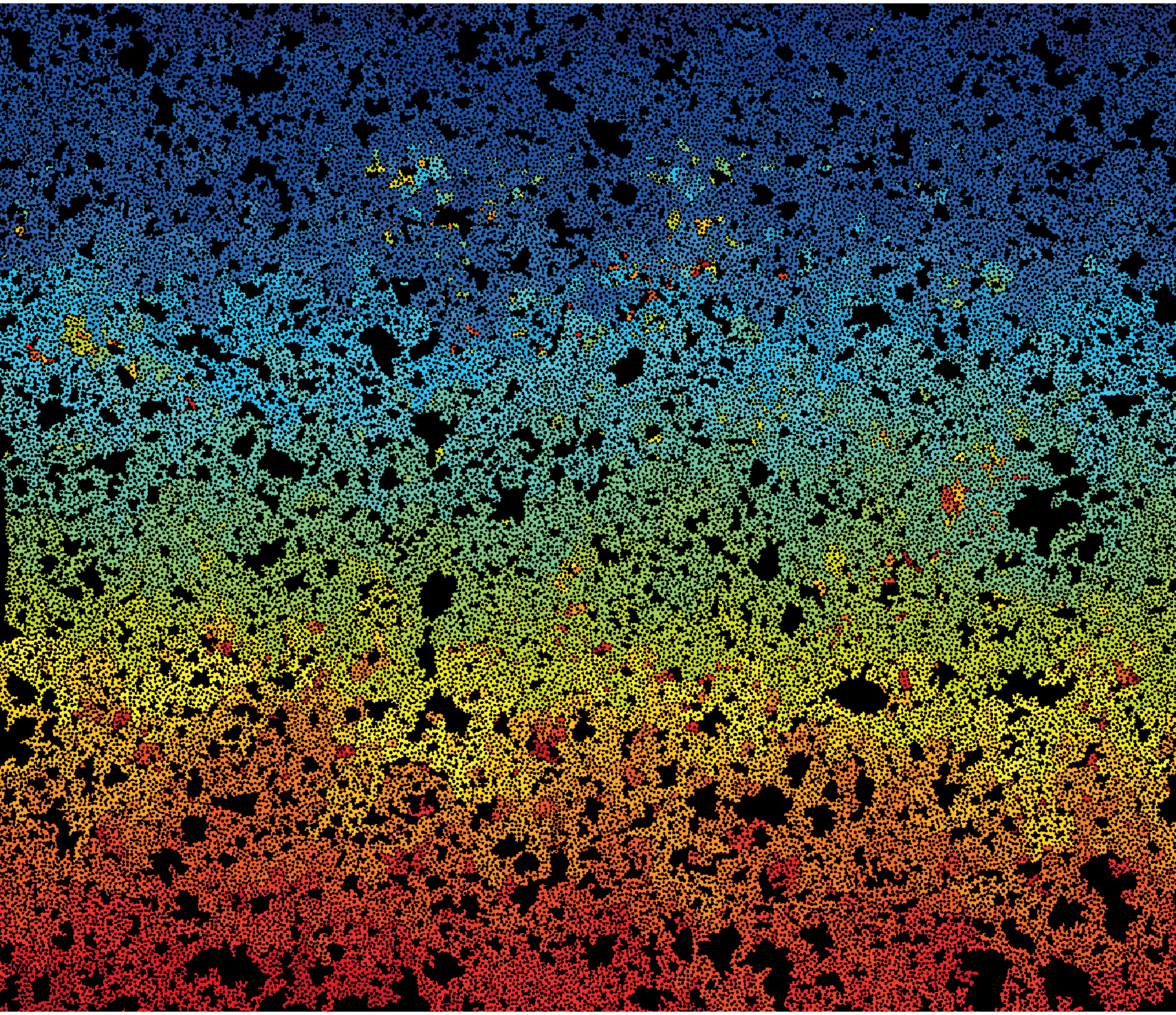
PoreLab
NTNU-UiO Porous Media Laboratory

Annual Report 2019



NTNU
Norwegian University of Science and Technology

UiO : University of Oslo

Norwegian Centre of Excellence
The Research Council of Norway

Our Mission

“To unify and advance our understanding of porous media

WHAT IS PORELAB?

The PoreLab center was recognized in 2017 as one of the ten new Centers of Excellence (CoE) by the Research Council of Norway. PoreLab is the acronym for Porous Media Laboratory.

A CoE is a funding scheme administered by the Norwegian Research Council. The goal of the CoE program is to give Norway's best scientists the opportunity to establish larger units focusing on frontier research at a high international level and to contribute to raising the quality of Norwegian research.

PoreLab has two nodes, at the Norwegian University of Science and Technology (NTNU) in Trondheim and at the University of Oslo (UiO). It is led by five principal scientists from physics, chemistry and reservoir engineering. At UiO, PoreLab is organized under the auspices of the Njord Center which is a recently established cross-disciplinary geoscience-physics center.

The mission of PoreLab is to advance the understanding of flow in porous media. Starting from a sound basis in physics we aim for a better description of flows that range from geological to biological and technological. Our objective is to develop a generalized statistical mechanics for porous media flow at the pore level which will give us an effective media description on the larger continuum scales like a generalized non-equilibrium thermodynamics for porous media flow. We work to link the physics at the pore scale to the large-scale differential equations. We address the upscaling problem using methods adapted from non-equilibrium thermodynamics and statistical mechanics.

PoreLab receives an annual funding from the Norwegian Research Council of about 15 MNOK for an initial five years period. NTNU and UiO contribute with the same financial support. Conditional to a positive outcome of a mid-term evaluation, an additional five years will be granted. If so, the date of completion will be August 2027.

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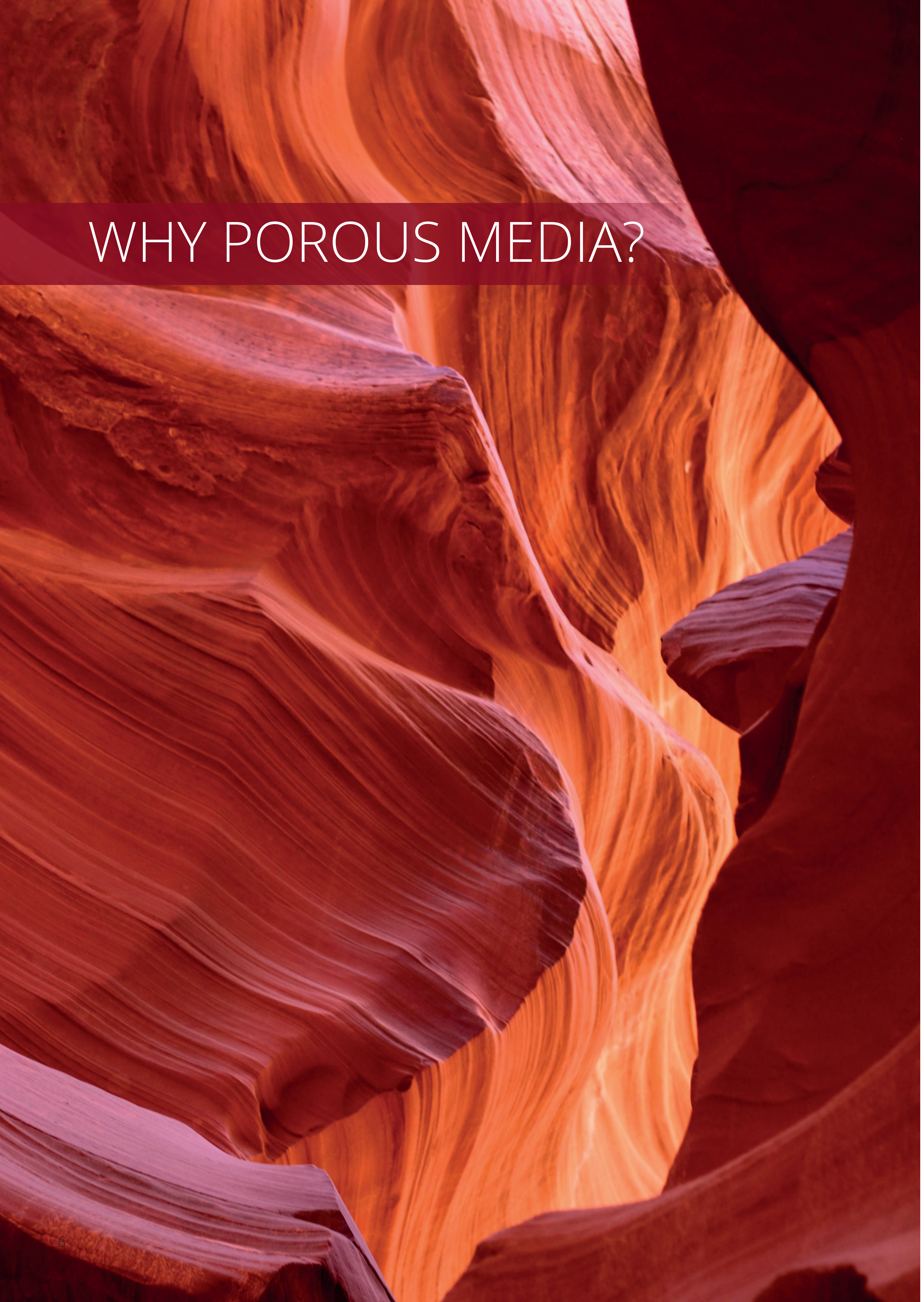
Slow drainage experiment in a gravitational field. The color code denotes the time for a given pore to be invaded, ranging from blue (early invasion events) to red (late invasion events).
Picture by Marcel Moura

PAGES 2 AND 3:
Water saturated with gypsum is injected into a radial disk plaster sample with a ramified dissolution pattern. The flow in the aperture above the sample is traced by fluorescence. The traced flow clearly shows the dispersion flowline influenced by the fractal-like initial ramified pattern.
Picture by Le Xu.

PoreLab group picture at the International Workshop on Non-equilibrium Thermodynamics in Porous Media (29-30 August 2019, NTNU, Trondheim, Norway)



WHY POROUS MEDIA?

It is only a decade and a half ago that Paul Roberts in his book *The End of Oil: On the Edge of a Perilous New World* stated that the dwindling oil reserves constituted *"arguably the most serious crisis our industrial society has ever faced."* This view was widely spread at the time. The development of alternative energy sources has in the meantime come to a point where optimism is warranted and it makes sense to somewhat lower our shoulders.

Seven years ago, however, the UN declared 2013 as the International Year of Water. They declared, *"By 2025, 1.8 billion people will be living in regions with absolute water scarcity, and two-thirds of the world population could be under stress conditions."* By 2019, the number of headlines that concern lack of water is increasing rapidly and in short it will be a full-blown crisis. But, lack of oil and lack of water – are they related problems? Yes, they are. Drilling for oil and drilling for water, i.e. the exploitation of sub terrain reservoirs are very much alike.

At the heart of the oil industry, and the budding water industry, an industry that will eclipse the present importance of the oil industry, one finds *porous media*. This is where the oil or water sit.

The water crisis is still somewhat hidden behind the broader climate change crisis. Here the capture of CO_2 plays a pivotal role. The large Northern Lights project, where storage of captured CO_2 in porous sub-sea reservoirs is the goal, is a great example of porous media playing a central role also in this worldwide challenge.

We also find porous media in biological systems: In any multicellular organism - that being trees or people - fluids need to be transported. In geology and/or geophysics, water moves in soils, with the risk of polluting aquifers. In cold areas, frost heave is the result of water transport through soil. On the opposite side of the temperature scale, geothermal systems rely on hot water transport in fractures – here seen as a porous medium at large scale. Industrial filters and fluidized bed reactors belong to the realm of chemical engineering and constitute examples of porous media. Hydrogen fuel cells rely on the simultaneous transport of water and hydrogen and oxygen through porous electrodes and electrolytes to work. In materials science, impregnation processes, e.g. wood impregnation, rely on the transport of fluids into porous media.

The fact that porous media are central to such a variety of fields does not mean that they are ill defined; porous media are porous media. What this diversity means is that many different fields with many different viewpoints have separately pondered them. Hence, the knowledge is fragmented. An interdisciplinary center focused on porous media that can bring these fields together would be in the position to sew together these fragments. Done wrongly, we would end up with a patchwork quilt of knowledge that does not bring anything new. Done correctly, we would be demonstrating that the whole is more – even much more – than the sum of the parts. PoreLab has this role as an interdisciplinary hub as a central goal.

Perhaps the most important outstanding problem in fundamental porous media research is the *upscaling problem*. In most practical applications of porous media, the length scale of interest is much larger than the scale at which the relevant physics is going on. The pores, where the physics is, are typically ten to a hundred micrometer in size – are some 7 orders of magnitude smaller than the scales of interest for practical purposes which are in the meter range or larger. Porous media look dramatically different on the pore scale from the meter scale where they look like continuous media. Here we have arrived at the core problem: *How to connect the physics at the pore scale with the behavior seen at large scale.* This is the central problem we try to solve in PoreLab.

Sandstones at Antelope Canyon, Arizona, USA.
Photo: Joshua Sukoff

DIRECTOR'S COMMENTS

Alex Hansen, Director for PoreLab.
Photo: Per Henning

The Porous Media Laboratory – PoreLab – has now passed the 2.5-year mark, a quarter of its funding period. This means we should be approaching peak performance. In terms of manpower we certainly are: There are 5 Principal Investigators, each heading one or two of the seven groups PoreLab is divided into. We also have 28 associate PoreLab members spending from all their time to some fraction of it at PoreLab. Then, there are 33 PhD/postdocs, 17 MSc-students and 6 administrators/technicians. This is about 90 in all. We also have visitors, more than 60 in 2019. With the PoreLab offices in the Physics Building at the University of Oslo finally having become ready by September 2019 after extensive reconstruction and upgrading, we now have excellent working conditions at both our nodes. And of course, we need to pose the crucial question, do we produce science that is being noticed? There are tables elsewhere in this annual report which give the detailed picture. However, a quick search on scholar.google.com using the search terms "PoreLab" and "262644" - our project number – returns 81 hits and 236 citations. Searching for "PoreLab" and "Norway" on google.com gives some 6320 hits.

Science in 2019.

It was a great year for PoreLab. Here are some highlights:

- Investigating statistical laws for earthquakes using a Couette cell, i.e. two concentric cylinders filled with small disks (see photo). Rotating this device creates a continuous restructuring of the disk packing. This restructuring leads to small *labquakes* whose statistics may be recorded. By continuously recording these events, the statistics becomes extremely good. Furthermore, they fit the laws describing earthquakes, e.g. in connection with the statistics of fore and aftershocks, leading to this work being the "Editor's Choice" in the journal *Science* in June (Lherminier et al., Phys. Rev. Lett. **122**, 210581).

- 'Oumuamua, a 100-1000 meter long cigar shaped object, entered our solar system in 2017. Its behavior puzzled the astronomers as it did not follow the trajectory that gravity dictates. So, speculations went high, e.g. it being an alien spaceship was seriously proposed. PoreLab researchers in collaboration with Professor Jane Luu (MIT), visiting the CEED center of excellence at the University of Oslo, suggested that the object is a *cosmic dust bunny*, i.e. a fractal structure made from dust particles. This would make it so light that the additional force from the light emanating from the sun would explain the anomalous trajectory. This explanation is now making waves. (Flekkøy et al., Astrophys. J. Lett. **885**, L41).

- One of the main problems we have set out to solve is the scale-up problem of immiscible two-phase flow in porous media. On the pore scale, we have two fluids that compete for the same pore space. This is a well-defined – but far from easy - hydrodynamic problem that also involves the thermodynamics of interfaces and contact lines. If we now are to construct a representative elementary volume on a scale large enough so that the individual pores are no longer discernable, what would be the thermodynamic and hydrodynamic variables and how would they be related at this level? This is the scale-up problem. Kjelstrup and co-workers tackle this problem using Euler scaling, an essential step in solving the scale-up problem. (Kjelstrup et al., Front. Phys. **6**, 126; ibid. **6**, 150)

- If we know the average flow rate of two immiscible fluids moving through a porous medium, may we find the average flow rate of each of the two fluids? This sounds impossible, but we have developed a theory in PoreLab that solves this problem. The paper where this is explained was published in December 2018. Already in early fall of 2019 it became the most downloaded paper *ever* in the journal in which it was published. (Hansen et al., Transp. Porous Media, **125**, 565.)

- Since long, people have been trying to relate the permeability (which is a quantitative measure of how easy fluids flow) of porous structures to geometrical properties such as pore volume. The old Kozeny-Carman equation is an example of this when the porous medium consists of packings of spherical beads. But, what about more complex porous media. There is a remarkable theorem from differential geometry which says that any function of a certain class – the permeability being a member of this class – should be fully describable by only four numbers characterizing the geometry of the pore space, the so-called *Minkowski functionals*. PoreLab researchers have tested this idea computationally, concluding that permeability (and its electrical equivalent formation factor) is *not* a unique function of the Minkowski functionals – a surprise for those of us who believe in a simple world. This is a clear invitation to further research along these lines. (Slotte et al., Transp. Porous Media, **131**, 705).

AMBITIONS FOR 2019: DID WE DO WHAT WE SET OUT TO DO?

In the 2018 annual report I wrote "The initial period of finding our traction is now over and we foresee that 2019 will be a period of consolidation." Indeed, it has. Despite the vast span of disciplines represented in PoreLab, we can understand each other and appreciate our different viewpoints on a given problem. This interdisciplinarity is present both in Trondheim and in Oslo. In Oslo, where geologists and physicists share neighboring offices, this is not a new thing. They started this close transdisciplinary collaboration already in 2002 when the Center of Excellence *Physics of Geological Processes* was created. Today, the echo of this center lives on as the *Njord Center* (see page 56) and PoreLab has found its natural place within this environment.

In Trondheim, there has been no such tradition. Furthermore, the span of disciplines is much wider there, ranging from civil engineering to biophysics. However, the way the PoreLab offices, indeed the entire floor in S.P. Andersens vei 15B is laid out, invites interdisciplinarity. It is, however, important to point out that geometry is not everything. It does take work and time as the disciplines *are* different. Looking back now at how the interdisciplinarity has evolved within PoreLab, I am reminded of the Dunning-Kruger curve, the one where confidence is plotted against knowledge. The curve starts at the origin: no knowledge and no confidence. It then rises rapidly with increasing knowledge and peaks early at a high value of confidence. This peak is jokingly called Mt. Stupid. As knowledge develops further, one realizes that it is not as simple as one first thought at Mt. Stupid and the confidence curve then falls rapidly towards a minimum after which it then begins to rise again. At this point, confidence and knowledge match each other. I believe we reached Mt. Stupid in Trondheim sometime early 2018 and we are now well into the region where confidence again rises. It has taken time to realize that Oslo is in fact an excellent role model for this kind of interdisciplinarity.

It is far from trivial to succeed with grant applications that are multidisciplinary. When two or more disciplines are involved, it is rare that the referees cover – and therefore appreciate – the entirety of a given application. We therefore realized early on that we need to compensate by jacking up the sheer quality of the proposals. Hence, in 2019 we reorganized the way we write proposals. Anybody who is planning a proposal, presents the proposal to PoreLab in a talk. Then, we assign internal referees to those proposals that are mature enough to warrant the investment writing a proposal requires. This procedure works well. Our success rate has gone up markedly between 2018 and 2019.

