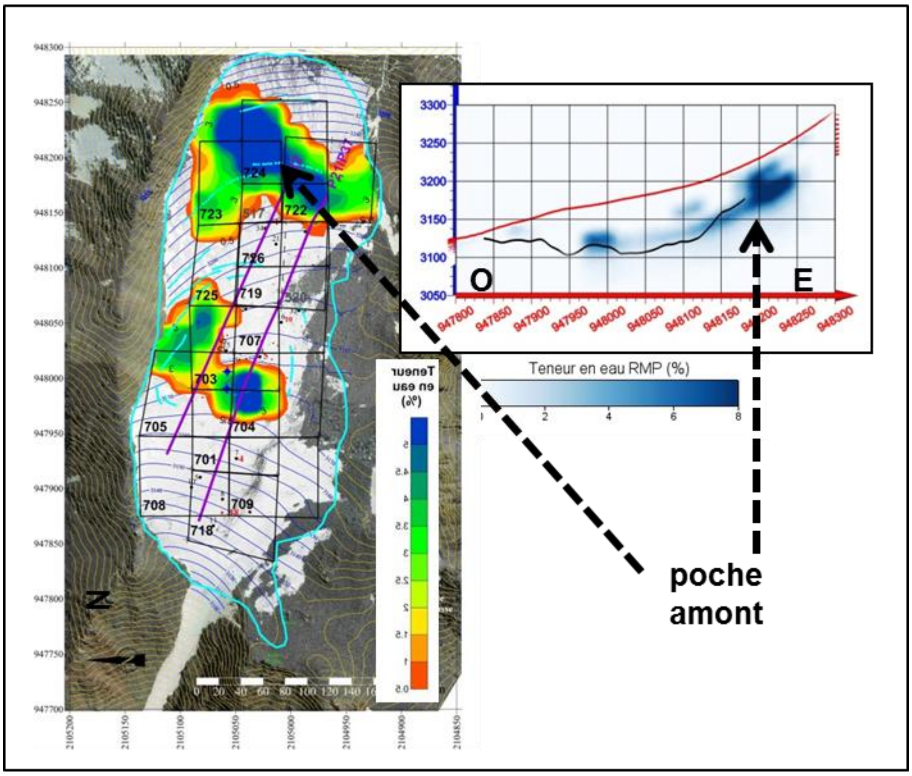

Fig. 2, Left, array of 14 loops performed in 2014 (black squares, 80 m side) allowing to map water content at depth (colorscale) and right, along a profile (altitude – distance)

Since 2010, once or twice a year, a complete 3D imaging of the glacier has been performed using magnetic resonance (Legchenko et al., 2014, Vincent et al., 2015). Comparison of water volumes with the yield of pumping performed in 2010, 2011 and 2012 has allowed to compare the vertical distribution of water estimated by MRS with the pumping. The correlation observed is excellent. Indeed, the total amount of water below the loop is directly the parameter measured by MRS. 3D imaging with MRS is affected by lack of sensitivity with depth, lateral resolution and the 3D model is not unique (Chevalier et al. 2014). But, when looking at cumulated water with depth, most of the equivalence issue is reduced.

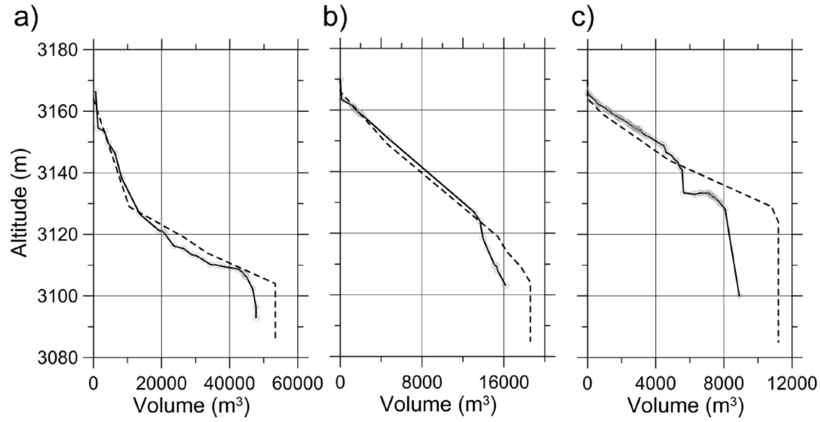

Fig. 3 Cumulated water volume with depth: comparison of 3D MRS estimate and in 2010, 2011 et 2012.

MRS as nowadays proved is usefulness in exploration in glacial environment (Lehmann-Horn et al., 2011, Nuber et al., 2013, Parsekian et al., 2013). But the repeated surveys on the Tete Rousse glacier has prove the efficiency for the monitoring issue when the dynamic of the water variation affects a significant volume, or if a large part is varying from frozen to liquid state. Further effort are to on-going to speed-up the measurements, improve the data quality for a better sensitivity, improve the arrays for better 3D resolution and study the MRS response of snow.

Acknowledgement

Authors thank all the staff who contributed to the success of the several program of monitoring, and the “mairie of Saint-Gervais”, and “préfecture de Haute-Savoie”.

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A 3D Forward Model For Maxwell's Equation with Induced Polarization

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ABSTRACT

A forward model in time domain is presented to simulate the diffusion of 3D electromagnetic field generated by a source transmitter at the Induced Polarization method. We discretize the Maxwell's Equations using the Yee Algorithm. This algorithm is based on a staggered mesh with a electrical field defined at the element edges or mesh points and a magnetic field defined at the center of the element faces. As described in Maxwell's equations, the update of electric field is coupled with the curl of the magnetic field, and vice-versa. A central fourth-order derivative operator is used to discretize the space derivatives. Similarly, a central operator is used to advance the magnetic and electric field in time using Leapfrog scheme. An auxiliary field, which is coupled to Maxwell's Equations to include the Induced Polarization effects, replaces the history depended quantities that are calculated instantaneously. The solution of the Laplace equation, obtained using a fast Fourier transform (FFT), gives the parallel components of the electric field above the air-water interface without an upward-extension of the mesh. In this novel approach, we couple the analytical solution of the electric field used as boundary conditions in mesh points around the source transmitter with the numerical solver of the diffusion of the electric field. Additionally, the infinite size of the real physical system requires an adaptative mesh size to overcome the computing limitations. The error measurements confirm the effectiveness of the discretization scheme and the modeling of the air-water interface. Preliminary results focus on the transient state of the propagation of the electric field in a 3D multi-layered domain after the source transmitter is turned on.

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Lattice Boltzmann Modeling of Streaming Potential : influence of the fluid-rock interface on the electrolyte conductivity

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ABSTRACT

The lattice Boltzmann method (LBM) is a computational fluid dynamics technique that allows to simulate advection and diffusion phenomena. We focus here on the streaming potential phenomenon by reproducing the mass transport of an electrolyte in a channel, and the electric field generated by the charges displacements. Streaming potentials are characterized by the ratio of the macroscopic potential difference arising from the flow on the pressure difference that generated the flow. This ratio is known under the name of electrokinetic (EK) coefficient, and is supposed to be inversely proportional to the conductivity of the electrolyte, according to the Helmholtz-Smoluchowski equation. The EK coefficient depends on three other parameters that are the permittivity, the viscosity of the electrolyte and the zeta potential, which is the potential of the plane separating the moving fluid from the charges adsorbed at the rock surface.

The LBM approach allows to explore the effects of the ionic distribution within the channel. The simulations show how this ionic distribution makes the bulk electrolyte conductivity differ from the conductivity of the electrolyte measured out of the rock. This difference increases with increasing zeta values, and is quantified through the calculation of an effective conductivity. This effective conductivity is a more precise expression of the bulk fluid conductivity, in the sense that it allows to take into account the effective repartition of the species within the channel, but also the nature of these species (valences, mobilities).

This study also allows to assess the error introduced by the Debye-Hückel approximation in the Helmholtz-Smoluchowski equation. The Debye-Hückel approximation is an expression of the potential within the channel that is valid with the assumption that the potential is inferior to 25mV in absolute value, which is far below the zeta values that are derived experimentally. The simulations provide an insight on the error that is made when the zeta potential is derived from streaming potential measurements without correction.

This model can be further developed for the comprehension of streaming potentials in unsaturated conditions.

Geophysical Monitoring of Changes to the Subsurface Caused by Fluid Injection

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ABSTRACT

As fluid is injected into the subsurface from a borehole during various industrial applications, geophysical properties such as seismic velocities and electrical conductivity are altered which leaves open the possibility of using time-lapse seismic and electrical surveys to monitor where the injected fluids go and what they do to the subsurface. Material properties are changing by three dominant mechanisms: (1) in situ fluid of one type is being replaced by invading fluid of a different type; (2) changing stress and pore pressure are causing pre-existing fractures to either close or open which alters the elastic moduli and the transport properties of the rocks; and (3) new cracks and/or fractures are created once thresholds are reached which further alters the elastic moduli and transport properties. Over longer time periods, chemical alterations of the rocks may occur but we do not focus on such alterations at this time. For the last 18 months, our geophysics group at LBNL has been tasked with determining ways to model the above processes and to formulate the inverse problem for obtaining the initial stress-state and material properties that held prior to the start of injection using time-lapse geophysical data. In this talk, I will present some of the approaches and models we have been developing. I will review models for how the elastic moduli and transport properties of rocks change with evolving stress and fluid pressure. Such models will be used in new finite-difference simulations to show by how much geophysical properties and geophysical signals are altered by a simulated brine injection process. In formulating the inverse problem for the initial conditions, it is important to be able to calculate how the fluid injection is altering the subsurface including the geophysical properties. The two principal remaining challenges that the hydro-geological and geophysical communities have not yet properly resolved is how to forward model immiscible invasion and how to allow new damage in the form of cracks and fractures to arrive in the subsurface and alter the properties. New approaches for tackling these two challenges will be presented as time permits.

Seismoelectric Study Of The Vadose Zone Using Shear Wave Sources

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ABSTRACT

We study seismoelectric conversions generated in the vadose zone, when this region is traversed by a pure SH wave. We assume that the soil is a partially saturated one-dimensional porous media where water flow obeys Richards' equation[1], and we use the van Genuchten[2] constitutive model to compute the water saturation as a function of pressure height. Correspondingly, we extend Pride's formulation[3] as suggested by Warden et al.[4] to deal with the described conditions, introducing two different saturation dependent functions, namely one monotonous[5] and a non monotonous one[6] into the electrokinetic coupling coefficient. We consider different soil textures and analyse how they affect, among other relevant properties, the electrokinetic coupling coefficient and interface responses, and observe that the latter are several order of magnitude stronger than the coseismic signal, contrary to what happens in the P-wave case.

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ITN FLOWTRANS

INTERNATIONAL CONFERENCE

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University of Strasbourg

KEYNOTE SPEAKER BIOGRAPHIES

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Alex Hansen obtained his PhD from Cornell University in 1986. He was then postdoc at the Ecole Normale Supérieure in Paris, the University of Cologne and the University of Oslo. This was followed by a permanent position at the University of Rennes 1. In 1994, Dr. Hansen was appointed professor in physics at the Norwegian University of Science and Technology. He is a member of the Norwegian Academy of Science and Letters, holds an honorary doctorate from the University of Rennes 1 and is currently vice president of the International Union of Pure and Applied Physics (IUPAP). Dr. Hansen is furthermore editor-in-chief of Frontiers in Physics besides serving on other editorial boards. He is chair of the board of the geophysics consulting company CEGNOR AS. Dr. Hansen has to date published some 275 papers.

Dr. Hansen's main research interests have two branches: fracture phenomena and immiscible multiphase flow in porous media. The fracture work has recently been concentrated on the use of the fiber bundle model in connection with stable crack propagation under mode I conditions. A book on the fiber bundle model authored with P.C. Hemmer and S. Pradhan has been published this year by J. Wiley-VCH. Another main topic under the heading of fracture has been the development of topological methods to compare quantitatively model fracture networks with fracture networks found in Nature. The work on multiphase flow in porous media has been concentrated on using methods from statistical mechanics and non-equilibrium thermodynamics to describe the flow.

Damien Jougnot

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Born and raised in Dijon, France, Damien Jougnot received a Bachelor in Environmental Geo-engineering from the University of Bordeaux in 2004 and a Master of Hydrogeology from the University of Avignon in 2006.

Over the course of his PhD thesis at the University of Savoie, Damien developed several petrophysical models to determine the transfer properties of a potential host rock for nuclear waste storage. This work was funded by the French Nuclear Waste Agency and supervised by André Revil. During this period, Damien spent 15 months as a visiting scholar at the Colorado School of Mines. He obtained a PhD degree in Geosciences in 2009. From 2009 to 2014, he was Junior Lecturer working in the group of Niklas Linde at the University of Lausanne, Switzerland. In 2013 and 2014 he has been appointed visiting professor at the Faculty of Astrophysics and Geophysics, University of La Plata (Argentina).