The communication between Trondheim and Oslo has been and still is hampered by the technology. In smaller meetings, things work very well. However, transmitting lectures with a large audience has proven difficult, e.g. with respect to sound. New equipment has been installed in Oslo and we are in the process to do the same in Trondheim.

The *PoreLab Junior Forum* has turned out to be a success. The junior center members, doctoral students and postdocs, have organized two meetings in 2019, in Oslo in the spring, in Trondheim in the fall. The meetings start in the morning with lectures by the center members themselves, but also by external invitees that e.g. tell about their careers. The members then continue with a session on how to improve PoreLab, e.g. by discussing what exactly does it mean to be "excellent." And they end the day with a good old-fashioned beer drinking session. We, the senior members of PoreLab, receive after the meeting a summary (over many pages) of the discussions the Junior Forum has had ending in recommendations to us.

We wrote in 2018 *"We will in the coming year put more emphasis on sending junior members to work with our international collaborators. This will be part of our effort to strengthen even further our contacts abroad."* We check the "done" box on that one.

The signing and implementation of Memoranda of Understanding have on the other hand proven difficult to finalize. They seem to disappear into a fog of legal questions not to be seen again, at least not so far. Things take time.

We promised the hiring of associate professors in experimental porous media physics and in physical chemistry in Trondheim. These two processes are now well underway. The physics position was announced in mid-2019. The announcement for the chemistry position is now being finalized.

The gender skewness continues to be a problem. At present, 12% of our PhD students are female. This is not good enough. The problem is, however, a societal one. Liv Sissel Grønmo and Rita Helgesen write in the newspaper Aftenposten on January 26, 2020 that only 4% of girls in Norwegian high schools choose physics as compared to 11% in Sweden and 20% in France. Hence, the boundary conditions we must deal with are anything but favorable. Nevertheless, we know that there are good ideas out there, implemented by other Centers of Excellence. We are looking over their shoulders.

AMBITIONS FOR 2020

Further integration of our research projects is very high on our priority list. For example, we have at present three theoretical approaches to the scale-up problem in immiscible two-phase flow in porous media: 1. Using thermodynamics to identify the proper variables and constitutive equations at a coarse-grained scale; 2. Using Euler theory for homogeneous functions to find relations between the flow rates of each of the immiscible fluids; 3. Expressing the thermodynamic functions at the coarse-grained level in terms of the Minkowski functionals. It is increasingly important that these three aspects of the *same* problem at some point merge into one description. We have as of now not reached the sufficient level of maturity for this. We will do so in 2020.

This integration is not only dependent on the projects themselves, but also on the people behind. By ensuring that we continue to weave an ever-denser network of collaborations, we ensure that PoreLab's research remains coherent and consistent with the vision.

As for external collaborations, we have a good and increasingly wide portfolio of running projects. At the same time, the number of associate members of PoreLab continues to increase. We need to ensure that this evolution remains consistent with the PoreLab vision and adds to the coherence.

We need to continue to develop the support mechanisms that we developed a year ago for proposal writing. It worked well in 2019. We will streamline the process further for this year.

Gender balance is still a headache. We will not be able to tick the "solved" box on this one in 2020. But we will make every effort to do better than last year – and hopefully not so good as in 2021. Perhaps someone will come up with a great idea.

The Junior Forum functions very well. Our ambition for the year is to keep it this way. With our great students, this will be an easy ambition to fulfill.

I will end with the most important ambition for this year, besides our scientific goals. We can see how PoreLab is turning into an important hub for porous media research in Trondheim and Oslo in that it is becoming a meeting place for people who work on porous media but coming from different disciplines. This was not at all emphasized in our original application, but we see how important such a role is. We recognize this and will work diligently to develop this role further.

COMMENTS FROM PROFESSOR DAAN FRENKEL, FROM THE SCIENTIFIC ADVISORY BOARD

Most students in the physical sciences obtain their degree without having learned anything whatsoever about the properties of porous materials. This is a regrettable state of affairs because, first of all, we are literally surrounded by porous materials (the soil on which we walk, the walls in our homes, the wood in our furniture – not to mention the fact that most living organisms consist at least partly of porous materials).

Professor Emeritus Daan Frenkel from the University of Cambridge, UK, spent a total of 3 months at PoreLab, Trondheim in 2019. He received the prestigious Onsager Medal in November as the NTNU Onsager Professor of the year. He is a member of the PoreLab Scientific Advisory Board.

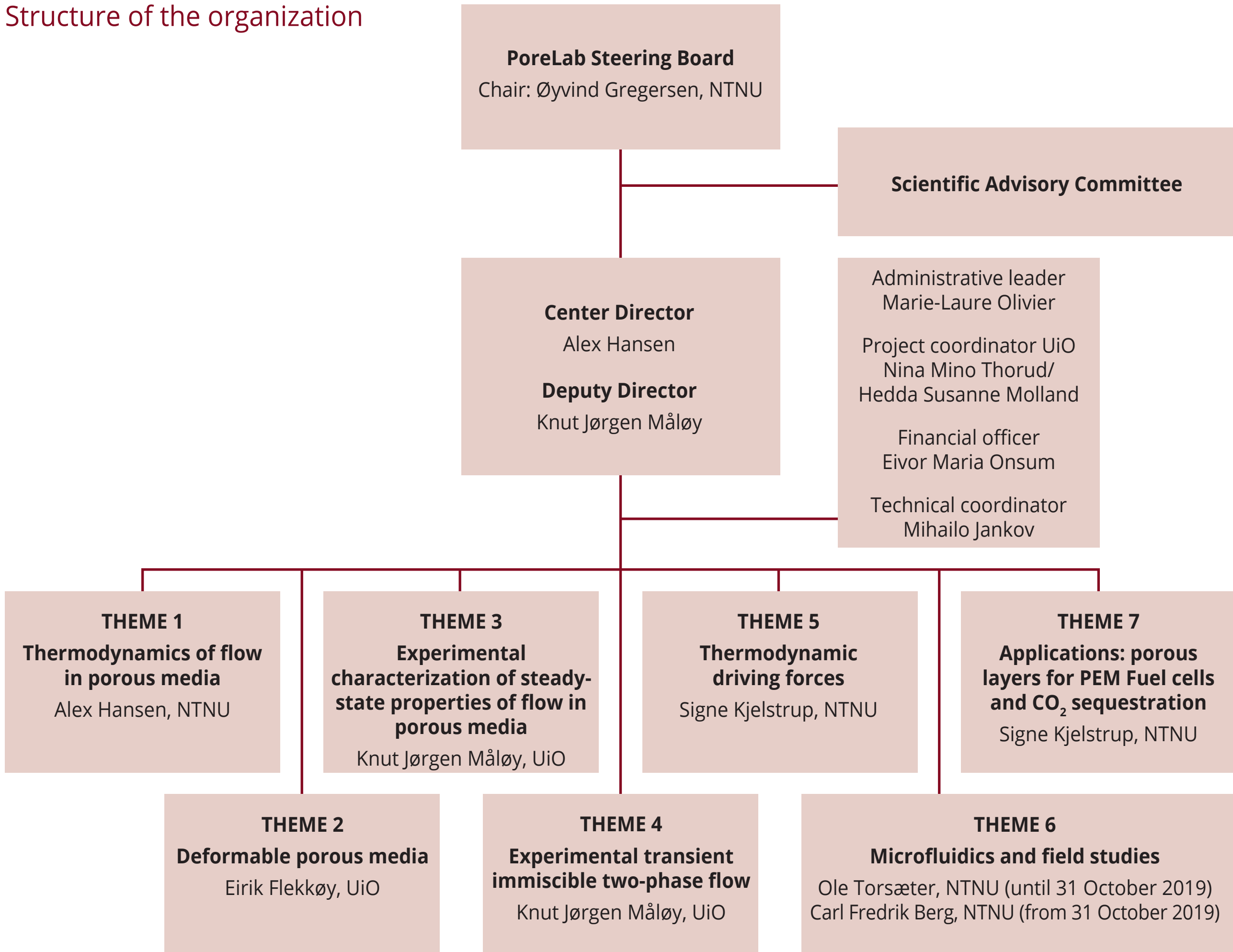
But there is a second reason why we need to know more about porous materials: they are different. Knowledge about the properties of pure liquids or defect-free solids does not prepare us for the wide range of phenomena that occur only in porous materials. And finally, processes in porous materials are of crucial societal importance: the transport of water, CO_2, natural gas or oil in porous rocks, the leakage of radioactive isotopes from underground storage sites, but also the chemistry of catalytic converters to name but a few, all require a good understanding of non-equilibrium processes in porous materials.

PoreLab, a joint research center of the Norwegian University of Science and Technology (NTNU) in Trondheim, and the University of Oslo (UIO), was created with the express aim of bringing our understanding (and appreciation) of processes in porous media to a new level. Of course, this research is not happening in isolation: there is a vibrant international community studying aspects of transport in porous media. However, there is probably no other center that brings the different thread of pore physics, chemistry and (chemical) engineering (both experimental and theoretical) together in the way that PoreLab does, and it is heartening to see that, already now – just two years after its creation - PoreLab is highly visible in this community: it has the potential to play a leading role in the development of pore-science. Of course, this strength is based on a long and outstanding local tradition – and the PoreLab researchers are well embedded in their respective universities. But PoreLab is definitely not just a label stuck on existing activities. What is striking to the visitor of PoreLab is the extent to which it is inter-disciplinary at its very core (no pun intended). Joint research seminars (with video links between the UIO and NTNU sites), frequent cross-visits and a steady stream of longer or shorter term visitors from academia and industry contribute to a unique and vibrant atmosphere that owes very much to the enthusiasm and unique expertise of its senior staff, an atmosphere that clearly stimulates the early-career researchers to achieve much more than they could have done in isolation.

As a member of the Scientific Advisory Board and a as a Porelab visitor, I was very impressed with the progress made by PoreLab, and I have high expectations for the future.

ORGANIZATIONAL CHART OF PORELAB

Structure of the organization



PoreLab gathers scientists from 5 departments at NTNU and UiO. The Department of Physics is the host. Partners are the Departments of Chemistry, Geoscience and Petroleum, Civil and Environmental Engineering, all at NTNU, and Department of Physics at UiO. SINTEF Industry and WesternGeco are external research partners.

The Center is managed by the Director, Alex Hansen NTNU jointly with the Deputy Center Director, Knut Jørgen Måløy (UiO) and the Center Administrative Leader, Marie-Laure Olivier (NTNU).

The organizational structure of the Center is flat. PoreLab's research has been organized in seven Research Themes lead by the Principal Investigators (PIs). The team of five Principal Investigators and the Administrative Leader forms the Leader Group and has bi-weekly meetings to discuss administrative and scientific issues and update each other on developments and progress. The system for immediate updates ensures interdisciplinary progress.

The PoreLab Executive Board includes members from the Faculties involved at NTNU and UiO. The board is responsible for overseeing that the activity takes place according to the contract with the funder, the Research Council of Norway. A central task of the Executive Board is to enhance the collaboration among participating Departments at NTNU and UiO.

The Scientific Advisory Committee of international experts aids in the development of a strategy for the scientific development of the center, thereby helping the leadership group to achieve the stated scientific aims.

MANAGEMENT AND ADMINISTRATION

THE LEADER GROUP

Alex Hansen
Director
Professor, PI Theme 1

Eirik Flekkøy
Professor
PI Theme 2

Knut Jørgen Måløy
Deputy Director
Professor, PI Themes 3 and 4

Signe Kjelstrup
Professor
PI Themes 5 and 7

Ole Torsæter
Professor
PI Theme 6
(until 31 October 2019)

Carl Fredrik Berg
Associate Professor
PI Theme 6
(from 31 October 2019)

Marie-Laure Olivier
Administrative leader

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Department of Physics
NTNU

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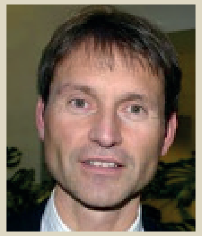
Director NTNU Ocean IV Faculty, NTNU
(until 31 October 2019)



Sveinung Løset
Professor, Department of Civil and Environmental Engineering, NTNU
Vice Dean Research and Innovation
Faculty of Engineering, NTNU
(From 31 October 2019)

Jøran Idar Moen
Head of Department
Department of Physics
University of Oslo

Brit Lisa Skjelkvåle
Head of Department
Department of Geosciences
University of Oslo

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Soil and Terrestrial Environmental Physics
ETH, Zürich
Switzerland

PARTNERS

NTNU

UiO : University of Oslo

SINTEF

WesternGeco

HIGHLIGHTS

January 2019
PoreLab is invited to join the H2020 EC MSC ITN ERICA project Workshop organized on March 7 and 8 at NTNU

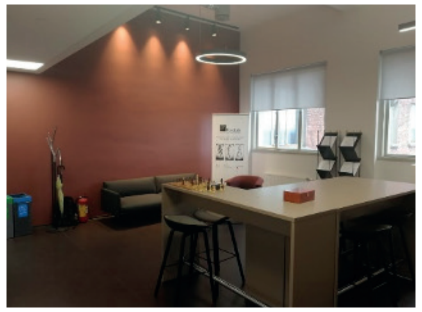
May 6-10, 2019
InterPore 2019
11th Annual Meeting
Valencia, Spain

May 27-31, 2019
Plenary talks at the XXVI Sitges Conference on Statistical Mechanics
Sitges, Spain

June 16-19, 2019
The Big Challenge, Science Festival, Trondheim, Norway, where Daan Frenkel and Alex Hansen give talks

June 28, 2019
PoreLab publication on "Labquakes" selected as the Editor's choice in the Journal Science

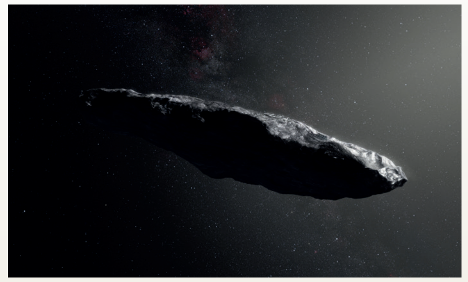
August 29-30, 2019
PoreLab celebrates Signe Kjelstrup (SK) 70th birthday with an International Workshop on Non-Equilibrium Thermodynamics in Porous Media, Trondheim, Norway



September 27, 2019
PoreLab UiO celebrates their new offices and laboratories

October 24, 2019
Workshop on Lattice-Boltzmann Modelling
Trondheim, Norway

November 7, 2019
Lecture of NTNU's Onsager professor 2019, Daan Frenkel



November 11, 2019
The theory that the interstellar object 'Oumuamua is a fractal cluster consisting of dust is published in Astrophysical Journal Letters

December 18, 2019
5 PoreLab related projects get funding from the Research Council of Norway

A COSMIC DUST-BUNNY: 'OUMUAMUA AS A SPACE FRACTAL

Eirik G. Flekkøy[1], Jane X. Luu[2,3] and Renaud Toussaint[1,4]

[1] Porelab, The Njord Center, Department of Physics, University Oslo, Norway
[2] Centre for earth Evolution and Dynamics, Department of Geosciences, University of Oslo, Norway
[3] Institute of Theoretical Astrophysics, University of Oslo, Norway
[4] Institut de Physique du Globe de Strasbourg, University of Strasbourg, CNRS, Strasbourg, France

The first interstellar guest in our solar system was discovered in October 2017 at an observatory in Hawaii. For the first time, one could observe a celestial body moving on a hyperbolic trajectory, that is, in open-path through the solar system.

This object, which was named 'Oumuamua, Polynesian for "guest" or "scouting from afar", is about 400 meters long and it is now on its way out of the solar system again to never return. This sets it apart from anything else that has been observed in the solar system, such as comets, planets and asteroids, all of which move along closed orbits around the sun and return along their cycles.

The exotic guest carries information about solar systems that may be completely different from ours. Among many unanswered questions is one related to its special movement: In addition to being open, it is also a bit faster than what can be explained from known gravity in our solar system alone.

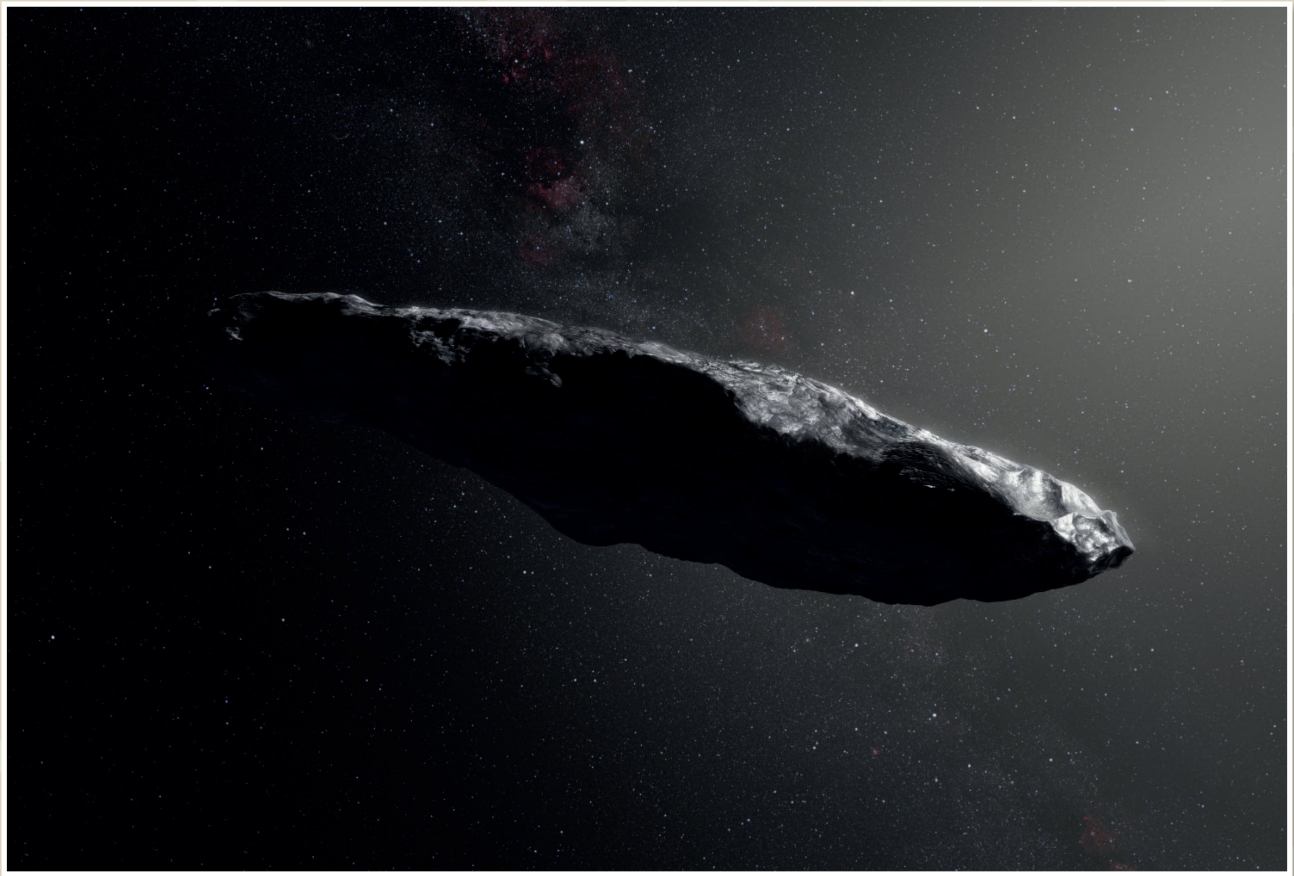
Disregarding a much-publicized speculation that it may be a foreign spacecraft, only pressure from the Sun's radiation can explain the extra power needed to explain the observed trajectory for the lack of observable outgassing. This pressure could only have the observed effect if 'Oumuamua was extremely light, that is, if it has a mass density around 1% of air at sea level. Such extremely light structures could naturally arise by dust aggregation in young solar systems. They would be fractal over large range of length scales and probably the most porous structure ever observed, with an overall porosity of 99.999 %. We have shown that such filamentary structures could indeed survive the mechanical forces it would be subjected to on its journey past our Sun. These forces include centrifugal, tidal and radiation pressure forces, and our results shows that space, in a sense, is a gentle environment compared to say, Earth. We have demonstrated that a fractal of dimension D=2.3-2.4 which is made up of micron sized particles that connect with by van der Waals forces could indeed withstand the forces it would be subjected to.