Since 2015, Damien is Associate Scientist at CNRS, at UMR7619 METIS, University Pierre and Marie Curie, Paris, France. His current research activities mainly focus on how self-potential and spectral induced polarization data can be used to better understand, quantify, and predict near surface processes, from the laboratory to the field scale. More recently, he has also been working on the theory of the seismo-electric method.

Manolis Veveakis

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Manolis Veveakis is an Assistant Professor of Geomechanics in the School of Petroleum Engineering of UNSW, since 2014. Prior to that he was a Research Scientist in CSIRO's Division of Earth Sciences and Resource Engineering. He holds a Diploma (BSc+MEng) in Applied Mathematics and Physics (MEng in Materials Engineering), an MSc in Applied Mechanics and a PhD Geomechanics. He received his PhD in 2010 from the Faculty of Mechanics of the National Technical University of Athens, Greece, under the supervision of late Prof. Ioannis Vardoulakis.

His research interests include Theoretical and Applied Mechanics, Geomechanics, Applied mathematics for nonlinear coupled partial differential equations and Continuum thermodynamics modelling for earth sciences. His current activities focus around fault (including landslides) and earthquake mechanics, fluid flow through nominally impermeable (unconventional) rocks, melt segregation through partially molten rocks, theoretical concepts of failure in materials with internal dissipative mechanisms, theoretical concepts of thermodynamic homogenisation, experimental thermographic techniques for geomaterials, and the development of the open source finite element code REDBACK (Rock mechanics with dissipative feedbacks), in collaboration with Dr. T. Poulet and CSIRO.

Steve Pride

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Steve Pride is a staff scientist at the Lawrence Berkeley National Laboratory and an adjunct professor at the University of California at Berkeley. His research interests are in all aspects of the physics of porous materials including acoustics, geomechanics and flow and other transport processes. He obtained his B.A. at the University of California at Berkeley and his Ph.D. at Texas A&M University in 1990. Following two years as a post-doc at MIT, he was a Maitre de Conferences at the Institut de Physique du Globe de Paris, a professor at the University of Rennes and a visiting professor at Stanford University before returning to Berkeley in 2003.

Bjornar Sandnes

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Bjornar Sandnes is Associate Professor at the College of Engineering, Swansea University. His research focuses on multiphase flows and complex flow behaviour in granular materials and granular-fluid mixtures. He took his PhD in renewable energy physics at University of Oslo where he subsequently worked as a postdoc in the Advanced Materials and Complex Systems group. He later worked at University of Sydney and Macquarie University in Australia on a personal fellowship, spent a year at NTNU, Norway as Associate Professor, before taking up his current position at Swansea University. At Swansea, Sandnes is a member of the Energy Safety Research Institute and the Centre for Complex Fluids Processing.

Stéphane Santucci

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Stéphane Santucci is a CNRS researcher working at the Physics Laboratory of ENS-Lyon since 2008. He obtained a Ph.D. in Physics at ENS-Lyon (2004), and spent 4 years at the University of Oslo (Norway), working in the "Complex Systems and Advanced Materials" group (2004-2007) and at the Physics of Geological Processes center (2008). His research activity – essentially experimental – concerns the "Deformation, Flow and Fracture" of heterogeneous materials. He focuses on the "avalanche dynamics of disordered elastic systems", in the context of material failure (subcritical rupture, rupture instability in adhesives, crack interactions and crack patterns) and fluid invasion of a porous medium (imbibition). In collaboration with industrials, he has also developed recently new patented methodologies to formulate novel complex fluids made of microcapsules.

Oliver Plümper

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Oliver Plümper is an assistant professor at the Department of Earth Sciences at Utrecht University, the Netherlands. He obtained a B.Sc. and M.Sc. in Geosciences at the University of Münster, Germany, and a Ph.D. at Physics of Geological Processes, University of Oslo, Norway. His research interests span the fields of fluid-rock interaction, nano(geo)science and rock deformation. He approaches his research questions through an interdisciplinary approach of field work, experiments, micro- and nanoanalytics and theory. Currently he focuses on the physics of mineral hydration reactions, reactive fluid flow in nominally impermeable rocks, fluid release during mineral dehydration and nanoscale processes in fault zones.

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Ziyadin Cakir is an Associate Professor in the Department of Geology at Istanbul Technical University, Turkey, where he has been a faculty member since 2006.

Ziya completed his Ph.D. jointly at Istanbul Technical University and Institut de Physique du Globe de Paris, France, his M.Sc. studies at Bristol University, UK, and his undergraduate studies at Ankara University, Turkey.

His research interests lie in the area of active tectonics, ranging from paleoseismology to mapping and modeling surface deformation using SAR interferometry, with a focus on how the faults and the crust behave during the earthquake cycle. In recent years, he has focused on the characteristics of surface creep along active faults.

Biographies,
ITN FlowTrans Participants and associates

UNIVERSITY OF GLASGOW

DANIEL KOEHN
FlowTrans Principal Investigator and FlowTrans Co-ordinator

My general background is Structural Geology, I study the deformation of rocks on various scales. My main interest is pattern formation in rocks and at the moment I am working on stress driven dissolution and roughening in rocks, banding in rocks, dynamic permeability changes in rocks, fracturing, fracture sealing and fluid flow as well as stress inversion techniques. I combine a lot of field research (working in Uganda, Namibia, Oman, Italy, Peru, Brazil…) and microscopy with numerical simulations and sometimes experiments. I work in collaboration with oil and gas, mining and geothermal industry partners.

I did my PhD in Mainz, had a 2 year post-doc position in Oslo with Bjørn Jamtveit where I met Francois, Dag, Eiric and Renaud, went back to Mainz as an assistant for 8 years and then started a permanent position about 3 years ago at the University of Glasgow. I started early on already during my PhD in Mainz to use numerical simulations and experiments to study the evolution of microstructures in rocks. When I was in Oslo in a mixed Physics and Earth Science group I continued with numerical simulations mainly focusing on dissolution and roughening in rocks.

In my experience interdisciplinary research is the way forward to achieve new and exciting results that are beyond a specific discipline. That's why I am very much looking forward to the FlowTrans research environment where we will hopefully generate such a vibrant experience for our fellows.