After the observation of 'Oumuamua another interstellar visitor known as Borisov, has passed through our solar system, this time with a coma and a comets tail. We are currently exploring the possibility that 'Oumuamua too was initially a comet that lost its water to radiation and produced a dust aggregate in the process.

RECOMMENDED READING

Eirik G. Flekkøy, Jane Luu and Renaud Toussaint, *The Interstellar Object 'Oumuamua as a Fractal Dust Aggregate* Astrophys. J. Lett., **885**: L41 (6pp), 2019

RESEARCH PROJECTS



The interstellar guest Oumuamua considered as a fractal aggregate (top) and as a rock (bottom). Both images are hypothetical.

USING MINKOWSKI FUNCTIONALS FOR POROUS MEDIA CHARACTERIZATION, AND PREDICTION OF TRANSPORT PROPERTIES

Per Arne Slotte[1], Carl Fredrik Berg[1] and Hamid Hosseinzade Khanamiri[1]

[1] PoreLab, Department of Geoscience and Petroleum, NTNU, Norway

The current macroscopic modeling of two-phase flow is based on the two variables saturation and pressure only, and it has long been recognized that this is too simplified to represent many important flow scenarios. Also, the problem of connecting transport properties to geometric measures and additive measurements remains unsolved. The project goal is to identify the important parameters needed for characterizing fluid flow in porous media

The set of geometric measures known as the Minkowski functionals has proven to be especially promising parameter candidates. Minkowski functionals are additive properties that in 3D correspond to

- Volume
- Surface area
- Integral of mean curvature
- Integral of Gaussian curvature, which is also a measure of topology known as the Euler characteristic.

Work relating to two-phase flow, that is the analysis of 3D µ-CT images of flooding experiments [1-2], and fluid configurations in simulations, is ongoing. In the current report we focus on work relating to single phase flow and electric currents [3]. The corresponding transport properties are permeability and formation factor.

PREDICTING RESISTIVITY AND PERMEABILITY OF POROUS MEDIA USING MINKOWSKI FUNCTIONALS

P.A. Slotte, C.F. Berg, H.H.Khanamiri

Permeability and formation factor are important properties of a porous medium that only depend on pore space geometry. Being purely geometric, It has been proposed that these transport properties may be predicted in terms of a set of the geometric measures known as Minkowski functionals. The well-known Kozeny--Carman and Archie equations depend on two of these measures: porosity and specific surface area. In this paper we investigate the possibility of generalizations that include the remaining Minkowski functionals.

Hadwiger's theorem states that any additive measure is equal to a linear combination of Minkowski functionals. A consequence of this is that if a non-additive measure, such as permeability or formation factor is a function of a set of additive measures, then it is also a function of the functionals. Estimates of permeability and formation factor based additive measurements can thus at best have the same predictive power as those based on the Minkowski functionals.

Two-dimensional computer-generated pore spaces that cover a wide range of Minkowski functional value combinations were generated and analyzed. Examples of such pore spaces are shown I Figure 1.

We conclude that the permeability and formation factor are not uniquely determined by the Minkowski functionals. Good correlations in terms of appropriately evaluated Minkowski functionals, where micro porosity and surface roughness is ignored, can however be found. For a large class of random systems, these correlations predict permeability and formation factor with an accuracy of 40% and 20% respectively.

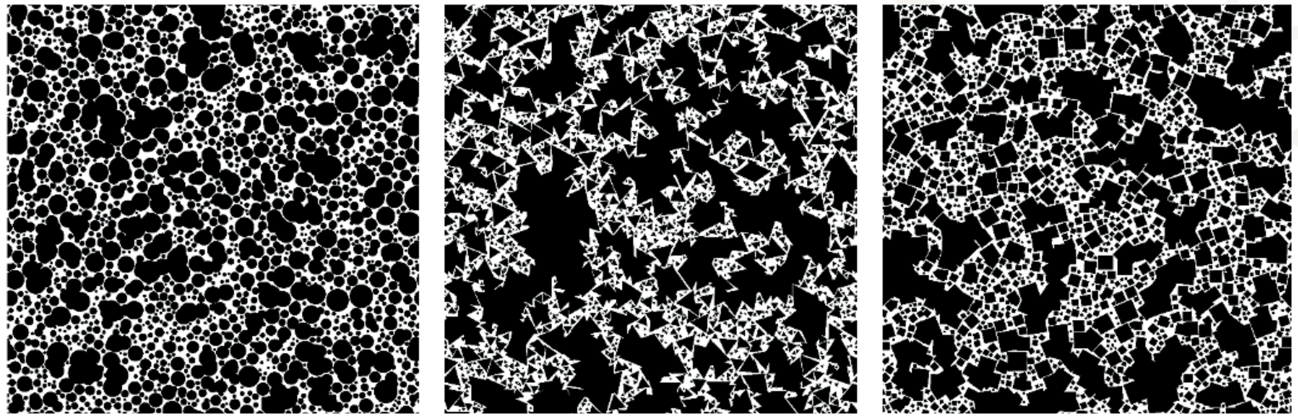


Figure 1: Examples of generated pore spaces.

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CURVATURE CORRECTIONS OF THE SURFACE TENSION REMOVE THE INCONSISTENCIES OF MULTI-COMPONENT NUCLEATION THEORY

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THE PROBLEM: CURRENT NUCLEATION MODELS FOR MIXTURES ARE INCONSISTENT

Most first-order phase transitions such as condensation, cavitation, boiling, and crystallization take place through a common mechanism known as nucleation. Here, the rate-limiting step is the formation of an incipient portion of the new phase exceeding the critical size required to continue growing spontaneo sly, which determines the nucleation rate *J*. This qualitative picture of the process is the basis of classical nucleation theory (CNT), which is the most popular model for predicting the rates of formation and properties of nucleating embryos [1]. For pure fluids, CNT is qualitatively correct. However, the predicted rates show systematic deviations from experiments, with errors reaching 20 orders of magnitude for argon [2]. The discrepancies are hypothesized to stem from the crude approximations involved in CNT, especially the so-called capillary approximation, which considers the nucleus to be a spherical portion of a bulk phase with the same surface tension as the planar interface. Since the critical embryo is nanosized, much effort has been devoted to estimate curvature corrections for the surface tension and evaluate their impact on nucleation in pure fluids [1,3].

Method	min	max	average	median
		ethanol-water		
CNT	-21.3	-0.2	10.9	12.7
c-CNT	-2.3	0.9	0.8	0.5
		1-propanol-water		
CNT	-35.2	1.5	14.8	9.5
c-CNT	-2.7	2.9	1.5	1.2

Table 1: Statistics for the logarithmic deviations $\log_{10}(J/J_{expt})$ from the experimental rates J_{expt}. The average and median are calculated using absolute values of the logarithmic deviations. The corrected theory (c-CNT) improves upon the classical theory (CNT) by many orders of magnitudes.

Most systems of interest are mixtures. As for pure fluids, predictions from CNT for multicomponent nucleation rates can be off by many orders of magnitude. But more severely, even the qualitative picture of nucleation is in some cases wrong, as CNT can predict a negative number of particles in the critical embryo [4]. Multicomponent CNT has therefore been rendered useless for many systems, especially surface-active systems such as binary mixtures of water and strongly interacting molecules like alkanols. Fig. 1 illustrates the density profiles that are characteristic of such mixtures.

THE SOLUTION: ACCOUNTING FOR THE CURVATURE-DEPENDENCE OF SURFACE TENSION

A simple yet general remedy for the shortcomings of multicomponent CNT has so far been missing. Using condensation of highly surface-active alcohol-water mixtures as example, we demonstrate in our recent work [5] that incorporating curvature corrections for the surface tension in nucleation theory removes the inconsistencies of multicomponent CNT (Fig. 2). This physical inconsistency can be visualized by a plot of onset activities (Fig. 2 top panel), which shows the curve of vapor activities corresponding to a specified nucleation rate. Using the First Nucleation Theorem [1], one can show that the characteristic "hump" from CNT translates into a negative number of water particles in the critical cluster due to the (Fig. 2 bottom panel). C-CNT has no hump and is in excellent agreement with experimental onset activities.

Importantly, our approach involves no fitting to nucleation measurements; only planar surface tensions and an accurate equation of state are needed to calculate the curvature corrections. c-CNT may be the key to quantitative predictions of condensation and cavitation rates for mixtures relevant to industrial processes, atmospheric science, and climate-change modelling.

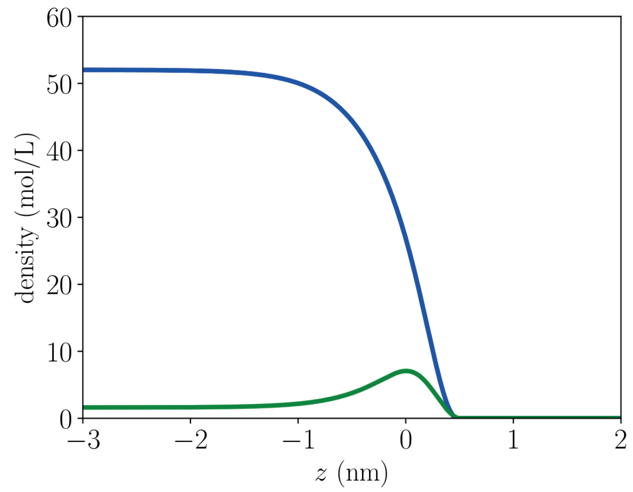

Fig. 1: Density profiles through a planar vapor—liquid interface for a binary mixture of water (blue) and 1-propanol (green) at 260 K. The accumulation of propanol in the surface is typical of surface-active mixtures. Here, z is the spatial position through the interface.

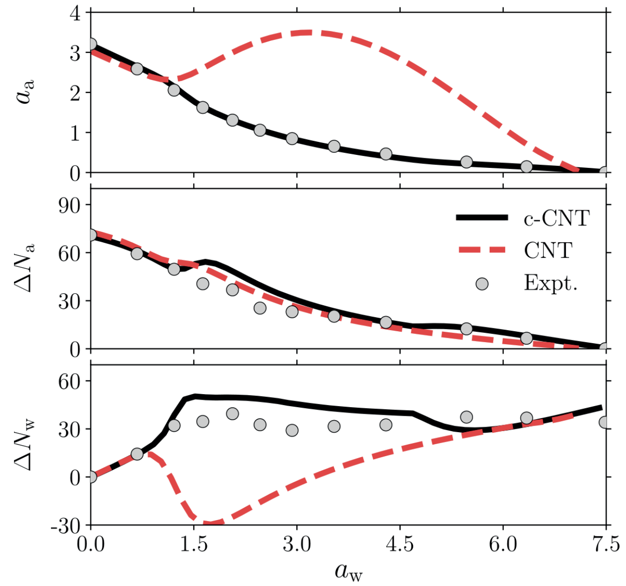

Fig. 2: Properties of critical droplets nucleating from an ethanol-water vapor. Here, The critical activity plots correspond to a nucleation rate of $J_{spec}=10^{13}$ $m^{-3}s^{-1}$. Predictions from CNT and c-CNT are compared to experimental data. Top: vapor activities of the alcohol (subscript a) and water (subscript w) corresponding to the specified nucleation rate. Middle: Number of ethanol molecules in critical droplets. Bottom: Number of water molecules in the critical droplets.

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EULER SCALING THEORY FOR IMMISCIBLE TWO-PHASE FLOW IN POROUS MEDIA

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Our understanding of how immiscible fluids flow in porous media on the scale of the pores is rapidly increasing. The correct term here is "revolution." However, to get from this pore scale understanding to predict how these fluids will move on scales large enough for the porous medium to be treated as a continuum is still too difficult. This difficulty has a name. It is called *the upscaling problem*. This means that our tools for making large-scale predictions are rather poor.

In December of last year, we published a paper on a relation between the simultaneous flow rates – or equivalently speeds – of two immiscible fluids flowing through a porous medium [1], see also [2]. This paper we see as a starting point of a theory that is intended to address the problem of how to model such flow at the continuum scale, turning "poor" into "good."

Let us name the immiscible fluids that flow simultaneously "wetting" (w) and "non-wetting" (n) indicating the direction the surface tension between the two fluids points. They each flow with an average speed v_w and v_n through the porous medium. The average speed of both fluids combined is v.

We derived the two equations

$$v_w = v + S_n(dv/dS_w - v_m)$$

$$v_n = v - S_w(dv/dS_w - v_m)$$

where S_w and S_n are the saturations, i.e. fraction of pore space occupied by each fluid, and v_m is a new type of velocity we named the *co-moving speed*. Hence, we had found a transformation $(v, v_m) \rightarrow (v_w, v_n)$. The significance of this transformation lies in that we do not need to make any assumptions on how any of these speeds depends on the forces that drive the flow, being pressure gradients or saturation gradients.

Already in 2009, the Oslo group under Professor Knut Jørgen Måløy (PoreLab, Oslo) found that there is a power law relation between flow rate, or average speed v, and pressure gradient ∇P when there is a competition between the viscous forces and the capillary forces that have their origin in the surface tension between the immiscible fluids and between the fluids and the solid matrix. Using the much-simplified capillary fiber bundle model, we could derive this power law dependence [3], and we propose that the constitutive law that relates v to ∇P has the form

$$v = -M\,|\nabla P|^{\beta-1}\,\nabla P$$

(so that the speed $|v| \sim |\nabla P|^{\beta}$) where β is an exponent having a values in the range 1.5 to 2. The two equations from [1] then makes it possible to relate the speed of each fluid, v_w and v_n to v, and therefore to ∇P even though the constitutive law is non-linear.

What about the co-moving speed? From preliminary studies it seems that it is a simple function of dv/dS_w, as seen in the figure which is based on data on relative permeability for Berea sandstone (Oak, Baker and Thomas, JPT 1990). It was a huge surprise when we saw how simple it was. We must indeed be on the right track.

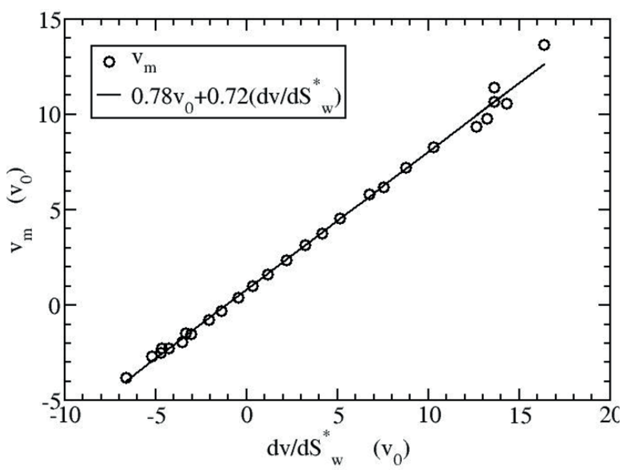

Fig. 1: The co-moving velocity as a function of the derivative of the average velocity with respect to the saturation.

Using the simple co-moving speed v_m and the complex average speed v, we are then able to calculate what the speed of each fluid is, v_w and v_n. This is a remarkable result which no other theory today can produce. Hence, we are well underway in developing a tool for calculating the flow of immiscible fluids on large scales, a truly predictive tool.

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DROPLETS, BUBBLES OR FILMS?

TOWARDS A HETEROGENEOUS THERMODYNAMIC FRAMEWORK FOR POROUS MEDIA

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Gases and liquids can form various structures inside pores. Some examples are bubbles, droplets, films and homogeneous gas or liquid phases. A non-trivial question in this regard is: For a given set of conditions, what structure is the fluid most likely to take if left to itself? The result is the equilibrium structure, or equilibrium state.

Such knowledge is of importance for several applications. One example is hydrogen fuel cells where condensation of water may block flow paths, depending on which kind of structure the liquid water takes. This can be detrimental for performance. Another example is sequestration CO_2 in geological formations, where the resistance of CO_2 towards movement depends on which structures it forms. Mobile CO_2 may be desirable during injection, but undesirable for long-term storage.

Classical thermodynamics offers a procedure for determining the equilibrium state. First, one must set up a model that enables calculation of the relevant energy function. The type of energy function will depend on the boundary conditions, e.g. whether fluid particles can flow in and out of the pore or whether the pore is thermally insulated or kept at a constant temperature. A stable configuration is a local minimum in the free energy landscape, while the equilibrium state is the global minimum. By finding the global minimum, we can identify, for a given set of conditions, which configuration that is the equilibrium configuration.

We consider a cylindrically symmetric pore and the structures illustrated in Figure 1. By varying conditions and finding the equilibrium state for each set, one can make phase diagrams. Figure 2 shows the equilibrium configurations of liquid water and water vapor at 358 K in pore of 10 nm in length, for different total densities and liquid contact angles in a closed pore kept at a fixed temperature.

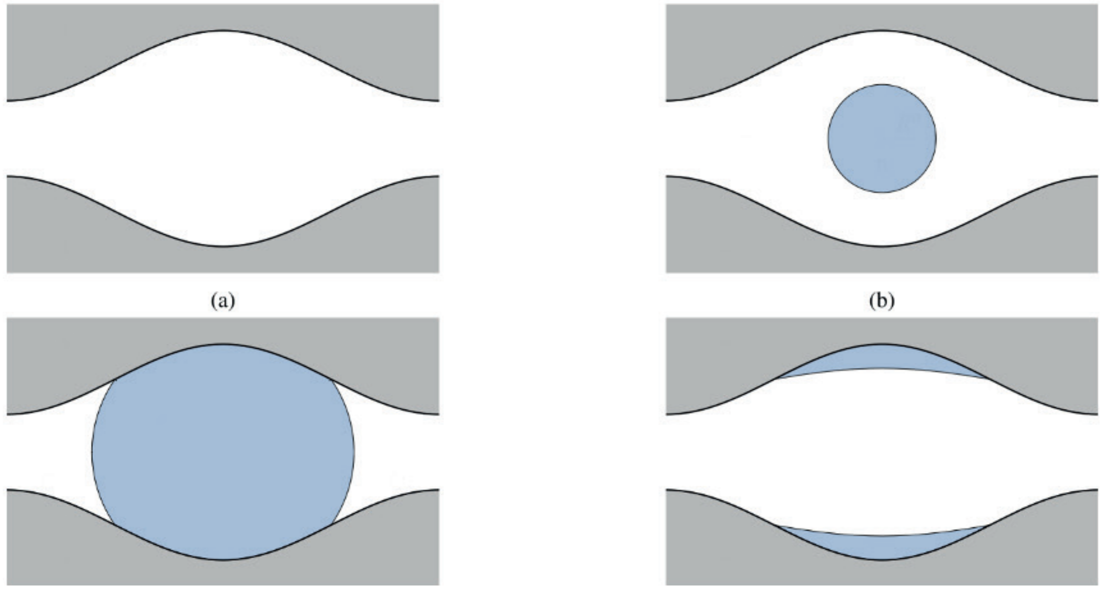

Fig. 1: Illustration of the fluid structures: (a) a homogeneous fluid phase, (b) a free droplet or bubble that is not in contact with the pore walls, (c) a droplet or bubble filling the entire cross-section of some part pore and (d) a thick film of gas or liquid.

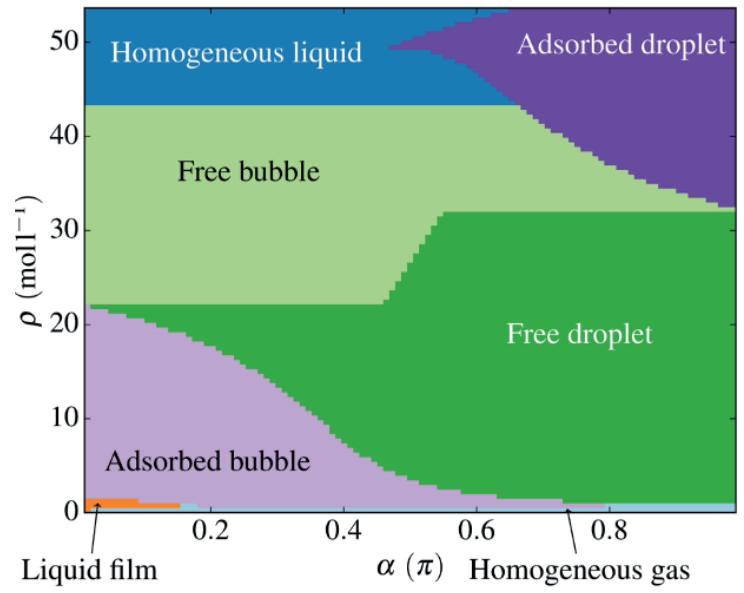

Fig. 2 Phase-diagram showing equilibrium configurations in a closed pore with a length of 10 nm. Considered configurations are homogeneous gas (light blue), homogeneous liquid (blue), free bubble (light green), free droplet (green), adsorbed bubble (light purple), adsorbed droplet (purple), gas film (light orange) and liquid film (orange). The equilibrium configurations are shown as a function of contact angle (x-axis) and total density (y-axis).

The calculation procedure requires models for the relevant free energy functions. Here, we have employed a capillary approach, where interfaces are described by a surface tension and fluid properties are calculated using the cubic-plus association Soave-Redlich-Kwong equation of state. This lets us draw on a large body of work done on developing thermodynamically consistent models for different kinds of fluids.

For the liquid water/water vapor system depicted in Figure 2, a key finding is that it matters greatly if the pore is open or closed. Furthermore, the pore size is important. Homogeneous gas or liquid phases (as seen in Figure 1) start to appear in sufficiently small pores, and the heterogeneous structures disappear as equilibrium structures.

In a future work, we will incorporate the concept of disjoining pressure into our modeling framework. This will enable the study of thin films.

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HOW FRONT HEATING CONTROLS FRACTURE PROPAGATION

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Fractures propagating in brittle media, whether artificial or natural, usually transit between slow propagation (creep), and "catastrophic" fast rupture. The alternation between these modes of rupture generates noise during fracture propagation, e.g. when a piece of glass or polymer is broken, or when polymeric glue in a tape is torn apart. Similarly, faults in the Earth crust happen in disordered media, where asperities induce intermittency, and their mechanical functioning results in an alternance of aseismic and seismic phases. The result of this intermittency is a distribution of the events whose shape and width depend on the scale of observation. During comparisons between models and experiments, it was shown that the mechanics on fracture in disordered media depends both on the toughness distribution for the heterogeneities on the fracture way, and on the thermal fluctuations that allow the fracture to go through these hard parts or asperities. Taking into account these two types of disorder, material and thermal, allows to account for many aspects of interfacial fracture, in the statistics of events, the fast dynamics and the slow creeping one. We study the influence of the dynamics of the evolution of the temperature field due to heat transport and generation, and to the transport of pressurized fluid along the fault. We developed a model of the heating of fracture tips due to energy released during fracture, and of the influence of temperature elevation on the velocity of rupture, expressed as a chemico-physical process taking into account energy barriers, that depend on the local stress state, and temperature at local scale. This proved to reproduce the velocity regimes of fracture, from very slow creep to dynamic fracture, including the jump from slow to fast velocities.

The model reproduces experiments done in mode I rupture of polymers, namely Plexiglas and polymeric glue in adhesive tape (Vincent-Dospital et al., 2020a) – cf Fig 1. This also explains features such as fractoluminescence during fast rupture. It also renders for a transition between brittle and ductile fracture mode and explains this transition as a critical point (Vincent Dospital et al., 2020b).

In a case where heating is negligible, we could also explain the distribution of local velocities (Cochard et al., 2019) and the distribution of global velocities and jumps (Santucci et al., 2019) – cf Fig. 2.

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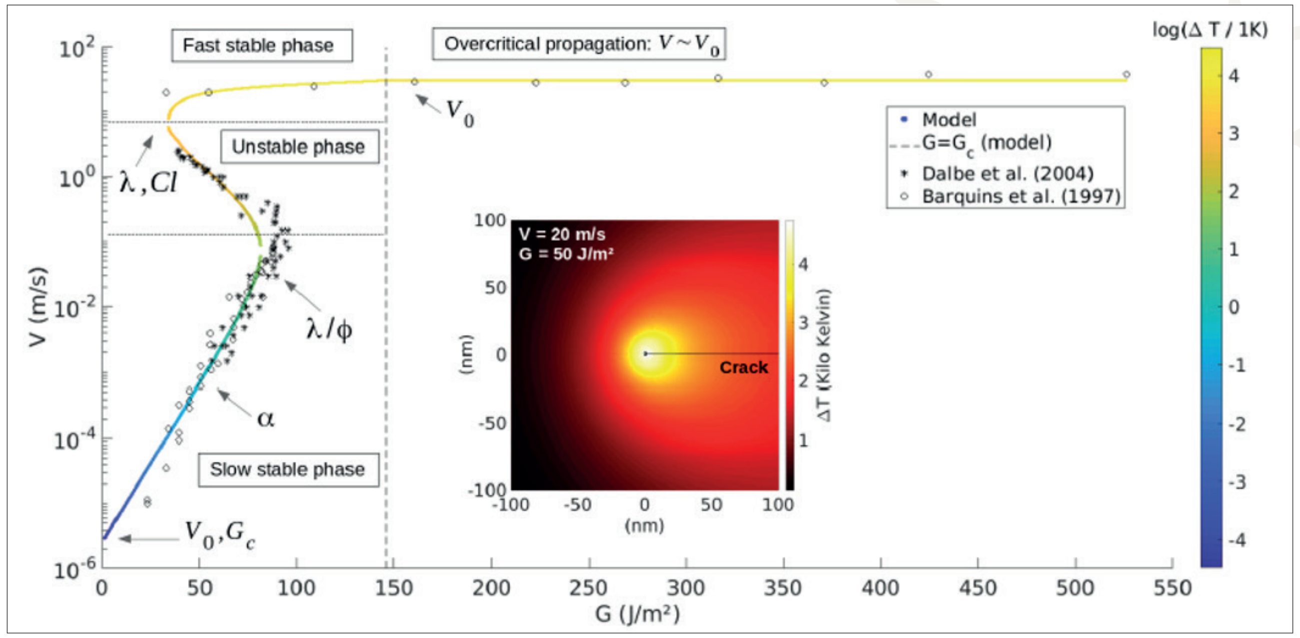

Fig. 1: Characteristic curve of energy release rate versus propagation velocity (G,v) theoreticallly obtained and fitted to experimental data (points) on fracture in tape glue, during tape peeling experiments. The unstable branch corresponds to G(v) decreasing, its presence is associated to a stick-slip instability. The tip temperature is visible in the colour bar. The arrows indicate which model parameters control the different parts of the curve. The inset shows the modelled temperature field around the crack tip, at the onset of the instability, v=20 m/s. After Vincent-Dospital et al., 2020a.

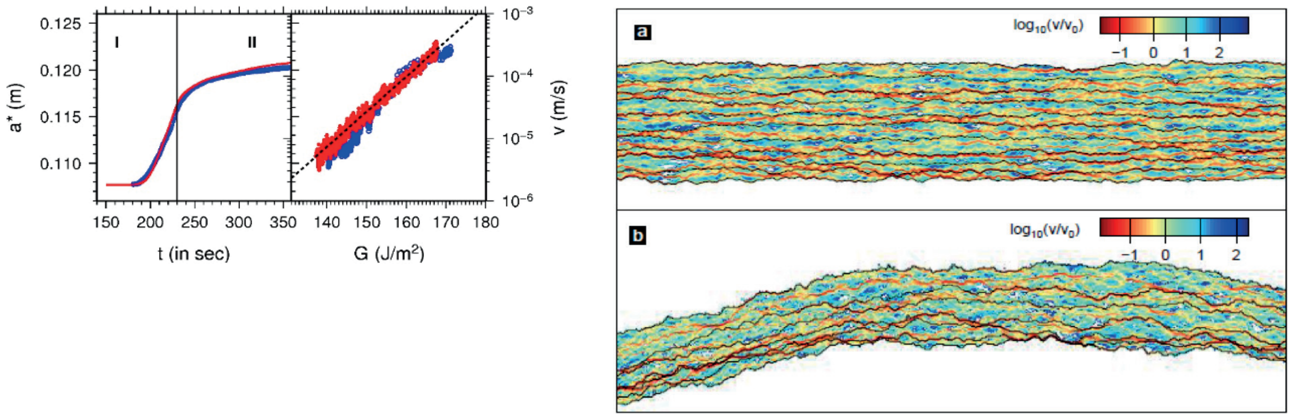

Fig. 2: (i): left: front position during a slow mode I experiments in PMMA. The imposed opening increases during stage I, and stops in stage II – the front still advances. Right: Energy release rate G vs. log(v) during the whole experiment, where v is the average front velocity, showing an Arrhenius law as in Eq. (2). After Lengliné et al., 2011. (ii): Velocity of a crack front propagating in mode I in a disordered interface, spatial map over the whole duration. Top: simulations. Bottom: experiments. After Cochard et al. 2019.

PREDICTING IMPENDING FAILURE: THE ENERGY-PRESCRIPTION

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It is obvious that if we increase stress or load on a composite material, at some point the system will collapse i.e., the material cannot bear the load and breaks into pieces. But when does this collapse point come? Is there any prior signature? Can we somehow predict this collapse point? These are some long-standing questions in the field of fracture-failure of materials under stress. We have addressed this problem using fiber bundle model (FBM) and we believe that new knowledge on the prior signatures of upcoming collapse will surely help mitigation plans to avoid major accidents (collapse of buildings, bridges, dams etc.) and save human lives.

Fiber bundle model is a simple and efficient model to describe the fracture-failure in composite materials under stress [1,2]. This is an old model, introduced in 1926 by a textile engineer F. T. Peirce and NTNU physics department has been involved in FBM studies since 1992.

In our recent work [3] we have observed that in equal load-sharing (ELS) FBM the elastic energy variation can tell us exactly when the bundle will collapse. The theoretical claim was supported by simulation results for different fiber strength distributions.

When a bundle is stretched by an amount Δ, the force on the bundle can be written as

$$F(\Delta) = Nk\Delta\,(1-P(\Delta));$$

where P(Δ) is the cumulative distribution of the fiber strengths, N is the total number of fibers and *k* is the force constant for each fiber. If we keep on increasing the stretch, generally the force assumes a parabola like shape having a single maximum. Clearly, this maximum point (Δ_c) is the strength of the bundle beyond which the bundle collapses.

We can easily calculate the elastic energy of the bundle when the stretch is Δ,

$$E^e(\Delta) = \frac{Nk}{2}\Delta^2\,(1-P(\Delta))$$

and the corresponding damage energy (total energy dissipated by the failed fibers)

$$E^d(\Delta) = \frac{Nk}{2}\int_0^{\Delta} x^2 p(x)dx;$$

where p(*x*) is the fiber strength distribution. If we plot elastic energy and damage energy vs. stretch together with the force (Fig.1) we can clearly see that while damage energy *grows* continuously, the elastic energy has a maximum. But this maximum appears after the critical stretch value (Δ_c). Therefore, it can not be used to predict the collapse point of the bundle. However, if we calculate the rate of change of elastic energy $dE^e/d\Delta$ (slope of elastic energy vs. stretch curve), the variation of elastic energy shows a maximum that appears before the collapse point (Fig. 2) and therefore it can be treated as a reliable signal of impending failure. It seems this is a universal behavior for any type of fiber strength distribution that has a parabola like force-stretch curve with a single maximum [3]. We believe this is an interesting observation and it can be applied to other stress-induced failure situations occuring also in very different domains -for example, in fracturing of concrete structures [4] or in breakdown of social relationships and mental health [5, 6].

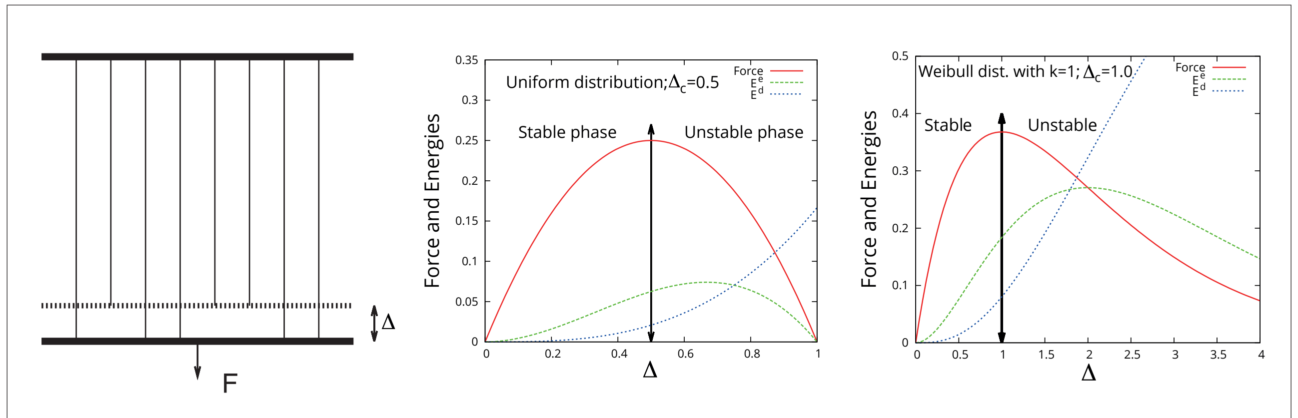

Fig.1. The fiber bundle model and the force, elastic energy (E^e) and damage energy (E^d) vs. stretch for uniform and Weibull distribution of fiber strength.

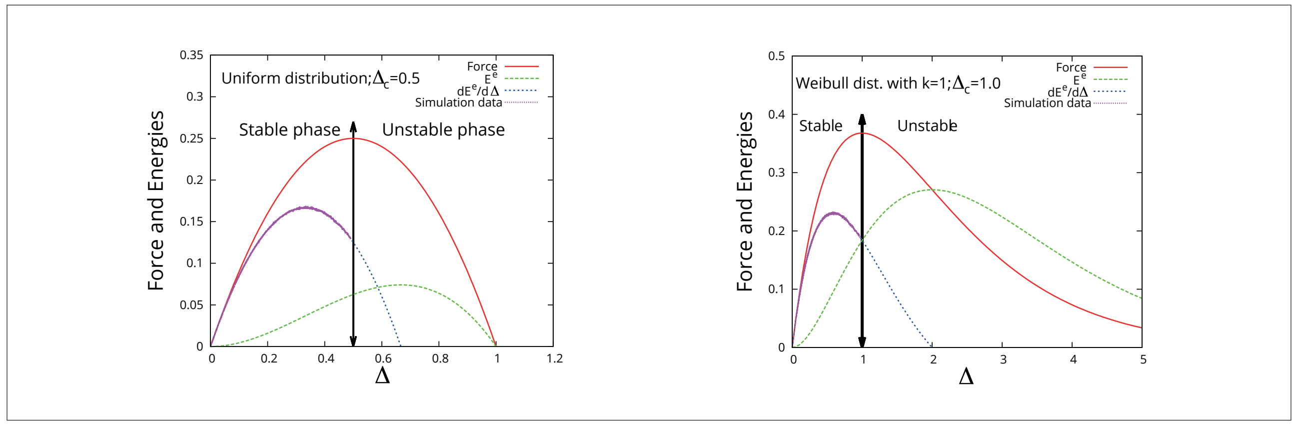

Fig. 2. Force, elastic energy and elastic energy variation vs. stretch for uniform and Weibull distribution of fiber strength. Results from simulations (purple) overlap with theoretically predicted curves (blue).

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ROLE OF DISORDER IN FRACTURE GROWTH

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Technological development of our civilization depends on strong and stable materials. Formation of defects or micro-cracks in a material under external stress is a primary concern for mega structures such as bridges, ships and aircrafts, as well as for smaller equipment. In recent times smartphones and laptops are becoming smaller and thinner which led the material designing for such devices increasingly important to prevent structural deformation and protection of internal electronics during everyday use. A stable material is often prepared by mixing several materials of different properties and making heterogeneous composites. A few examples are concrete and carbon-fiber reinforced composites which possess larger strength and toughness compared to the individual materials.

Heterogeneities in a material not only create spatial fluctuations in the local material strength but also introduce spatially dependent dynamic stress field. When a sufficiently large external stress is applied to a heterogeneous material, a microcrack appears at the weakest point and creates higher stress at the crack tips. Whether an existing microcrack will grow in size or a different microcrack will appear, depends on the dynamic competition between local stress concentration and local material strength. When the local stress intensity becomes so large that local material strength cannot compete anymore, the system undergoes a catastrophic failure. In this way, the disorder plays a crucial role in the fracture growth, in general, the more disordered the material is, the more spatially uncorrelated cracks will appear before a catastrophic failure. However, the type of transition from a single abrupt rupture to random failures depends on the type of disorder and is complex to understand.