I have a family and two kids, this is probably my main hobby at the moment. I like traveling, hiking, running, used to do music and gymnastics, love rocks and pattern formation, like to read, play lego and playmobile and get beaten in chess by my son!

NICOLAS BEAUDOIN
FlowTrans Experienced Researcher

I am FlowTrans Experienced Researcher, based at the University of Glasgow.

During my education and PhD thesis at Université Pierre et Marie Curie in Paris, France, I specialised in analysing fluid-rock interactions during deformation from chemical, structural, and mechanical points of view.

My PhD thesis especially focused on decipher the evolution of the temperature, pressure and the chemistry of fluids (called fluid system) moving through a diffuse fracture network formed in relation with the development of folds and foreland basin. This interdisciplinary study bridged the fields of field geology, structural and microstructural analysis, fracture mechanics, and paleofluid geochemistry, requiring a multiscale analysis of fracture geometry and fluid chemistry from the vein cements to foreland basin (case study: the BigHorn Basin, Wy, USA). I developed and applied a novel structural sensibility to fluid-rock interactions that I now apply to the research subject of the drain/barrier capability of stylolites and fracture networks, and when pressure solution was triggered in a natural compressive environment.

My postdoctoral fellowship namely focus on understand the role of stylolite on fluid migration during compression at several scale, from the grain scale to the fold-thrust belt scale. I address this question through a natural case study, the appeninic Umbria-Marche belt, in Italy, where I am reconstructing the fluid system that characterized the limestone from the early pressure-solution event to the current extension that experience the area.

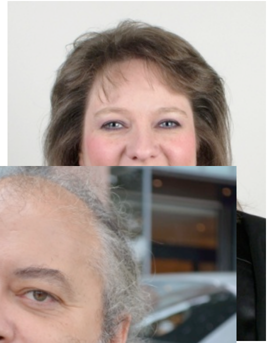
ULRICK KELKA
FlowTrans Early Stage Researcher

I am the FlowTrans Early Stage Resarcher at the University of Glasgow.

The aim of my FlowTrans research is to understand the genesis of the so called zebra textures in Dolostones. These structures often occur in MVT-ore deposits and are probably linked to the hydrothermal ore-forming processes. In order to obtain highly diagnostic information on the involved processes, samples from the San Vicente Mine in Peru will be analysed with optical microscope, SEM and X-ray microtomography. By this procedure knowledge is acquired on the processes which occur during the genesis of the zebra textures and the ore-forming processes. These findings will finally be implemented in a numerical model. For this purpose a special microdynamic simulation software (ELLE) is used.

I received my Diploma in Geology in January 2013. My main topics were applied geology, geophysics and tectonophysics. The subjects of applied geophysics and tectonophysics became my main interests. The major aim for my Diploma thesis was to obtain knowledge on the functionality of a commercialy destributed measurement device, which is supposedly able to detect electromagnetic signals generated during the formation of microcracks. For the purpose of understanding this “black box” another very simple device was developed which was, in contrast to the other, able to save the raw data.

WENDY-LOUISE SMITH
FlowTrans Research Administrator



I am the FlowTrans Research Administrator. My BSc(Hons) degree is in Agricultural, Food and Environmental Chemistry, from Glasgow University. My PhD research involved hexavalent chromium reduction by sulphate-reducing bacterial biofilms.

I am an artist and particularly enjoy mixed media. I am inspired by the textures, shapes and structures of both the natural and man-made landscape, and create responses to these through drawing, painting and textile art. I also make quilts and textile art.

CNRS/UNIVERSITY OF STRASBOURG

RENAUD TOUSSAINT,
FlowTrans Principal Investigator

I am CNRS researcher in geophysics at the experimental physics group at the Institute for Globe Physics in Strasbourg, CNRS / University of Strasbourg, France.

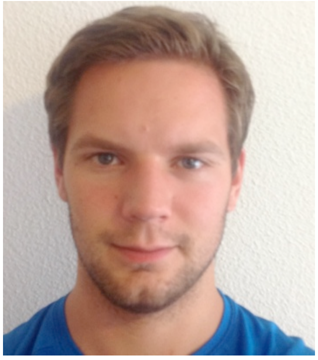
I am the PI for 2 FlowTrans projects in Strasbourg, on which Fredrik Eriksen and Semih Turkaya are ESR. One of them relates porosity changes and fracture during fast fluid flow in porous media, involving one or two fluids in a deformable media, as during aerofracture or hydrofracture. The other one relates to porosity changes involving both momentum exchange, and/or material exchange and chemical reactions during flow. Seismic and acoustic monitoring techniques are used in addition to fast optical measurements of the fracking processes. Both ESR working on these subjects will use a combination of experimental and modelling techniques, and will collaborate with other groups in the ITN.

My background is originally on theoretical physics, with through the years interests shifting towards complex systems in earth science, and the addition of computational techniques and experimental work to my toolbox. I studied at the Ecole Normale Supérieure de Lyon and at IPG Paris in maths, physics and geophysics, and later on did a PhD at the University of Rennes on theoretical aspects of fracture, three years of Postdoc in the complex group in Oslo and Trondheim, and joined CNRS in Strasbourg in 2004.

I'm interested in a variety of complex pattern forming processes in Earth science: slow and fast fracture processes, multiphasic flow in deformable or reactive media, stylolite formation, what they can tell about their environment and how they impact the rocks, and surface processes, as avalanches, quicksand and soil liquefaction, on which Cécile Clément is doing her PhD.

My hobbies are various, they include wandering and meeting different cultures, photography, and recently playing with the evolution of three dimensional stereophotographic techniques, composition of 360 degrees panorama, and in general science popularization, and interaction with children and education – mine, Nino and Yann, and others around.

FREDRIK ERIKSEN,
FlowTrans Early Stage Researcher



I am an Early Stage Researcher in the FlowTrans ITN, and am based at CNRS/IPGS in Strasbourg. I will be researching flow in chemically evolving fractures. The project will study the evolution of porosity during a slowly reactive flow in porous and fractured carbonates, and the evolution of stress for confined rocks associated to reactions.
I have a Bachelor in Natural Sciences and a Master of Physics, from the University of Oslo. My Masters project consisted of experiments with two-phase flow in non-deformable and deformable media. My research interests are two-phase flow, porous media, granular materials and general experimental work.