We explore in detail the role of disorder in the breakdown process of brittle materials by using *Fiber Bundle Model*. In this model *N* fibers or Hookean springs of different strengths are placed between two clamps under an external force *F*. The model was first introduced in 1926 by F. T. Peirce to model the strength of yarn. Since then it has come a long way and has become a fundamental model of fracture similar to the Ising model for magnetic systems. We adopted a *local load sharing* (LLS) scheme of the model where the load carried by a failed fiber is distributed only to the nearest intact fibers and thereby creating a dynamic stress field which compete with the local strengths. The disorder in the thresholds of fiber extensions are generated by raising uniform random numbers to a power *D*, which allowed us to control the amount of disorder by tuning the value of $|D|$ and also to choose whether strong or weak fibers are more probable in the system. This can be done by selecting $D>0$ or $D<0$ respectively.

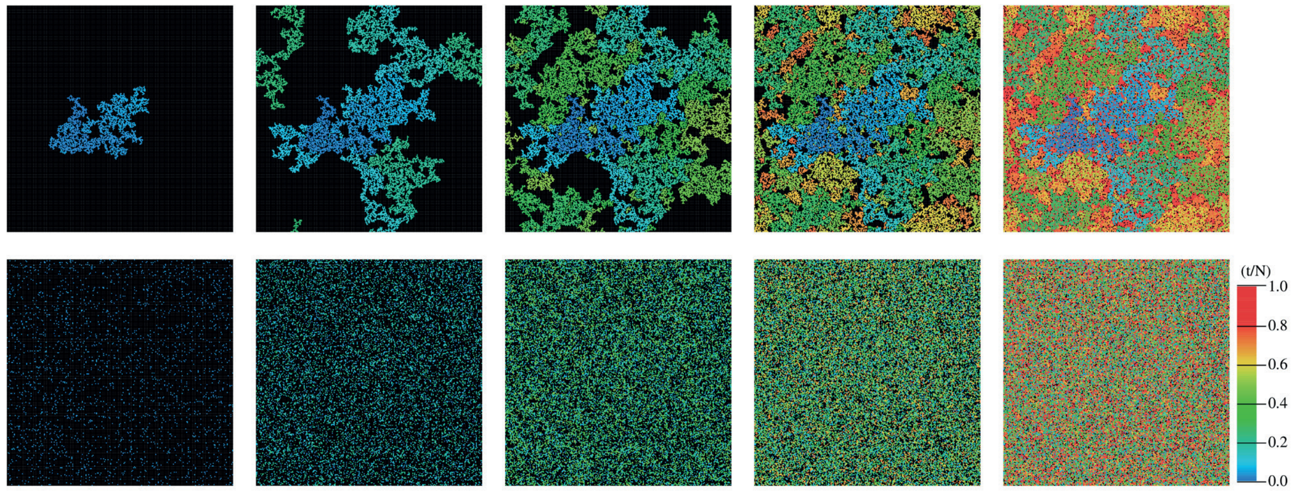

Figure 1. Growth of cracks in a bundle of 256 × 256 fibers. The top row corresponds to low disorder and the bottom row corresponds high disorder. The black and colored sites are the intact and broken fibers respectively. The colors indicate the breaking sequence, the blue fibers failed in the beginning whereas the red fibers failed at the end. A single crack grows at low disorder creating clusters of different colors, whereas at high disorder, random cracks appears creating a mixture of colors.

Fig. 1 shows the fracture growths at low and high disorders. At low disorder with $D=0.02$, a single crack grows from the beginning whereas at high disorder with $D=2.0$, cracks appear randomly. The colors represent the sequence of failures and interestingly, different colors show clusters at low disorder showing spatiotemporal correlations in the failure process.

We ask two main questions here. What is the nature of the transition between these two fracture regimes as we vary the disorder? Is it different for the two different types of disorders, $D>0$ and $D<0$? Secondly, how can we quantify the spatiotemporal correlations of the failure dynamics that we see in the color map of Fig. 1? To answer the first, we defined an order parameter by measuring the number of individual cracks as a function of time. The order parameter revealed an interesting feature: The transition is first order for negative *D* while it is similar to a second order percolation transition when *D* is positive.

For the second part, we calculated a pair correlation function $G(r,\Delta t)$, that is, if a fiber at position r_0 fails at a certain time *t*, what is the probability that another fiber at r_1 will break at time $t+\Delta t$, where $r=|r_1-r_0|$. Here *t* refers to the sequence of the fiber breaking. The function shows the form,

$$G(r,\Delta t)=r^{-1}g(r^z/\Delta t),$$

where $g(u)$ has an interesting limiting power-law scaling as shown in Fig. 2, with a peak at $r^{d_f}=\Delta t$. Here d_f is the fractal dimension of the crack.

What does this study reveal? It explores how different types of disorder lead to different failure scenarios in fracture. The pair correlation function quantifies the spatiotemporal correlation of the failure dynamics. It therefore provides a detailed understanding about the role of material disorder on fracture growth where the competition between the local stress enhancement and local material strength controls the failure dynamics.

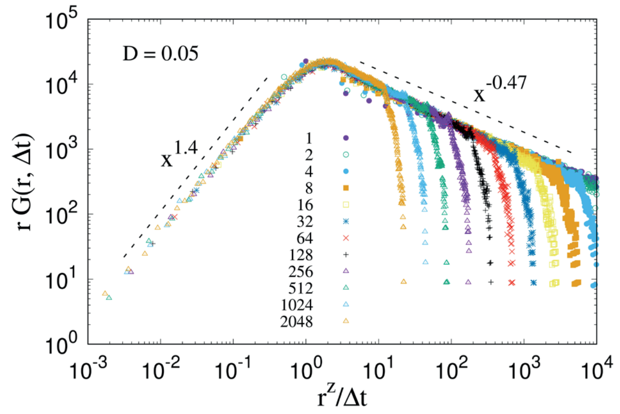

Figure 2. Pair correlation function $G(r,\Delta t)$ for different values of Δt as indicated in the figure. The function shows two limiting power-law scaling for short and long time limits. The peak at $r^{d_f}=\Delta t$ implies the most probable growth of the crack happens around $r_t \sim \Delta t^{1/d_f}$.

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TWO-PHASE FLOW EXPERIMENTS IN POROUS MEDIA: INVASION MORPHOLOGY AND DYNAMICS IN 2- AND 3-DIMENSIONAL SYSTEMS

Marcel Moura[1], Joachim Falck Brodin[1], Eirik Grude Flekkøy[1], Gerhard Schäfer[2], Renaud Toussaint[1,3] and Knut Jørgen Måløy[1]

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One really does not need to have a very trained eye to find examples of porous media two-phase flows lying around. Consider a tea bag (Figure 1A). A wet one. Now if you place the tea bag on top of a napkin, you will notice that as the napkin gets wet, an interesting intermittent dynamic happens: sudden pockets of air are sucked from the surrounding environment into the void spaces (pores) between the tea leaves. This is an example of a two-phase flow in a porous network, one of the virtually infinite number of systems in which an invading fluid phase displaces a defending phase from a porous medium. Such systems are relevant for many practical applications, such as the treatment of polluted soils and the development of modern solar cells. In this project, we have studied the invasion dynamics of porous media two-phase flows in detail, by employing artificial transparent networks. Contrary to the tea bag (toy) experiment, our models allowed us to have full visual inspection of the dynamics. We have performed experiments both in the classical 2-dimensional Hele-Shaw geometry and in a more challenging 3-dimensional setup using a recently developed 3D optical scanning technique.

2D EXPERIMENTS: FROM INVASION BURSTS TO THIN FILM FLOW

The intermittent invasion dynamics seen in the tea bag experiment is indeed a rather general feature of slow drainage experiments in porous media, irrespective if the medium is a porous rock, a bucket of soil, or the Englishman friendly example from below.

We have studied this burst activity in detail by employing custom-built transparent porous networks (Figure 1B). The influence of boundary conditions to the dynamics was considered and we measured both the visual aspects of the invasion bursts and their characteristic pressure signatures. Finally, we have proposed a fully integrable analytical model that describes, for a specific set of boundary conditions, the power spectrum of the intermittent pressure signal.

Another interesting aspect of slow drainage experiments is the fact that, quite frequently, some thin liquid films are still found in the porous medium even after it has been invaded by air (or any non-wetting phase). If you look close enough at the tea leaves, you will find that they are not completely dry after the napkin sucks the water away: thin liquid films are still found covering their surfaces. Again, there is nothing special about tea leaves and this kind of phenomenon can be observed in many other natural or engineered systems. Even more interestingly: sometimes these thin liquid films are found to be interconnected, creating new links between different parts of the porous medium (Figure 1C). These links can be used as a *secondary network* for transporting fluids from one area of the porous medium to another (transport via thin film flow). We have employed our transparent porous networks to characterize this interesting secondary transport mechanism. We have shown the formation of a *film flow active zone*, a region where the probability of fluid transport through the thin film network is maximized.

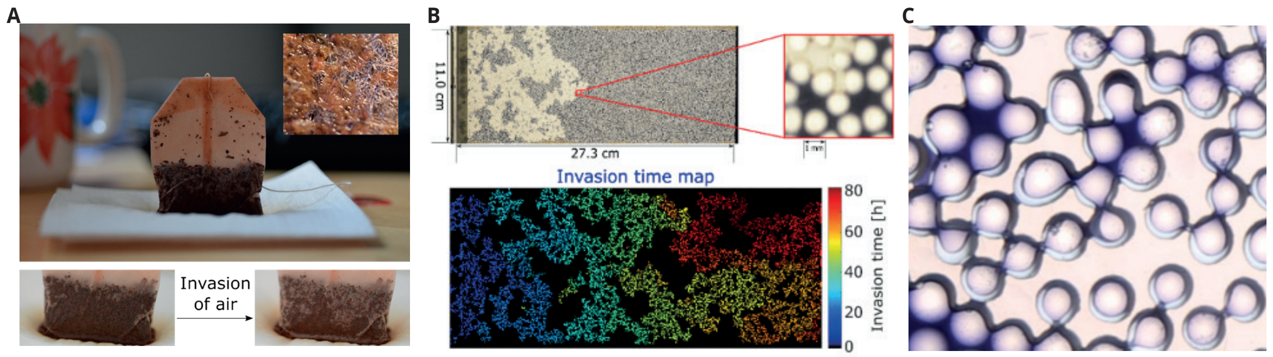

Fig.1. A The tea bag experiment. As the wet tea bag dries, pockets of air suddenly invade the voids (pores) between the leaves, in a typical example of the intermittent burst activity observed in drainage experiments. The inset on the top right shows a macro image of the porous matrix. B The intermittent drainage dynamics is studied in a transparent model where air invades a porous medium filled with a viscous liquid. The invasion map shows the time a pore is invaded by air. C Thin liquid films left on the surface of the porous matrix can merge and interconnect different parts of the medium, acting as a secondary pathway for fluid transport.

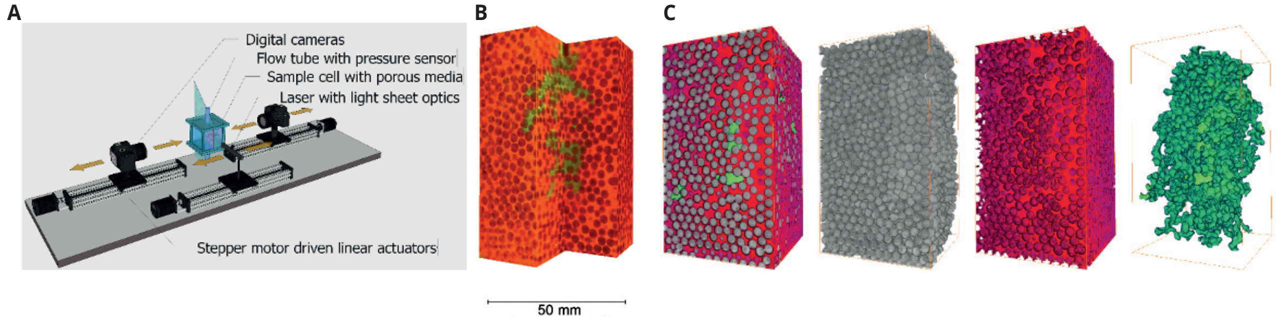

Fig.2. A The scanner is based on optical index matching and fluorescence. A random packing of 3 mm glass beads forms the porous medium, index matched with two immiscible fluids. The fluids contain different fluorescent dyes that are excited with a 2D laser sheet, that is driven through the sample during a scan. The fluid phases appear on the images with different colors, making them distinguishable through the analysis. B Raw 3D data. The 2D images captured as frames by the cameras are put together to build up the third dimension. C Segmented phases. The porous medium and the two liquid phases are fully separated.

3D EXPERIMENTS: THE INTERPLAY BETWEEN VISCOUS, CAPILLARY AND GRAVITATIONAL FORCES

The interplay of forces in two-phase flow in porous media has been an active topic in 2D experimental studies, using the Hele-Shaw geometry. The findings have led to a level of understanding of the circumstances related to different flow regimes and to connections between the geometry of flow structures and system parameters, such as the flow velocity, the pressure gradient or the viscosity contrast between fluid phases.

Using our newly developed 3D optical flow scanner (Figures 2A and 2B), we wish to confront the findings from the 2D experiments with the 3D scenario. Our setup allows for the full segmentation of the two fluid phases and the porous network in 3D (Figure 2C). In the first series of experiments, we investigate how to derive a meaningful dimensionless Bond number, to quantify the balance of viscous, capillary and gravitational forces and we explore the possibility that such a dimensionless number could figure in a function describing geometric parameters of the flow structures. This work will relate to studies conducted in 2D (see references), where a relation between a modified Bond number and a characteristic width, of the invasion pattern, has been derived. By extending these successful theoretical results obtained originally in 2D to our 3D setup, we will be able to make predictions about fluid front morphology in realistic 3D scenarios where gravity cannot be neglected.

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MICROFLUIDICS: A SCREENING TECHNOLOGY PROVIDING SIGNIFICANT OBSERVATIONS FOR EOR APPLICATIONS

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Microfluidics has become a vital research area in the Petroleum Industry. It is highly appreciated owing to significantly improving our current understanding of pore-scale displacement events and interactions occurring within tiny fluid volumes moving within well-defined pore-structures. In addition, it enables capturing the dynamic changes within the medium with a high spatial and temporal resolution. The energy and chemicals fed to a microfluidic setup are much less compared to the core-flooding apparatus, which lowers costs and risks. The heavy and large conventional core flooding setup is reduced to a smaller apparatus with a higher level of accuracy and significant observations.

Microfluidic experiments produce a huge amount of data in the form of images coupled with data from pressure sensors. These images go through several processes to make them suitable for data extraction. The extracted data also go through several processes to provide parameters and descriptors with a valuable meaning. This is called image processing and analysis. In our studies, these processes are digitalized to reduce the researcher's time on processing and increase it on drawing conclusions.

NANOCELLULOSE AS A GREEN ADDITIVE FOR IMPROVED OIL RECOVERY

Recently, nanocelluloses have been introduced as environmentally friendly nanoparticles for EOR applications. Cellulose is the most abundant biopolymer extracted from plants. Cellulose nanocrystals (CNCs) and TEMPO-oxidized cellulose nanofibers (T-CNFs) dispersed in brine (0.1 wt. % sodium chloride (NaCl)) have been tested in core-scale flooding experiments. T-CNFs resulted in higher incremental oil recovery (35.4 %) compared to CNCs incremental oil recovery of 2.9 %. Three microfluidic experiments were designed to evaluate the dynamic change in oil recovery, connectivity, and clustering. Similarly, T-CNFs led to the highest oil recovery. T-CNFs flooding (experiment M3) led to the best sweep efficiency, resulting in the lowest connectivity of the residual oil, and a significant reduction in the size of the remaining oil clusters compared to CNCs (experiment M2) and brine (experiment M1), (see Figure 1).

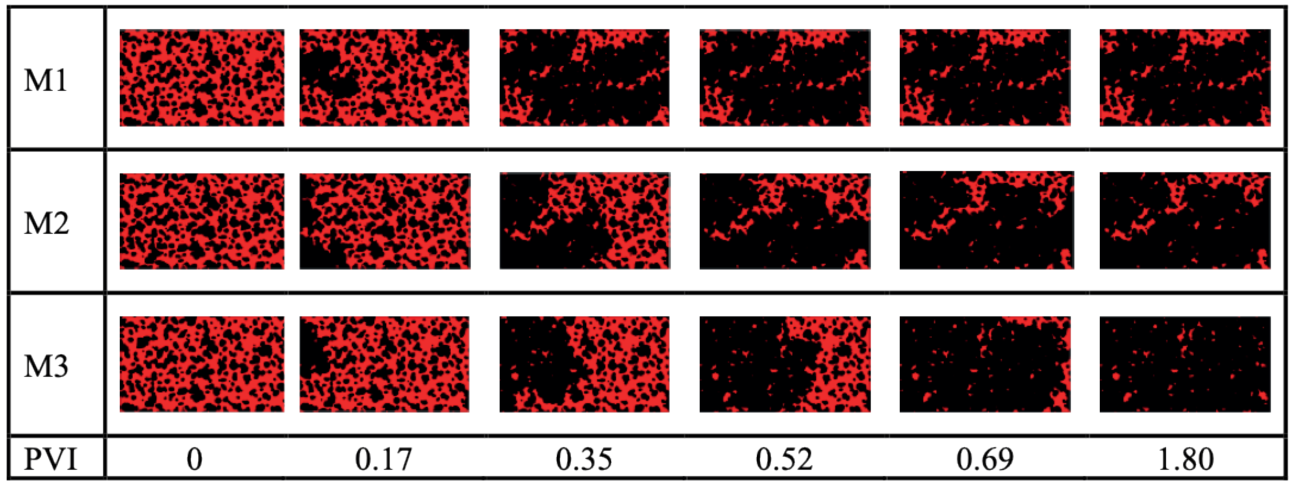

Figure 1: Change in the oil configuration in the analyzed part of glass microchips as a function of pore volume injected (PVI) for experiment M1 (T-CNFs flooding) , M2 (CNCs flooding) and M3 (brine flooding). Lowest residual oil connectivity and smallest size of the remaining oil clusters are observed in T-CNFs post-flooding state at PVI = 1.80. (Aadland et al., 2020).

INVESTIGATION OF THE EFFECT OF ADDING NANO-PARTICLES TO POLYMER FLOODING

Polymer flooding is described by adding polymer molecules to the aqueous injected phase to increase its viscosity. The increase in the injected fluid viscosity reduces its mobility in the reservoir, resulting in improved flood efficiency. Nanoparticles (NPs) enhance recovery efficiency by reducing the interfacial tension and altering the rock wettability. Using glass microfluidic chips, the combination of the polymer flooding technique and nanotechnology was investigated as a promising method to reduce trapping efficiency. Xanthan Gum to prepare the polymer solution and surface-modified silica NPs were selected for this study. It was found that NPs-assisted Xanthan Gum flooding resulted in the highest oil recovery and the smallest residual oil cluster sizes compared to Xanthan Gum flooding and NPs flooding, (see Figure 2)

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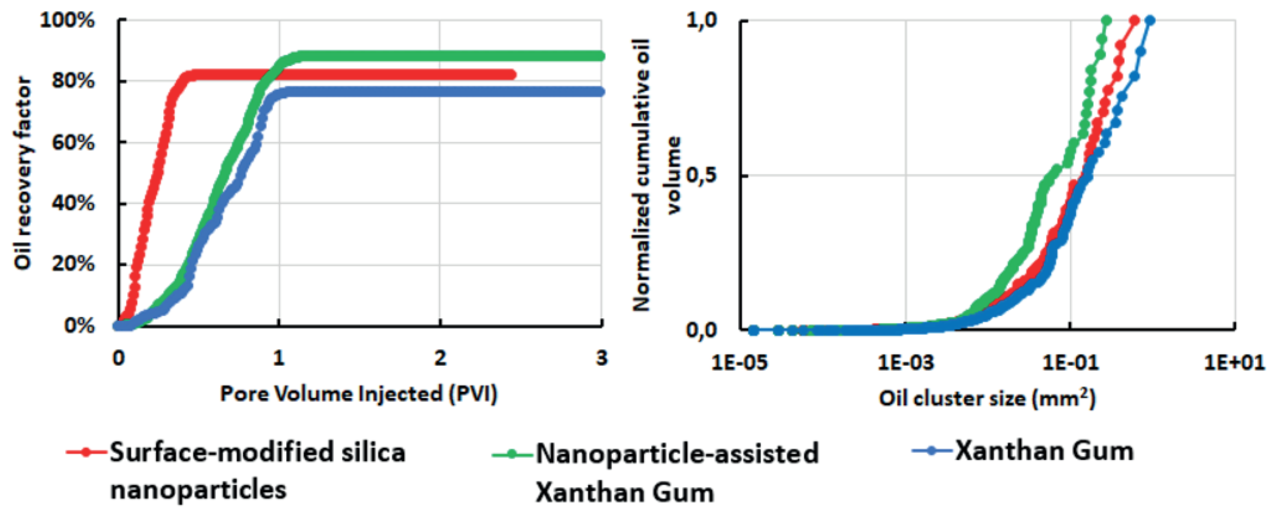

Figure 2: Left: oil recovery factor as a function of pore volume injected (PVI). Right: normalized cumulative residual oil volume as a function of oil cluster size. (Rueda et al., 2020)

DIFFUSION AND DISSOLUTION IN COMPLEX MEDIA

Kristian S. Olsen[1], Le Xu[1], James M. Campbell[1,4], Luiza Angheluta[1], Renaud Toussaint[1,2], Piotr Szymczak[3], Eirik Grude Flekkøy[1], Bjørnar Sandnes[4] and Knut Jørgen Måløy[1]

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Deformation and dissolution processes in porous media and fractures presents a rich arena where pattern formation can be studied. This project focuses of the formation and transport in such patterns.

One example is the dissolution process that takes place when a reactive fluid is injected into a fracture, creating complex structures on the fracture surface (Fig. 1). This process is important for many naturally occurring phenomena, such as the weathering and diagenesis of rocks, dissolution in salt deposits and melt extraction from the mantle. We have performed experiments by injecting a reactive fluid into an analog fracture and investigated the structure and dynamics of the patterns.

Our experimental results show a number of features consistent with the theoretical and numerical predictions on finger growth dynamics such as screening and selection between the fingers. Different dissolution patterns were obtained depending on the flow rate, the fracture aperture and fracture roughness. In general the dissolution patterns were found to depend on the characteristic timescales for diffusion, convection and reaction.

We have also studied diffusive transport in patterns emerging from deformation processes in frictional fluids. Although diffusion is a simple example of a non-equilibrium process, complications can arise when the flow takes place inside a non-trivial geometry. In these cases there are interactions between the diffusing particles and the boundaries of the system that may lead to anomalous behavior at large space and time scales. This anomalous behavior can be characterized in many ways, for example through the temporal scaling of the mean square displacement (MSD) or the entropy production. The anomalous diffusion can be modeled by a non-Gaussian distribution, where the degree of non-Gaussianity measures the anomaly of physical quantities like the MSD and entropy from the normal diffusive case. This has been studied in the case of frictional finger patterns (fig 2), where the diffusing particles have been interpreted as probes of the system geometry, and their MSD and entropy has been used to indirectly measure geometric features of the pattern.

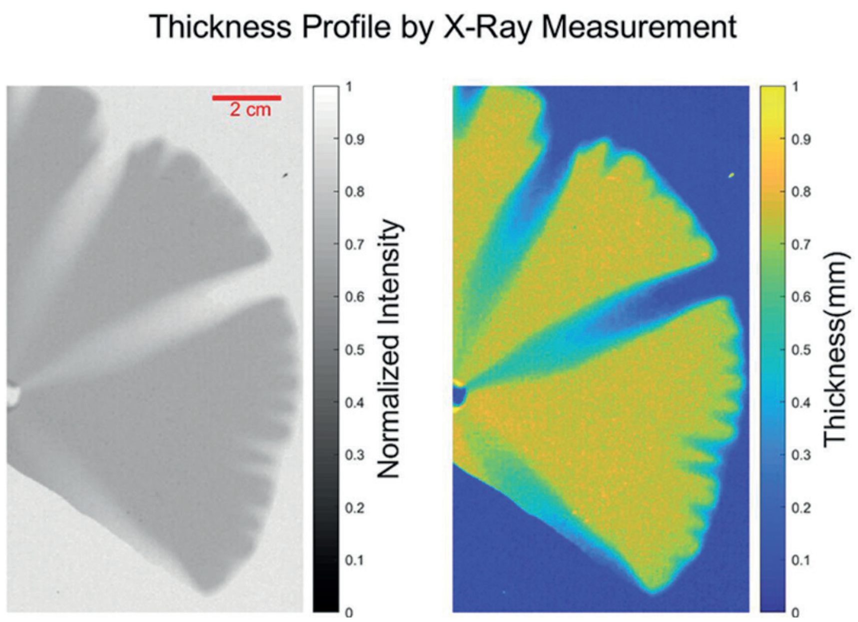

Figure 1. (Left) X-ray image of dissolved plaster sample captured by X-ray thickness gauge REX-CELL 4X from Flow Capture. The gray-scaled picture shown in the left panel is the normalized intensity of the X-ray measurement together with the color bar. (Right) Thickness profile of the dissolved plaster sample is displayed with the gradient-color picture together with the color bar.

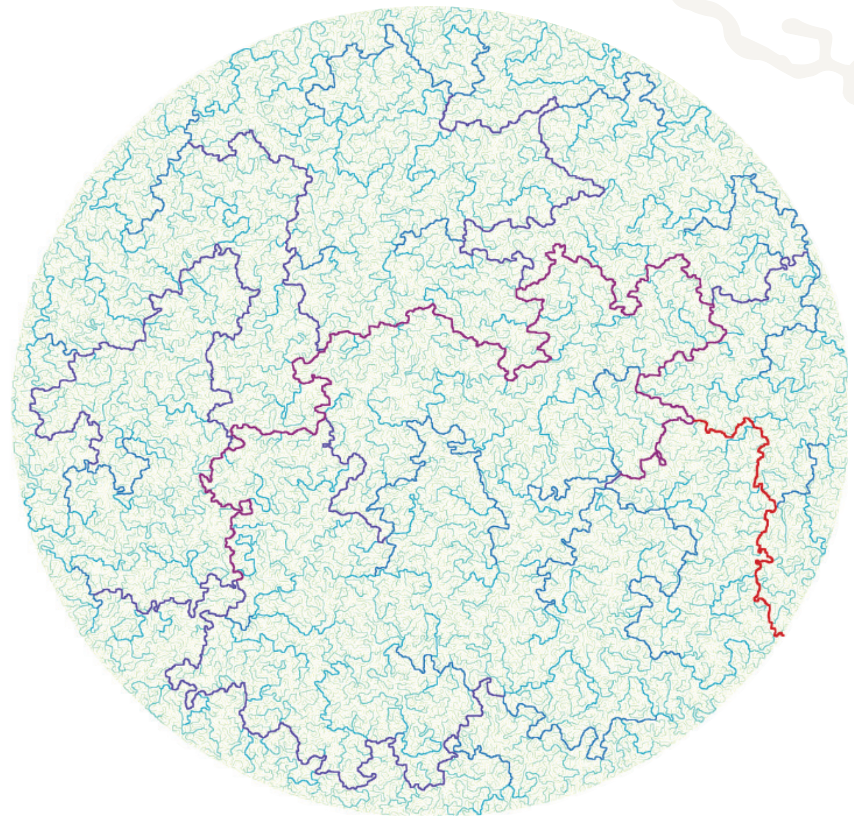

***Figure 2.** Figure showing the network topology of numerically simulated frictional finger patterns*

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EXPERIMENTING WITH DEFORMABLE POROUS MEDIA MODELS TO UNDERSTAND THE BEHAVIOR OF COMPLEX SYSTEMS

F. K. Eriksen[1,2], R. Toussaint[1,2], A. L. Turquet[2], K. J. Måløy[1], S. Lherminier[3], R. Planet[3], V. Levy dit Vehel[3], L. Vanel[3], E. G. Flekkøy[1], O. Ramos[3]

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Accurate descriptions and predictions about deformable porous media, e.g. granular media, are important in a wide range of applications. For example, deformable porous media are involved in earthquakes, landslides, structural engineering, food industry and farming. Therefore, this is a very active field of research. It is also a challenging field, both theoretically and experimentally. A granular medium, like sand, is generally a large collection of particles in contact with each other. The interaction between all these particles forms a complex network, which makes it extremely hard to predict the response of the medium when subjected to an external deforming stress. Experiments and simulations in analog models are good approaches to simplify and explore the problem.

FLUID DRIVEN DEFORMATION AND CHANNEL FORMATION IN CONFINED GRANULAR MEDIA

When a fluid is injected into a porous or granular medium at a sufficient overpressure, it will deform the medium and open up flow channels or fractures. The observed patterns and deformation depend on overpressure and the external forces.

Processes like this often occur in industry, for example to enhance oil & gas recovery, CO_2 storage, ground water and thermal energy production. Industrial fluid injections and deposits have sometimes led to deformation of the earth's crust resulting in unwanted damage, even earthquakes far away from tectonic plate boundaries. In this project, we study the phenomena of fluid driven deformation and channel formation in a fine grained medium (80 μm beads) confined between two horizontal glass plates (separated by 1 mm). We systematically study air injections with overpressures in the range 50 – 250 kPa while filming from above with a high-speed camera, as well as measuring the acoustic emissions with accelerometers. We have characterized the channel structures and deformation over time from the images, evaluated the pore pressure evolution numerically, and identified characteristic acoustic signals and their sources. We are currently linking our observations with real-world fluid induced seismic events (natural and industrial).

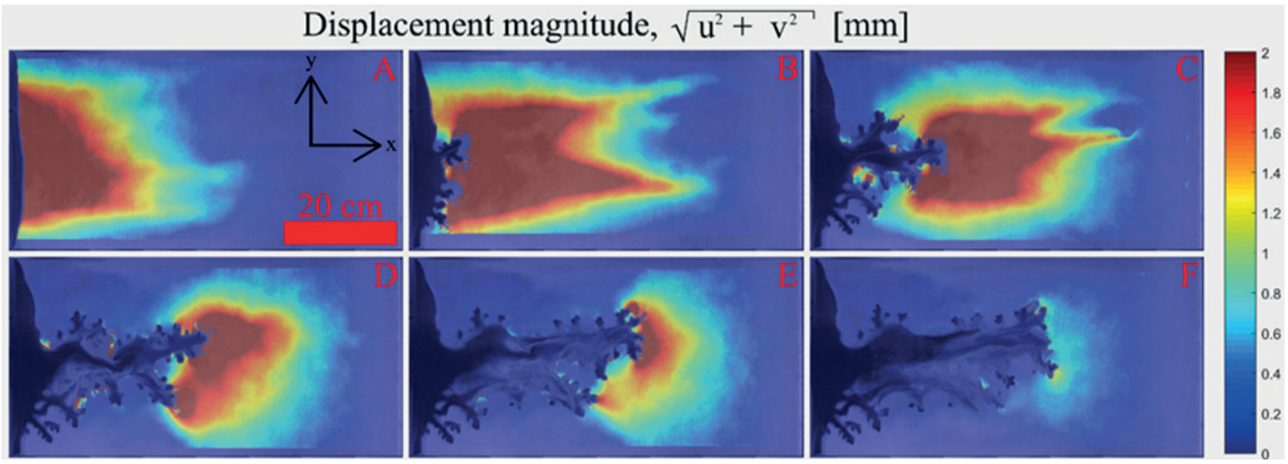

Figure 1. Snapshots of experimentally obtained deformation of the granular medium surrounding the evolving channel. The colormap is shown on top of experimental images, indicating the magnitude of displacement in the porous medium surrounding the channel at subsequent times in the experiment (from A to F). Bead displacement is mainly in the positive x-direction. Initially there is a growing compacting zone in front of the channel (A – B). After the compacting zone has reached the outlet boundary (C – F), the medium continues to compact and the deformation focuses towards the channel tips.

CONTINUOUSLY SHEARED GRANULAR MATTER AND COMPARISON WITH SEISMICITY LAWS

The frequency and size of earthquakes follow universal statistical laws which has been difficult to replicate with lab experiments. In our experiments small disks confined to a 2D cylindrical shell has compiled a huge number of "lab quakes". By continuously and slowly shearing a compressed monolayer of photoelastic discs, we have been able to replicate several statistical features of earthquakes like the Gutenberg-Richter law, the Omori law and interevent time distribution. In our system, the granular force network provides an emergent and evolving heterogeneity in terms of energy thresholds. The heterogeneity of energy thresholds is the key ingredient of the dynamics, and it is responsible for a distribution of events that resembles the Gutenberg-Richter law. In this experiment we used a 2D system of 3500 disks that were 7mm or less in diameter. These disks were confined in the narrow gap between two concentric, vertical cylinders. The top edge was covered with a weighted ring to induce pressure on the disks, while the bottom edge was rotated slowly with a rotation period of about 18 hours. Having a system that matches geological observations may lead to the essential ingredients that control the dynamics of real earthquakes.

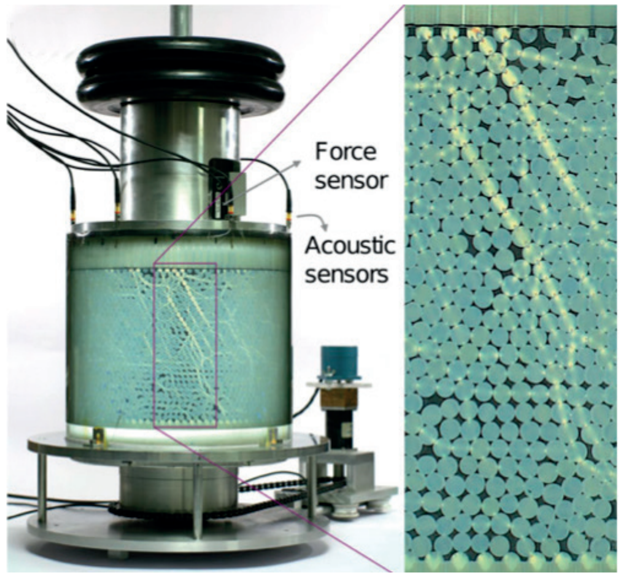

Figure 2. Photograph of the setup, displaying the mechanical and acoustic sensors. Inset: force chains in the granular layer observed thanks to photoelasticity.

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RESEARCH PROJECTS

3D X-RAY MICROSCOPY OF HIERARCHICAL MATERIALS

Basab Chattopadhyay[1]; Aldritt S. Madathiparambil[1], Fredrik K. Mürer[1]; Kim Robert Tekseth[1]; Elvia Anabela Chavez Panduro[1]; Benoit Cordonnier[2]; Jessica Ann McBeck[2]; Malin Torsæter[3]; Kamila Gawel[3]; Pierre Cerasi[3]; Alain Gibaud[4]; Ragnvald H. Mathiesen[1]; François Renard[2]; and Dag W. Breiby[1,5]

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Over the last decades, X-ray microscopy (XRM) which utilizes the high penetrating power of X-rays, has emerged as the most ideal probe to nondestructively explore interior structural features of materials across research areas in geological, biological, and material sciences. Besides, XRM can be used in combination with complicated sample environments for time resolved measurements as well as to study materials in their native state.[1] The contrast in the 2-dimensional (2D) or 3-dimensional (3D) images obtained in XRM arises from the interaction of X-rays with matter: absorption, phase change, scattering and diffraction. Due to recent advancements in instrumentations as well as in computational resources, the last few years have witnessed remarkable progress in the application of XRM enabling studies of nanoscale structural features. However, there is growing need to develop new methodologies for 3D quantitative imaging of dynamical processes in real time. Described below are projects that demonstrate the use of different XRM methods to investigate material characteristics focusing on challenges in biomedical and environmental research.

X-RAY TOMOGRAPHY STUDY OF CARBONATE PRECIPITATION IN CEMENT

Cement, a very common and easily available construction material, is crucial in dealing with environmental challenges. For example, for the storage of CO_2 in abandoned oil reservoirs cement is the primary sealing agent. In a series of experiments we have performed detailed X-ray microcomputed tomography (µ-CT) studies to monitor the microstructural changes in Portland cement upon exposure to CO_2-saturated brine, see figure 1. [2,3] Particular attention has been given to the carbonation in the cement bulk and self-filling of an artificial defect by precipitation of calcium carbonate, studied under in situ conditions realistic for deep ground reservoirs, notably high temperature and pressure.

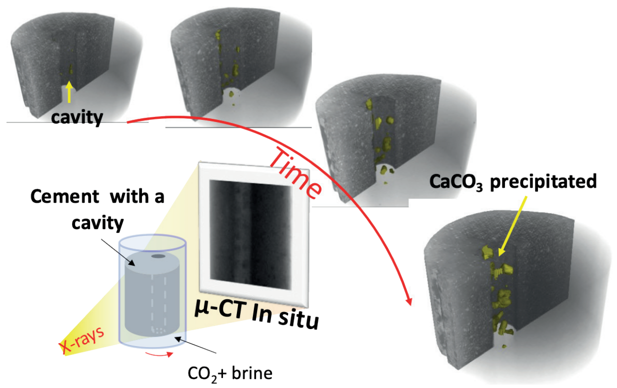

Figure 1. Perspective sketch of the home laboratory µ-CT study. Selected µ-CT images with cutaway-view highlight the calcium carbonate deposition inside the channel in the cement sample.

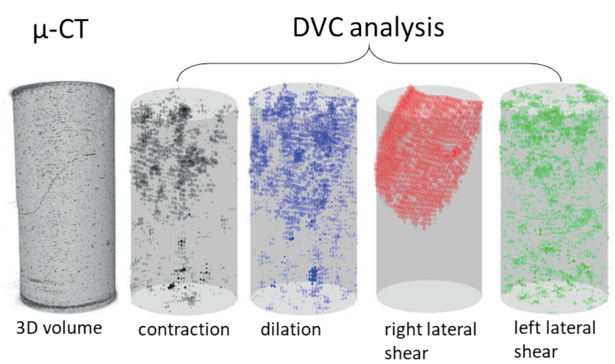

Figure 2. Results of in situ µ-CT measurements using the HADES deformation rig, performed at the beamline ID19 at ESRF. The 3D reconstructed volume of shale at an axial pressure of 60 MPa and the corresponding incremental strain field obtained from DVC calculations are shown.