I enjoy working out, good movies and TV shows, reading news and books, travelling and technology.

SEMIH TURKAYA,
FlowTrans Early Stage Researcher

I am the FlowTrans Early Stage Researcher based at IPG Strasbourg, working with Professor Renaud Toussaint. My topic title is "Evolution of tight rocks during fluid injections: channeling, fracturing and mechanical instabilities due to fast fluid flows." We are doing experiments in a rectangular Hele-Shaw cell with granular material to predict and control the mechanical stability of rock formations and soils during the injection or extraction of fluids. In time, some numerical and theoretical studies will follow.
In my undergraduate period, I studied Civil Engineering in Turkey. Then, I continued my studies with Erasmus Mundus Masters of Earthquake Engineering and Engineering Seismology Programme in UJF Grenoble and IUSS Pavia (Rose School). As a researcher, I like playing with waves, investigating mechanics of granular materials and fluids.
In my daily life I like involving with modern dances, often hiking, swimming, and exploring medieval history.

HEBREW UNIVERSITY OF JERUSALEM

EINAT AHARANOV
FlowTrans Principal Investigator

I am a Professor of geophysics and structural geology at the Hebrew University in Jerusalem, Israel. As PI of the FlowTrans project at HUJI, I host Stanislav Parez as ER (i.e. postdoc). Stanislav and me are working together on simulating and theoretically analysing coupled deformation of granular media fluids using a DEM code coupled with fluids, and we also collaborate on this project with Renaud Toussaint from Strasbourg. In the first part of his post-doc Stanislav analysed non-steady dry granular flows down slopes to understand the evolution and runout of landslides. Stanislav obtained equations of motion of non-steady flows and compared to theory, and finally applied this to landslides. Now we are working on adding fluid flow and seeing how this fluid addition effects landslide initiation and also liquefaction.

I did my BSc at Tel-Aviv Univ, my PhD in MIT, and my post-doc at Columbia Univ. My PhD was on reactive ow in deforming porous rocks, and my post on granular media deformation and reactive flow. I continue to work on rock physics, in particular how small-scale (granular, pore) effects change large scale behavior. I focus on pressure solution, stylolites, granular media, faults and friction, and I love to combine theory, modelling, lab and field work!

In addition to doing science and teaching i also love hiking up and down and generally being outside - so lucky i am doing geology….

STANISLAV PAREZ
FlowTrans Experienced Researcher

I am a FlowTrans postdoc at the Hebrew University in Jerusalem, working with Prof. Einat Aharonov. My background is in pure physics but during my postdoc I have moved to work on physics of rock deformation. Specifically, I model coupled granular-fluid deformation, studying the physics and mechanics of landslides, fault zones, and earthquakes. I study dynamics of granular aggregates subject to shear by means of discrete element simulations. My recent results address the question why large landslides have longer runout compared to small slides.

My previous work concerned properties of the so-called “electric double layer” formed by an aqueous salt solution at mineral surfaces. Using molecular simulations, I studied behaviour of dielectric constant and viscosity in the thin interfacial region, where they significantly differ from their bulk values. The results challenged the classical implicit solvent models which overlooks the molecular nature of the solvent. My general interests include soccer, table tennis, running and hiking. I also enjoy rock and jazz, and Latin rhythms.

SHAHAR BENZEEV
Guest Student

I studied B.Sc in Geology in the Hebrew University in Jerusalem (2012-2015). Currently I'm a M.Sc student under the supervision of Prof. Einat Aharonov from HUJI and Dr. Liran Goren from BGU.

My research areas include Mechanical Coupling of Fluid-Filled Granular Material in general, and in particular the Buoyancy Effect in Fluid-Filled Granular Material Systems.

I am also generally interested in traveling ,hiking and music.

ANNER PALDOR
Guest Student

I Studied Geology in the Hebrew University 2008-2011 (B.Sc). I started my M.Sc in 2012. I am currently a Ph.D student in the Freddy and Nadine Harman Institute of Earth Sciences, HUJI, working under the supervision of Prof. Einat Aharonov.
My research areas include Submarine Groundwater Discharge and its effect on seafloor stability, long-range groundwater flow regime.

My interests also include basketball, hiking, and history.

INSTITUTE OF STAVANGER (IRIS)

Jan Ludvig Vinningland,
FlowTrans Associate

I am a research scientist at the International Research Institute of Stavanger (IRIS), based in Oslo. IRIS is an associated partner in the FlowTrans ITN and we are a secondment institution for the two FlowTrans ESRs based at Strasbourg.
I work at the Enhanced Oil Recovery (EOR) group at IRIS where we try to understand the physical and chemical mechanisms at play when water is injected into oil bearing rocks, with special focus

on porosity/permeability changes and maximum recovery. Through both experimental and numerical activities we try to cover the whole range of scales from pore-scale via core-scale up to reservoir-scale. Long lasting water flooding experiments at reservoir conditions (e.g high temperatures and pressures) using both outcrop and reservoir core samples provide measurements of the chemical and mineralogical changes (dissolution and precipitation) taking place in the cores. In a new project (a collaboration with Prof. Dag Dysthe at the University of Oslo) we will now also investigate pore scale mineralogical changes in-situ. IRIS also collaborate closely with the University of Stavanger (UiS). The Norwegian Ministry of Petroleum and Energy recently decided that a new national research center for enhanced oil recovery will be hosted by UiS and IRIS.

At IRIS we have a close collaboration between experimental, theoretical and numerical activities. Using numerical pore- and core-scale models we try to predict the chemical and mineralogical changes we observe in the experiments. Through the interplay between experiment and simulation we try to establish effective theories that can be employed on larger scales, ultimately on the reservoir-scale, in order to predict changes in rock properties and to optimize the use of enhanced recovery methods in producing reservoirs.

I mainly work with numerical models for reactive flow at pore-, core- and reservoir scales. At the pore- and core-scale we employ a Lattice-Boltzmann model that is coupled to a geochemical solver which predicts the amount of dissolved or precipitated minerals based on the concentration of a set of basis species. At the field-scale we use streamline models and both commercial and in-house reservoir simulators.

I graduated from the University of Oslo as a PhD in Physics in 2007 with a thesis on the granular Rayleigh-Taylor instability. During my PhD and later as a PostDoc the main focus of my research was numerical modeling of granular flows using a hybrid model where the grains are discrete objects that interact hydrodynamically via a continuum fluid pressure field.