TIME-RESOLVED IMAGING OF FAILURE IN SHALES

Being able to image the internal strain localization, fracture initiation and collapse of rocks under external loading is of key importance for the understanding of porous media. Time-resolved µ-CT was performed using synchrotron radiation at the microtomography beamline at European Radiation Synchrotron Facility (ESRF) using the triaxial deformation rig called HADES.[4] The progression of shear failure in a jacketed shale sample was imaged under increasing axial pressure. Analysis of the tomography datasets using digital volume correlation (DVC) [5] allows 3D mapping of the evolving strain tensor fields that provide insights into strain localization accompanying the fracture process. Results from this project (to be published) are highlighted in Figure 2.

3D ORIENTATIONAL MAPPING OF HYDROXYAPATITE CRYSTALS IN BONE USING X-RAY DIFFRACTION COMPUTED TOMOGRAPHY (XRD-CT)

XRD-CT, as the name suggests, is a combination of X-ray diffraction with computed tomography, and it facilitates 3D mapping of crystalline microstructures.[6] In this project we demonstrate a novel technique, tensorial XRD-CT (Fig. 3), to resolve in 3D the bone mineral composition, crystallite size and preferred orientation at the bonecartilage interface. The motivation is to understand the crystallization of hydroxyapatite, the mineral phase of bone. The results of this ongoing research (to be published) provide insights into cartilage mineralization and bone growth. It is expected that the developed methodology will be important in biomedical research – for example, for the development of new synthetic implants, fracture repair and for understanding the pathologies of bone diseases such as osteoporosis, osteoarthritis and osteochondrosis.

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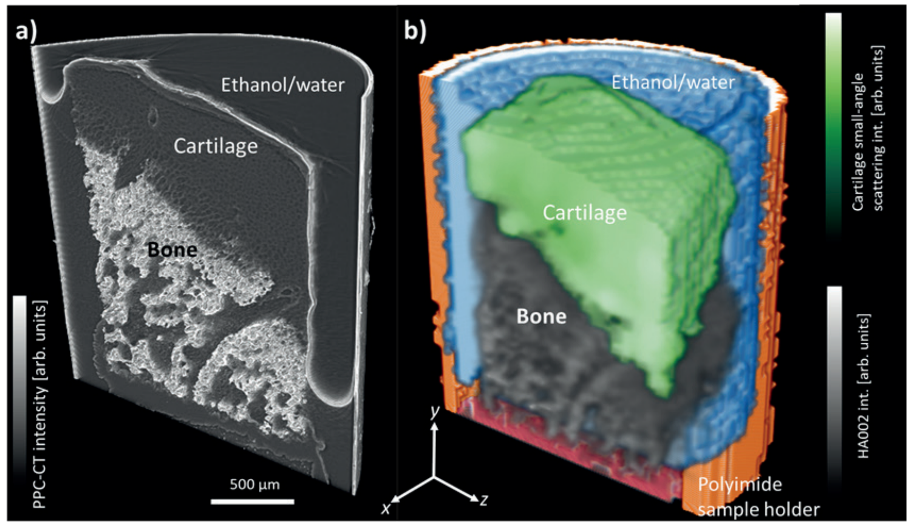
Figure 3. Cross-sectional view of a) phase contrast µ-CT and b) material-specific XRD-CT of a bone-cartilage sample obtained from a porcine femoral joint.



THERMAL EFFECTS IN THE LI-ION BATTERY

Astrid F. Gunnarshaug[1], Signe Kjelstrup[1], Dick Bedeaux[1], Odne S. Burheim[2]

[1] PoreLab, Department of Chemistry, Norwegian University of Science and Technology, NTNU, Trondheim, Norway
[2] Department of Energy and Process Engineering, Norwegian University of Science and Technology, NTNU, Trondheim, Norway

The life of a lithium battery depends largely on the temperature inside the battery. So far, one has assumed that heat has been uniformly produced in the battery. We have shown, however, that there is a large asymmetry in the heat production. There is even a heat sink on one location, while there is a heat source on the other. This may lead to local gradients, which are detrimental for the battery.

The large organic carbonyl compounds in the solvent and the lithium salt, the solute, will build concentration gradients in a temperature gradient, a manifestation of the Soret effect.

The lithium ion battery is shown schematically in Figure 1. It consists of a porous graphite anode, with intercalated lithium, an inorganic crystal of iron phosphate as cathode, also with intercalated lithium. The electrolyte of a lithium salt in a mixture of two organic carbonyls are contained in a microporous membrane. Figure 2 shows the cell we use to measure the electric response to the temperature and concentration gradients, the Seebeck coefficient. The coefficient is found by dividing the cell potential by the applied temperature difference (upper left corner).

When the electrodes on each side of the electrolyte are identical, theory shows that the Seebeck coefficient gives the single electrode heat effect, the Peltier heat. Figure 3 shows the cell potential (blue curve) that arise when a temperature difference (red curve) is applied as a function of time (bottom left). The local reversible heat effects are deduced from this curve.

While the temperature difference is constant after the start of the experiment, the cell potential varies, signaling that the transport of mass changes with time, as ions and other components diffuse in the temperature gradient applied. We see a curious peak in Figure 3, possibly due to the first chemical component in the electrolyte reaching a steady distribution in the thermal field. After 400 minutes (about 3 days), all electrolyte components are in their steady state.

From the observed variation, we deduce the deviation from Fourier's law in the equation for the heat flux, and compute the magnitude of the heat source or heat sink at the electrodes.

This is helpful in battery design, and may in turn improve the state of health of the battery.

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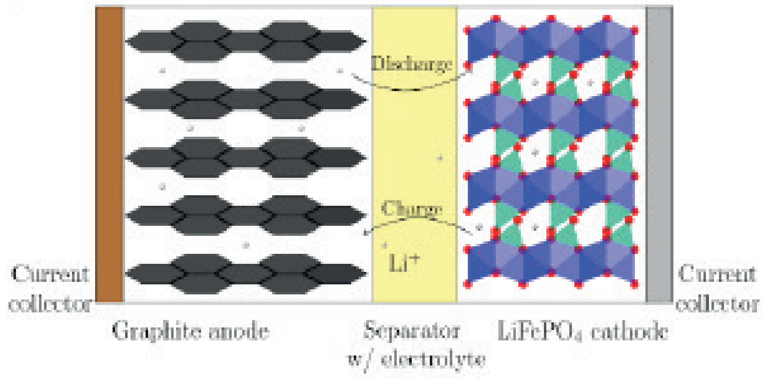

Figure 1. The Lithium battery is shown schematically to the left. It consists of a porous graphite anode, with intercalated lithium, an inorganic crystal of iron phosphate, also with intercalated lithium. The electrolyte of a lithium salt and two organic carbonyls are contained in a microporous membrane.

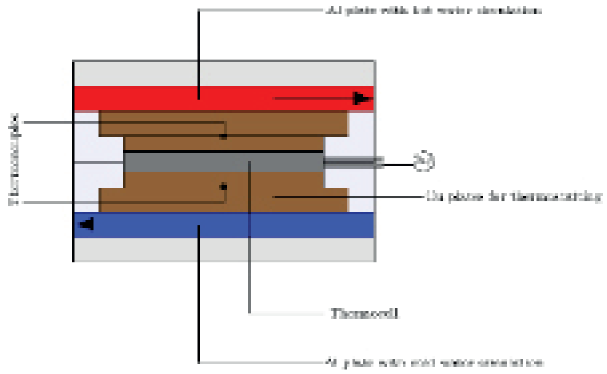

Figure 2. The cell to measure Seebeck coefficients; the cell potential divided by the applied temperature difference (upper left corner). The electrodes on each side of the electrolyte are identical, they only differ by the temperature used, as indicated by the red and blue thermostats

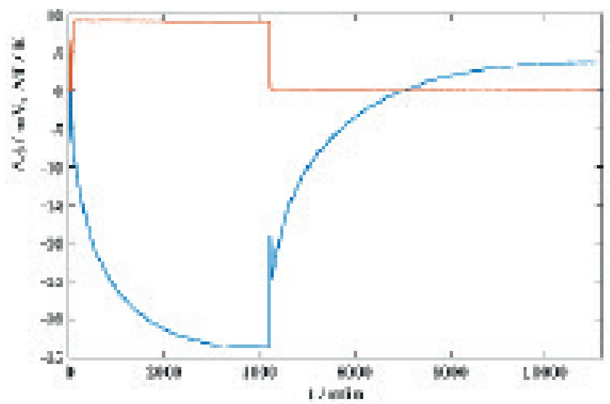

Figure 3. The cell potential (blue curve) and the temperature difference (red curve) as a function of time (bottom left). While the temperature difference is constant after the start of the experiment, the cell potential varies, signaling that the transport of heat in the electrolyte also varies with time, as charge and other components diffuse in the temperature gradient applied.

NATURE-INSPIRED CHEMICAL ENGINEERING (NICE): FUEL CELL FLOW FIELD

Marco Sauermoser[1], Signe Kjelstrup[1], Natalya Kizilova[1,2,3], Bruno G. Pollet[4] and Eirik G. Flekkøy[1]

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[2] Warsaw University of Technology, Institute of Aviation and Applied Mechanics, Warsaw, Poland
[3] V. N. Karazin Kharkov National University, Department of Applied Mathematics, Kharkiv, Ukraine
[4] Department of Energy and Process Engineering, Norwegian University of Science and Technology, NTNU, Trondheim, Norway

Many biological systems have evolved to become highly energy-efficient, with uniform fluid delivery systems [1,2]. This has inspired new designs for optimal fluid transport in artificial systems. One of these biological systems is the human lung. It uniformly transports air, and it can be proven that there exists equipartition of pressure drop on the bronchial level.

The flow field plate in a polymer electrolyte fuel cell (PEMFC) has the same purpose as the human lung. Fuels, being hydrogen and oxygen, are being distributed along the channels into the membrane electrode assembly inside the fuel cell.

However, when the lung (Fig. 1 top left) is compared to an industry-standard flow field plate (Fig. 1 top right) we can see that the industry standard has a highly non-uniform way of gas distribution. This can lead to several different problems like dead spots, hotspots and non-uniform ohmic losses. [3] Therefore, our target is to optimize the flow pattern (bottom right) by minimizing its entropy production. This has been shown to be beneficial to the system. [4]

So, the goal is to design a flow field plate pattern, which distributes the gases uniformly. Therefore, we can transfer the knowledge of the biological flow systems to PEMFC flow field patterns. This can be done by projecting the 3-dimensional flow channels in the lung on a 2-dimensional plane. The result is a tree-shaped flow pattern (Fig. 1 bottom right) that can be described by different scaling factors, for example like a width scaling or length scaling parameter. Scaling factors describe how a certain parameter, like channel width w_j at a certain generation level j, changes when j is increased (Eq. 1).

$$w_j = a^j\, w_0 \tag{1}$$

Depending on which length scaling parameter is chosen, the covered area changes. For fuel cell applications, a square-shaped cross-sectional area is desired in most of the cases. To achieve this, no length scaling parameter can be used, and the length needs to be set manually. The width or diameter of the channels, however, can still be scaled. The entropy production of the tree-shaped flow pattern changes significantly with the chosen width scaling parameter. Therefore, we try to minimize the entropy production at a given channel width or diameter, i.e. to optimize the flow channels, by varying the width scaling parameter. Biological flow systems like the lung, differ from channels in flow field plates by their boundary conditions, and equipartition of the pressure drop in the flow field channels does not in general lead to minimum entropy production. Biological flow systems with equipartition of pressure drops, like the human lung, usually conform with Murray's law. Murray's scaling of the diameter of the channels is described as cubic scaling. [5] If this is used in the flow system for a PEMFC, the width scaling parameter a is approximately 0.79. To minimize the entropy production, we have to increase a above the one given by Murray's law. This causes a faster reduction of the pressure drop with increasing generation levels of the pattern, leading to smaller entropy production values.

As described in the beginning, biological flow systems offer highly uniform flow distribution, meaning that all branches at a certain generation level j, have the same flow rate. 3D simulations can be used to analyze the patterns for the PEMFC, showing that as long as the width to length ratio of the channels is not higher than a certain threshold, this uniform distribution is also achieved (Fig. 1 bottom left). Non-uniformity can be created due to the sharp branching with an angle of 90 degrees, creating asymmetries in the flow. If the flow has not enough time to get symmetric again, the asymmetries get amplified, leading to non-uniform flowrates at the channel outlets. Therefore, it is important to have thin and long channels instead of wide and short channels.

Combining this knowledge, it is possible to create a flow field pattern for a PEMFC, which uniformly delivers the gases and has a minimized entropy production.

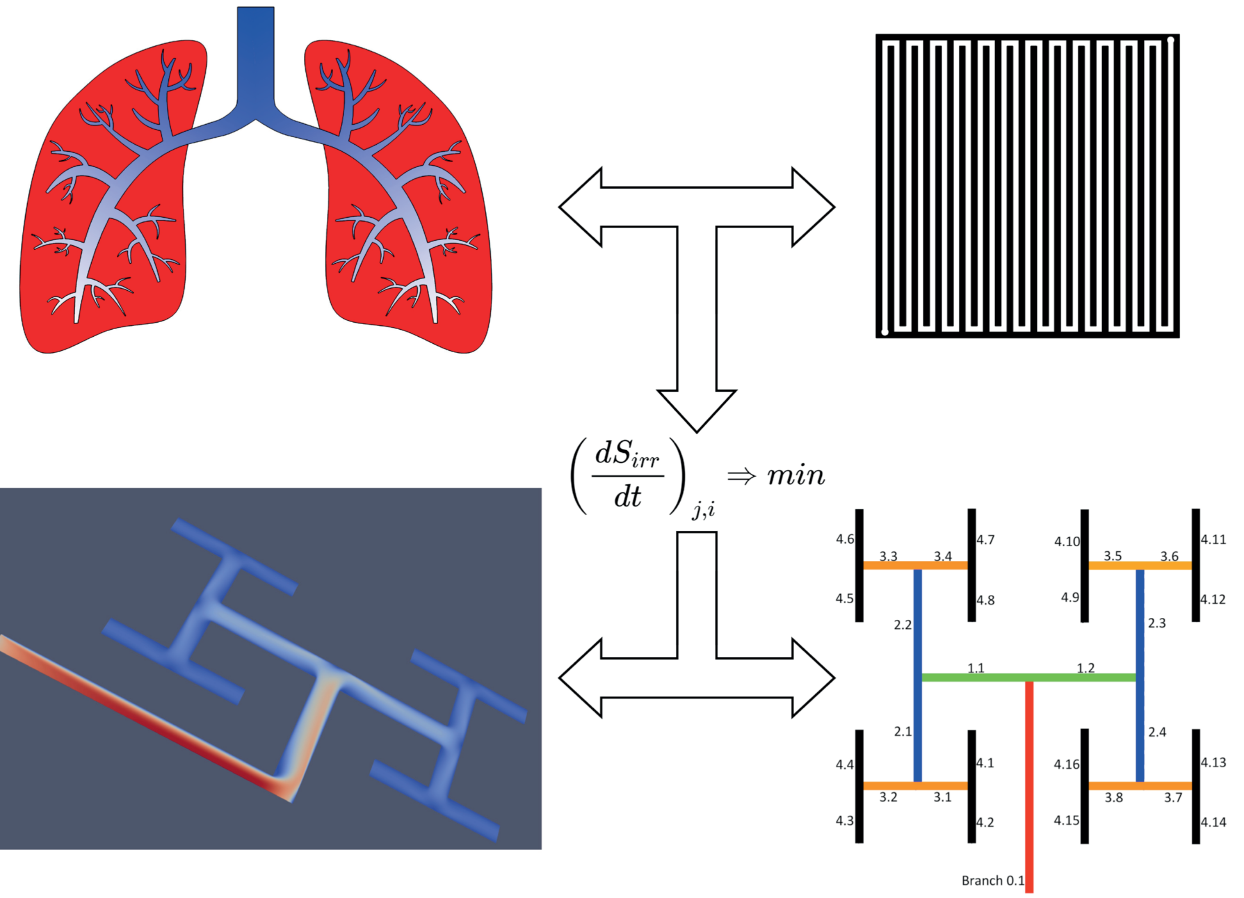

Figure 1. Taking inspiration from biological flow systems like the human lung (top left), conventional flow field plate patterns (top right) in polymer electrolyte fuel cells can be improved. This can be done by creating a tree-shaped pattern (bottom right) which can be further optimized by minimizing its entropy production. The advantage of this type of flow field pattern is that it delivers the gases in a uniform way (bottom left).

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NATURE-INSPIRED CHEMICAL ENGINEERING (NICE): REACTOR DESIGN

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[2] Warsaw University of Technology, Institute of Aviation and Applied Mechanics, Warsaw, Poland
[3] V. N. Karazin Kharkov National University, Department of Applied Mathematics, Kharkiv, Ukraine
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In this project, we have been inspired by the convoluted structure of the reindeer nose to re-design the geometry of a chemical reactor. In a broader setting, we are looking for properties of designs with as little energy dissipation as possible. Indeed, thanks to the complex geometry of the reindeer nose (Fig. 1), heat and mass transfer in the nose are very efficient [1].

Chemical reactors are used for many applications. For this reason, many have studied chemical reactors to find ways to improve their efficiency. This has been done by, for example, optimally controlling the catalyst distribution or the temperature of the medium used to cool down the reactor. However, it was often difficult to apply the outcomes of these studies in practice.

On the other hand, many interesting designs and patterns are found in nature, which respond to principles of efficiency and functionality [2]. An interesting example of this is the reindeer nose. Figure 1a shows how complex its internal geometry is. It has been shown that such a complex structure allows for a more efficient heat and mass exchange than a uniform one would do [1].

How can this serve as an inspiration in engineering design?

We can draw an analogy between the evolution of the reindeer nose and the optimization studies on chemical reactors. Indeed, in both cases, the scope is to design a system that reduces dissipation and improves the efficiency of the system. While geometry is a key factor to achieve the goal in the reindeer nose case, reactor optimization studies have focus on other factors, such as cooling medium temperature and catalyst distribution. Inspired by the reindeer nose, we have optimized the geometry of a tubular chemical reactor, to obtain the perimeter profile which minimized dissipation in the process while maintaining the outputs constant. Figure 1 shows the resulting optimal geometry (the amphora shaped tube).

Quite interestingly, the optimal geometrical profile has some analogies to the one of the reindeer nose, with smaller perimeter at the inlet and outlet of the system, and larger perimeter in the central part, see the upper part of the figure to the right. The reactor with the optimized geometry dissipated 16 % less energy than the original reactor, in spite of being shorter. Such a geometrical optimization approach could be used in other application as well.