MAGNITUDE

Guillaume Daniel,
FlowTrans Principal Investigator

I am a seismologist and work as a research and development scientist at Magnitude, France. Magnitude is an earth science company providing comprehensive microseismic monitoring services to a range of industries worldwide including the petroleum, gas and mining

industries. Commercial activities range from the long-term monitoring of mining/underground storage environments, to the monitoring of microseismicity induced by hydraulic fracturing operations.
My research focuses on the analysis of (micro-)seismic swarms, of the role of crustal fluids in triggering earthquakes, and on the retrieval of sound geomechanical information from miroseismic data. Previous research activities also includes the statistical modelling of earthquake timeseries, and the study of large earthquake sequences and long-short-range interactions.

I am the PI for the Experienced Researcher at Magnitude – Megan Zecevic. Our FlowTrans research will focus on microseismic low-frequency events. Hydraulic fracturing is a procedure used to increase permeability of unconventional reservoirs by injecting fluid at high pressure into the rock formation. This forced fluid flow significantly affects reservoir geomechanical properties, such as permeability and stress state. Monitoring the induced microseismicity during and after reservoir fracturing has proven to be an effective tool in characterizing these changes. Recent advances in seismology suggest that together with micro-earthquakes low frequency events could have an important role in accommodating the deformation and therefore could be used to characterize fluid/rock interactions.

This research project aims at identifying and analyzing such low frequency events in hydraulic fracturing data sets to provide geomechanical information on pre-existing faults, fluids and slow deformation processes.

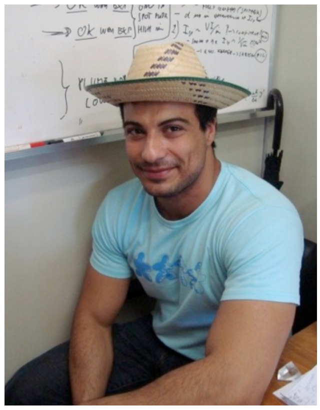
ORG GEOPHYSICAL

Eirik Flekkoy, FlowTrans Principal Investigator

My current activities are research leadership, teaching and communication. My research and teaching concerns petroleum related problems of physics/geophysics, in particular granular flows, two phase flow in porous media and hydrodynamics. The research is based on computer simulations and theory in collaboration with experimentalists. I teach one course on computer simulations in physics and one on statistical mechanics and hydrodynamics.

Apart from Norwegian, I speak English and French. For play I enjoy time with my kids, as well as sailing, kiting, surfing and mountain climbing.

MARCUS VINICIUS CARNEIRO
FlowTrans Experienced Researcher



Experienced Researcher at ORG Geophysical. The current project aims at the development of a 3D inversion algorithm at the electromagnetic response for induced polarization at the identification of oil reservoirs offshore.
I have got my bachelor in Computer Science with emphasis in computational physics and complex systems. Previous works include study of population dynamics and chaotic behavior in granular media. Degrees obtained in Brazil at UFLA, and at the Institute for Space Research.

I recently concluded my Ph.D. at ETH Zürich. Thesis investigated the sand transport in Aeolian saltation. My results are mainly from numerical simulations using DEM, which were compared with experiments done later at the wind tunnel. The main challenge at the numerical modelling was the momentum coupling between the sand grains and the airflow.

I cannot live without lifting weights at the gym. I enjoy movies, cartoons, history, languages, cultures, psychology, and spiritualism. The different perspective of life between people from the developed and developing countries is my main personal open question

UNIVERSITY OF COPENHAGEN

JOACHIM MATHIESEN
FlowTrans Principal Investigator

I am an associate professor at the Niels Bohr Institute and have a PhD degree in theoretical physics. I have previously been a postdoc at the Weizmann Institute in Israel and at NTNU in Norway and I was for a period professor at University of Olso in the Norwegien Centre of Excellence “Physics of Geological Processes”.

The FlowTrans objective is material deformation by advection or diffusion of an internal scalar variable, such as a reactant concentration or temperature that couples to the mechanical strength of a material. The project will focus on analytical models and/or the development of numerical methods.

My research interests are in complex systems including fluid flow, solid mechanics and complex networks. I usually find many pattern forming processes in nature intriguing and have lately been working on columnar joints, stylolites, viscous fingers etc. At the Niels Bohr Institute, I give lectures in continuum mechanics and mathematics for physicists.

My general interests are physics, running, classical literature / playing music and…. Physics - there is nothing else!

ANIER HERNANDEZ GARCIA,
FlowTrans Early Stage Researcher

I am an Early Stage Researcher in the FlowTrans ITN. This research will relate to the characterisation and understanding of fluid flow and chemical reactions within rocks and granular media. I will be using the Lattice Boltzmann Method (LBM) and/or Unstructured Lattice Boltzmann Method (ULBM) to simulate flows in such complex geometries. There is an interplay between complex fluids and complex geometries which can be modelled in a relatively simple way and can be useful to shed light in complex flow phenomena, such as multiphase flows and the effects of wall roughness in flows within rocks and confined micro-shells.
My background is in mathematical modelling of complex fluids. My recent research was focused on flow properties of oscillating viscoelastic fluids in confined geometries and on modelling the transport of momentum in weak turbulent flows.

My general interests include sports – mainly football and swimming. I play chess and enjoy reading about aircraft technology.

AMALIE CHRISTENSEN,
Guest PhD Student

I am a PhD student at the Niels Bohr Institute in Copenhagen where I also did my master's studies in physics.

I am working on crystalline phases confined to curved surfaces, and I am especially interested in the defect structures that arise in curved geometries but are absent in flat space. An example of a crystalline phase on a curved surface is polysterene particles adsorbed to the surface of a spherical droplet.

To study these crystal structures, I use the Phase Field Crystal model, which operates with a continuous density field representing particles and constitutes an efficient computational alternative to traditional atomistic methods.

I really enjoy cooking for/with friends, reading newspapers, running and playing classical piano.

UNVERSITE JOSEPH FOURIER, GRENOBLE

FRANCOIS RENARD,
FlowTrans Principal Investigator
Host of Workshop 4

I work at the Institute of Earth Sciences at Univeriste Joseph Fourier, in Grenoble, France. I am the co-supervisor for the 2 FlowTrans Early Stage Researchers at the University Joseph Fourier – Frans Aben and Maor Kaduri.

Our FlowTrans research will involve the development of experiments to study the effects of earthquakes on rocks in fault zones that will be compared with field data. One of the chosen fields will be the North Anatolian Fault in Turkey, which is one of the most active continental faults in the world. We are particularly interested in the processes that couple seismic deformations (earthquakes) to aseismic deformations (creep).

My main research area is petrophysics, related to fluid rock interactions in porous and fractured media. I develop studies in two kinds of systems - faults zones and geological reservoirs – using laboratory experiments and micro numerical models.

FRANS ABEN
FlowTrans Early Stage Researcher

I am a FlowTrans Early Stage Researchers based at ISTerre (Institute de Science de la Terre), Universite Grenoble-Alpes in Grenoble, France. My supervisors are Mai-Linh Doan, Jean-Pierre Gratier and Francois Renard.

The focus of my PhD-thesis is on permeability in the damage zone rocks in fault zones and how it changes throughout the seismic cycle. To do so, I perform experiments that mimic two stages of the seismic cycle:
1. Damage created by earthquakes during the coseismic stage increase the permeability, i.e. dynamic brittle failure.
2. The healing or clogging of the newfound permeability during the postand interseismic periods by typical longer term processes such as pressure solution and mineral precipitation.

The first stage is executed in the lab by dynamic high strain rate experiments using a Split Hopkinson Pressure Bar (SHPB) apparatus. A special kind of damage zone rock, so-called pulverized rock, is extensively studied in these experiments as well because such rocks might reveal important knowledge on earthquake rupture properties.
The second stage is performed in two triaxial pressure cells that allow uid circulation through the (damaged) rock samples. Such percolation fluids can be pre-saturated with a mineral phase that will precipitate within the sample, thereby healing the sample over longer periods (weeks-months).

My background is in geology with a focus on the properties of earth materials. My interests include rock deformation, rock mechanics, rock magnetism and paleomagnetism.

Outside of work, I like to cycle, hike and being in the mountains in general. You can also wake me up for movies, beers or sports on TV!

MAOR KADURI
FlowTrans Early Stage Researcher

I am the FlowTrans Early Stage Researcher at the Institut des Sciences de la Terre (ISTerre) at the University of Grenoble, France, working with Professor Francois Renard, Jean-Pierre Gratier and Cecile Lasserre.
My FlowTrans research will focus on studying the interplay between creep/aseismic deformation, earthquakes and fluids in fault

zones mechanical properties, with a special emphasis on the North Anatolian fault zone in Turkey.

I have a Bachelor Degree in Physics and Chemistry from the Hebrew University of Jerusalem and I did my Master of Science Degree in Geology under the supervision of Professor Einat Aharanov. The focus on my research here was on the physical processes related to the stylolite network formation.
I am particularly interested in structural geology and rock deformation using both modelling and field work in a broad range of scales. My aim is to develop my career in sciences.

My favourite hobbies are hiking, cycling, drinking beer and reading books.

UNIVERSITY OF MUNSTER, GERMANY

ANDREW PUTNIS,
FlowTrans Principal Investigator

I am Senior Professor at the Institut für Mineralogie, Universtität Münster, Germany and Director of The Institute for Geoscience Research (TIGeR) at Curtin University, Perth, Australia.

I am the PI for the 2 FlowTrans projects in Munster, co-supervised by Christine Putnis. Both projects relate to the porosity generation during fluid-rock interaction. The first project studies fluid flow through fluid-altered rocks in Norway by a combination of microscopic and analytical techniques. Stephen Centrella is involved in this research. The second project will study porosity generation during hydrothermal reactions between calcite and various fluid compositions. Elisbete Pedrosa is involved in this research.

My background is in mineralogy and petrology. I worked at Cambridge University for 25 years before moving to Munster in 1995 and since February 2015 I have been dividing my time between Germany and Australia.

My general interests are mainly in Australian aboriginal art and field work in Norway and Australia.

CHRISTINE PUTNIS,
FlowTrans Co-supervisor

- I am a research associate in the Institut für Mineralogie at the University of Münster, Germany, where I have worked for the past 18 years. Previously I was funded by Mobil North Sea on a project researching enhanced oil recovery at the University of Cambridge, UK.
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- I am an experimental geochemist and my research interests centre on reactions occurring at the mineral-water interface. This involves dissolution and growth processes as well as mineral replacement reactions and the subsequent development of porosity. I use a variety of analytical techniques but I concentrate mainly on direct observations using atomic force microscoipy (AFM). Currently I am also an adjunct professor in the Nanochemistry Research Insitute at Curtin University, Perth, Australia.
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- My first degree (BSc in geology) was from the University of Newcastle, Australia. My doctoral degree (Dr. rer Nat) was awarded from the University of Münster. Above all, I am the mother of 6 children (now all independent) and the grandmother of 8 children (more coming!). At the same time when my children were young I was a chemistry teacher in many Cambridge secondary schools for several years before taking up the research position at Cambridge University. My other interests (not much time left) are travelling, geology field work, and spending time with my grandchildren, as well as enjoying the good company of family and friends. I am happiest when my house is full – which is very often.

ELISABETE PEDROSA
FlowTrans Early Stage Researcher

I am one of the FlowTrans Early Stage Researchers at Institute for Mineralogy, University of Münster, Germany. My background is in Environmental Engineering. I've finished my bachelor degree at the University of Aveiro in Portugal, in 2008. In mid-2009, I was granted a Leonardo da Vinci grant from the European Commission Lifelong Learning Programme 2007–2013 at the University of Elche, in Spain, where I was working in collaboration with a Portuguese research group on studying erosion after forest fires, in which I also worked for some time when I went back to Portugal.

In 2010, I started an European Master Programme called Joint European Master in Environmental Studies (JEMES), which was offered by the Technische Universität Hamburg-Harburg (TUHH), Universitat Autònoma de Barcelona (UAB), Universidade de Aveiro (UA),and Aalborg Universitet (AAU).

Finally, in early 2013 I was given the opportunity to participate in the FlowTrans project. My work is focused on the study of porosity generation and evolution during mineral replacement reactions. Currently, I'm performing a number of laboratory hydrothermal experiments, during which minerals are transformed in new minerals (replacement reactions) when in contact with different fluids. During this phenomena, porosity is formed. I'm using different techniques to measure and categorize this porosity, hoping to get answers regarding the mechanism of these reactions.

STEPHEN CENTRELLA
FlowTrans Early Stage Researcher

I am the FlowTrans Early Stage Researcher based at the University of Munster.

My FlowTrans research correspond of the relation between chemistry and texture across shear zone. For this, I study rocks from Norway in the transition granulite-eclogite and granulite-amphibolite. Previously, I did my Bachelor degree in Poitiers (France) and my Master in Rennes (France). My Master thesis subject was the Structure and the metamorphic evolution of the Ile de Groix (France). This small island is characterized by high pressure and low temperature rocks (blueschist-eclogite).
I have been doing karate for 17 years. I like sports in general. I like spending time to watch films, to read comics and mangas.

UNIVERSITY OF OLSO

BJORN JAMTVEIT
FlowTrans Principal Investigator

I work at the Department of Geosciences, University of Oslo. Along with Dag K. Dysthe from our physics department, I am supervising Daniel Keszthelyi, FlowTrans Early Stage Researcher. Daniels project is focused on the mechanisms of chalk compaction in and around the Ekofisk petroleum field in the North Sea.

My background is from petrology (rock-formning processes) and I did a PhD in Oslo and a PostDoc in Bristol. Then I moved general focus towars fluid-rock interaction and the coupling between fluid migration, chemical reactions and deformation processes. Studying fluid-rock interactions, I became very interested in pattern-formation in geological processes. This was the focus of a research center in Oslo called PGP (Physics of Geological Processes), which I started along with physics professor Jens Feder and many others in 2003.

KNUT-JORGEN MALOY,
FlowTrans Principal Investigator

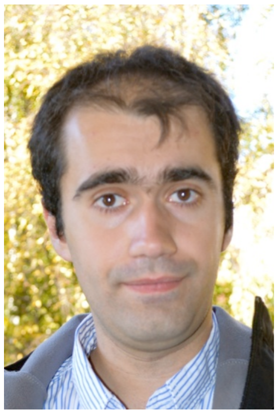
I am Professor of Physics at the University of Oslo. I am PI for the FlowTrans project at the University of Oslo and am supervisor for Le Xu, the FlowTrans Early Stage Researcher.

My research focuses mainly on complex physics within porous media, granular materials, fractures and breakdown. My group has a range of advanced scientific instrumentation and imaging equipment available. The equipment includes an ultra-fast video camera, an infrared camera and a broad range of tabletop experimental equipment. The group studies a wide range of topics related to complex systems and soft materials, including two-phase flow in porous media and fractures, deformable porous media, granular flow, fracture, burst dynamics, crackling noise and other non-equilibrium phenomena. The group has a strong tradition for interaction between experimental activity, theory and the simulations.

Dag Kristian Dysthe,
FlowTrans Co-Supervisor

I work at the Department of Physics at the University of Oslo. My research interests focus on pattern forming processes in nature. I am involved in research in the fields of statistical physics, condensed matter physics, complex system and physical chemistry.
I am particularly interested in fracture networks, drainage networks, flow in porous and granular media, weathering, carbon capture and storage (CCS) and coupled mechanical and chemical transformation of solids.
I am co-advisor for Daniel Keszthelyi, who is one of the FlowTrans Early Stage Researchers.

DANIEL KESZTHELYI
FlowTrans Early Stage Researcher



I am the Flowtrans Early Stage Researcher at the department of Physics and Geological Processes at the University of Oslo. My FlowTrans research involves working on a compaction model for a chalk reservoir.
During the early stage of oil production at the Ekofisk Field, Norwegian North Sea Territory, the chalk reservoir suffered a considerable pressure drop which triggered its compaction and the consequent subsidence of the sea floor. The compaction and the sea floor subsidence remained after initial pressure conditions were restored. Until now, several models of compaction have been created, none of which has a

clear physical background. The aim of my project is to create a chalk compaction model based on basic physical assumptions depending on independently measurable variables.

I have a Masters Degree in Geophysics (2012), a Bachelor Degree in Earth Sciences (2011) and a Bachelor Degree in Computer Sciences (2009). My research interests involve the analytical and numerical modelling of geological processes.
My hobbies include hiking, travelling, water sports, reading and photography.

LE XU,
Early Stage Researcher

I am the FlowTrans Early Stage Researcher at University of Oslo, working under the supervision of professor Knut Jorgen Maloy. My FlowTrans research will involve investigating dissolution and clogging in porous media and fractures. My project is focused on experiment and now I'm studying the dynamic process about dissolution phenomene in porous media.

I have a number of years professional experience, gained through a range of internships, including: an internship for the study of sensitivities of Dark Matter (2010-2011), an internship for the study of photon measurements by ECAL of CMS (2011-2012) and an internship for the study of top partner at the LHC (2012-2013), all at The Institute of Nuclear physics of Lyon (IPNL) cooperated with the University of Lyon.

My interests include sports, particularly basketball, swimming and tennis, and music, reading, travelling and movies.

Marcel Moura
Guest Student

I am a PhD candidate from Brazil working in the Physics Department of the University of Oslo, Norway.

My background is in theoretical fluid mechanics from the Federal University of Pernambuco, in Brazil, where I focused my research on vortex dynamics in ideal fluids.

Currently, I perform experiments on two main areas: two-phase flow in porous media and fracture dynamics.
Outside working hours, I am most of the time trying and failing to produce the World's best cup of coffee!

UNIVERSITY OF WARSAW

PIOTR SZYMZCAK
FlowTrans Principal Investigator

I work at the Faculty of Physics at the University of Warsaw. I am a theoretical physicist by training and work on different subjects at the intersection between physics and other fields: from the dissolution of porous or fractured rock to the dynamics of knots in proteins. The approach taken is to model the system in a simple but physically meaningful way, and then explore the model using the combination of analytical and numerical techniques.

KARINE PETRUS
FlowTrans Early Stage Researcher

I am the Early Stage Researcher of the University of Warsaw in the FlowTrans project supervised by Piotr Szymczak.

At the University of Warsaw we work on the phenomenon of dissolution in porous medium. I am currently involved in understanding the effect of stratified medium on the growth of wormholes. We are trying to make models representing the interesting geological patterns seen in nature in order to catch the essential physics.

I obtained my French Engineer Diploma in Geophysics and a Master 2 ISIE (Engineering for Environmental Science) from EOST Strasbourg. I have a strong interest in hydrogeology and am interested in linking research to applied environmental projects.

Concerning my hobbies, I am keen on hiking, travelling and exploring new places and discovering (and learning) new languages as well. I like classical music (used to play the violin and now just beginner in guitar) and swimming.

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