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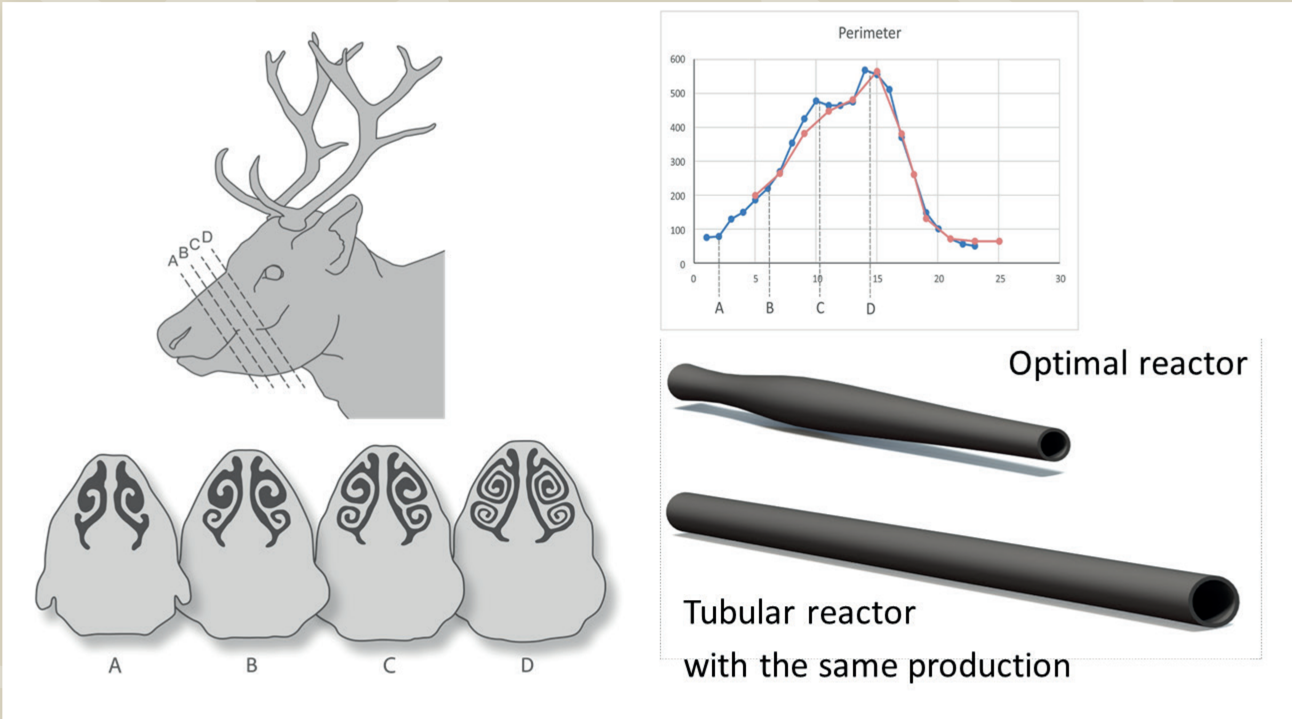


Figure 1. Taking inspiration from the flow of water and heat in the reindeer nose (left top and bottom), a chemical reactor has been optimized to minimize energy dissipation in the process (bottom right). The optimal reactor (top tube) reduces dissipation by 16%. It has a shape more of an amphora, compared to the straight tubular reference (bottom). The perimeter of the optimal reactor (right top upper figure) is similar to that of the reindeer nose. Positions A, B, C, D refer to sections of the nose.

RESEARCHER

GUILLAUME DUMAZER

Department of Physics, UiO

Who are you? What is your background?

I am a physicist interested by complex phenomena emerging from simple systems in interaction. I have an initial background as a theoretician and numerician for dynamical systems. Along my postdoctoral career I got familiar with code development and experimental techniques. My research activities are to model complex flow or transport phenomena with theoretical, numerical or experimental approaches.

How did you come being interested in physics?

Because of the frustration of not being able to understand the over popularized content of some French science magazine I developed a taste for research. Following this curiosity took me towards scientific studies, somewhere between mathematics and physics. I remember specifically an article in another science magazine "La Recherche" written by Hugues Chaté physicist at CEA. It was about dynamical systems, and how a sophisticated mathematical approach can encompass the complex behaviour of chaotic systems. I was undergrad and I kept this article as a perspective to follow.

Later I filled my scientific career along with various topics: combustion, crystallization, rarefied gas flows, granular systems, flow in porous media, geophysics, etc. I got familiar with various mathematical and numerical tools. I feel my experiences are like trials in a Monte Carlo scheme: it does really look random in the beginning, but after enough samples, a scientific landscape emerges.

What are you doing now in your research?

I am now working on hydraulic and pneumatic transport of a granular matter. It is to be able to describe the complex interplay between viscous dissipation and solid friction among grains, and within geometrical confinements. My current research is making use of contributions from several fields such as rheology of dense suspensions, physical chemistry of surfaces, flow in porous media, tribology, etc...

Do you think that the work you are doing now can help changing handling of particulate materials in industry?

I realized that the understanding of industrial processes handling of granular phases is quite poor and limiting upgrade of pilot installation to full operation scale. Complex transport regimes emerge when a granular phase is conveyed by a viscous flow in a pneumatic transport line. The influence of confining walls trigger the formation of travelling granular plugs behaving like a deformable porous wave. This research topic can also help to design processes involving grains at millifluidic or microfluidic scales using capillarity. The meniscus between a wetting and a non-wetting phase acts as a capillary bulldozer, or a soft piston, driving granular matter in strong confinement.

How is it to be a post-doc and researcher at PoreLab?

I got the opportunity to work a first postdoc with two of the PIs at PoreLab before the centre was created. So, I have had the chance to observe the hard life of scientific ideas in a real life context, i.e. squeezed between funding opportunities, scientific staff resources availabilities, births and deaths... At PoreLab my scientific ideas and practices matured with frustrating ambition rescaling, and nicely achieved works.

Being non-Norwegian in Norway helped focus on my own personal motivations. Every attempt I made to reduce this distance by learning Norwegian, or presenting science dissemination events in schools, featured important interactions with people which changed my way to socialize. It would have happened anywhere maybe, but I am happy it happened in Norway.

POSTDOC

SUBHADEEP ROY

Department of Physics, NTNU

Who are you? What is your background?

My name is Subhadeep Roy and currently I am a post-doctoral fellow at PoreLab NTNU. My academic background is theoretical and computational physics. I have completed my M.Sc. from India at The Institute of Mathematical Sciences (2010-2012). After that, I continue doing my Ph.D. at the same place on *"The Interplay of Stress Release Range and Disorder"* in fracture. Prior to joining at PoreLab, I have 1.5 years (2016-2018) of job experience at Tokyo University as a Research Scientist.

How did you come being interested in physics?

For me, it was a continuous process of being interested in physics. Physics is something that you can always apply in your daily life for better understanding of it. I guess, this is the most fascinating thing I find about it. There is always a nice story behind every derivation and calculation of physics. To me, it makes it more connected and real than any other topic. If I had to choose one moment, it will be during my bachelor when I spent several days studying theory of relativity, I knew I would want to explore further in this field.

What are your activities at PoreLab?

My research project focuses on the numerical study of two-phase flow in porous media. I am working here with Prof. Alex Hansen and collaborating with Dr. Santanu Sinha of CSRC Beijing. For numerical simulation we study the dynamic pore network model under different driving condition in order to understand its rheological behavior. Currently, we have explored an 1D prototype of porous media called the Capillary Fiber Bundle Model and we believe this model has a lot to offer in the context of porous media.

How is it to be a researcher at PoreLab?

It's always nice when you are surrounded by such capable researchers from whom you can always get help. PoreLab has created a nice atmosphere for both individual research as well as collaboration. I had many personal and academic interactions with my colleagues and it is fruitful each and every time.

What made you decide to come to Trondheim?

I think the connection between me, and Trondheim is made through my supervisor Prof. Alex Hansen. I have followed his research since my Ph.D. and met him many times in India at different conferences. We always had nice discussions on various topics. Joining PoreLab gave me the opportunity to work with him. At the same time, it brings me to Trondheim. Also, I have been to Trondheim for a brief period in 2013 and loved how quiet and beautiful it is.

Do you think that the work you are doing now can help changing the discipline?

The study of multiphase flow is directly linked to the oil and gas industry. The pore network model that we use can produce results of large scales from pore scale knowledge. In that light, I believe it is important to explore the network model numerically as it is easier and convenient than conducting large scale experiments. At the same time, it can offer a detailed insight to the effective rheology during a multiphase flow through a porous media.

PHD

LE XU

Department of Physics, UiO

Who are you? What is your background?

My name is Le Xu and I am originally from China. My background is in physics. I did my Bachelor degree in Wuhan, China and I did my Master degree in Lyon, France. I have just graduated as a PhD in physics at University of Oslo on the research topic "Dissolution in fractures in circular geometry: dispersion and reaction-infiltration instability". My educational background of bachelor and master is about theoretical physics while my PhD studies focus on experimental physics.

How did you come being interested in physics and how did that bring you to Norway?

All starts from some simple but weird kid's questions, "what's the outside of the boundary" and "what's it before the beginning". This kind of questions fascinated me a lot when I was a kid but no one could really answer my questions properly, which made me more curious. Then I learned some fancy words like "Big Bang", "Twin paradox", "Schrodinger's cat" and so on. Surprisingly all of these bizarre questions and the beautiful concepts are in the scope of a domain called "physics". That is how I magically became interested in physics.

I joined PoreLab through an EU's Marie Curie Initial Training Network Program "FlowTrans". Knut Jørgen Måløy is my supervisor and I am very lucky to have him guiding me during my whole PhD. Norway ranks No.1 in the happiest countries in the world for many years, so having a life experience in this fairytale country is another convincing reason to bring me here and I do not regret it.

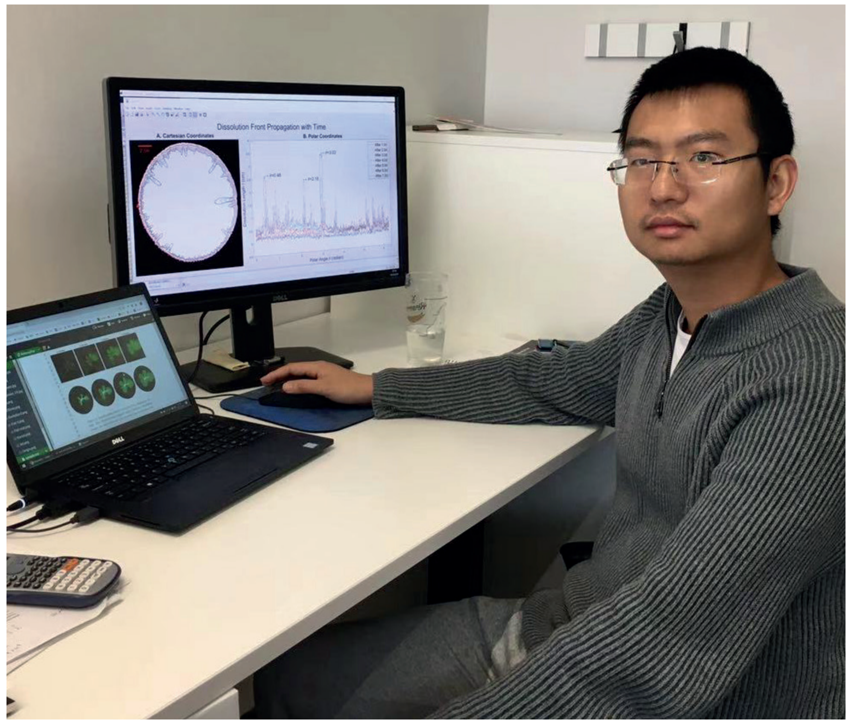
Do you think that the work you are doing now can help changing the oil and gas industry?

Yes, I do think so. The important applications of this dissolution-related project in the oil industry include the acidization of petroleum reservoirs in order to enhance oil and gas production by increasing the permeability of the rock.

Since the real industry situation is much more complex than lab model, my research might not directly apply to industrial practice but it could be a useful benchmark, which gives some good predictions in certain cases.

How is it to be a researcher at PoreLab?

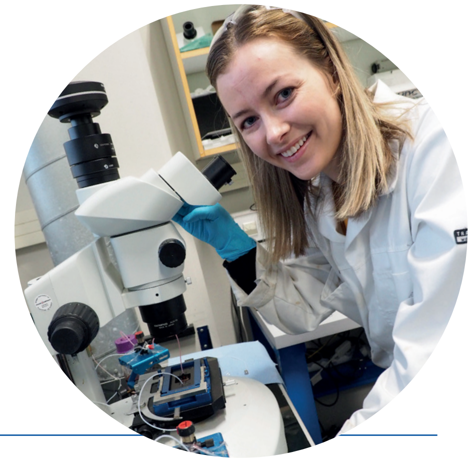
The research environment at PoreLab is excellent as the discussions and communications within our group is very convenient without any barrier. The networking and international collaborations are great here. It is getting better when we move to new offices and reinstall our laboratory with better facilities for video conference, educational lectures and state-of-the-art experimental setups. I believe that PoreLab will be a Unique Hub for porous media research in the world.



PHD

REIDUN CECILIE AADLAND

Department of Geoscience and petroleum, NTNU



Who are you? What is your background?

My name is Reidun Cecilie Aadland, and I am from the oil capital Stavanger. I started my academic career at the University of Stavanger studying petroleum geology. After one year I decided to follow my heart and move to Trondheim to be with my boyfriend at the time, now husband. At NTNU I completed my master's degree in Petroleum Geoscience and Engineering with specialization towards reservoir engineering. During my last semester, I was offered to join an exciting project called *"Green High-Performance Systems for Enhanced Oil Recovery"*, so from August 2015 I became a PhD student at the department of Geoscience and Petroleum.

How did you come being interested in Petroleum?

I have always had an interest in science and mathematics growing up, so I knew at an early stage that I wanted to take an education within this area. However, I am also a person who struggles making big decisions, so I used the method of elimination when deciding which program to choose. I have always liked taking care of other people, unfortunately, I do not like the sign of blood or needles. Thus, medicine was not an option. Instead, engineering caught my interest. I knew the oil and gas industry well since I am from Stavanger, the oil capital of Norway. I choose therefore petroleum to give me a higher chance to get an interesting job in my hometown. I am very glad I picked petroleum.

The more I have learned about this subject, the more fascinating it has become!

Tell us more about your project

To explain my research, you can think of the North Sea reservoirs as a bunch of half-eaten apples. Not literally of course, but I compare it with half-eaten apples because today we can only extract around 50 % of the oil on average. In other words, half of the oil is still remaining in the North Sea petroleum reservoirs. Discovering new fields is difficult, and drilling new wells is expensive. Therefore, would it not be a lot better if we could just extract as much oil as possible from existing fields? This was the main concept behind my research, where I investigated the potential nanocellulose particles had as an enhanced oil recovery method. The nanocellulose particles were dispersed in brine and tested through various experiments: injectivity in sandpacks and core plugs, oil recovery experiments, contact angle and interfacial tension to name a few. The particles did indeed help to produce more oil, especially when injected as a secondary recovery agent. I completed my PhD in December 2019.

Since you just finished your PhD, what do you do now?

A lot of exciting things happened during the last year of my PhD: I had the pleasure of becoming a mom for the first time, and my husband decided to expand his company to New York. I realized towards the end of my PhD that I wanted to take a break from work for a couple of months before starting something new - as we all know, the PhD can take its toll. It was perfect timing that we were moving to New York, and that I am fortunate enough to stay home a bit longer and spend quality time with my son. For now, I am living in the moment, but I am looking forward to applying for a job when the time comes.

One thing I have learned from completing a PhD – when you first set your mind to something, anything is possible. I am therefore excited what the future holds and looking forward to the new chapter as new yorkers. Carpe diem!

PHD

JONAS TØGERSEN KJELLSTADLI

Department of Physics, NTNU

Who are you? What is your background?

My name is Jonas Tøgersen Kjellstadli, and I grew up in Arendal, Norway. I have just finished a PhD in physics after a fairly straightforward educational path: BSc (2010-13) and MSc (2013-15) in physics, both from NTNU.

How did you come being interested in physics?

I don't know; as far as I can remember, I have always found physics fascinating. Perhaps this stems from my desire to understand how things work, rather than just explaining them. (Which makes me enjoy a wide array of subjects, ranging from science and computers to team sports and video games.) As a boy, I was enthralled by particle physics and astronomy, which I was certain that I would end up working on. However, I discovered that physics includes other areas of research that are just as intricate, and just as rewarding to study.

So what area of physics is your PhD about?

It concerns fracture: we use the fiber bundle model, an idealized model used to study the general properties of fracture processes. In particular, I have been working on the local load sharing version of the model, which distributes the applied stress locally in the material. The goal is to understand how this force distribution scheme affects the fracture process.

Although my work is purely theoretical, this research is meant to be applied. I hope that experimentalists will find it interesting enough to test our findings experimentally.

How is it to be a PhD student at PoreLab?

It is a wonderful opportunity to learn about other areas of research. With all the seminars, presentations, and general discussions with people from the other research groups in PoreLab, it's nearly impossible to not discover interesting things outside the scope of your PhD.

PoreLab is also surprisingly close-knit, considering how many people it comprises. Being part of such a welcoming and unified community is a great boon: problems are solved by cooperating instead of banging your head against the wall.

What about the future, where do you see yourself in 5 years?

The safe bet would be to say that I'll be doing data analysis and programming, since that is what my new job is about. But that's hard to say for certain. Perhaps I'll miss analytical math enough that I end up returning to research?

PHD

ALBERTO BILA

Department of Geoscience and petroleum, NTNU

Who are you? What is your background?

My name is Alberto Bila and I am from Mozambique. I am a PhD candidate at NTNU division of the PoreLab Center of Excellence. I hold bachelor's degree in chemical engineering and master's degree in petroleum engineering, both from the University of Eduardo Mondlane, Mozambique.

How did you come being interested in chemical engineering and petroleum engineering

Well, I enjoyed studying chemistry when I was in high school, and just fell in love with it. But I was interested in pursuing a career in Engineering rather than in chemistry alone. I wanted to study petroleum engineering at the university, but there was no petroleum related course in Mozambique at that time. I went for chemical engineering instead.

After completion of my studies, I worked at the University of Eduardo Mondlane as an assistant lecturer. Five years later, I joined a master program in petroleum engineering. My dream came true! However, the more I learned about oil and gas, the more I wanted to improve my knowledge. I decided to embark on research as a PhD student. Nanoparticles for enhanced oil recovery was the topic I came across with. The work is entirely experimental and met my expectations. The "Nanoparticle technology" is still in its infancy and presents numerous challenges in the oil industry, which makes every single laboratory experiment gratifying and rich in learning opportunities.

What are you doing now in your research?

My research focuses on the application of silica nanoparticles to improve microscopic sweep efficiency of water flood. This PhD project was carried out for Evonik Indutries. The main objectives are to identify the nanoparticles with the highest oil recovery potential; and determine the underlying oil production mechanisms of the nano-particles. So far, I have tested a variety of surface functionalized silica nanoparticles in water-wet and neutral-wet Berea sandstone reservoirs for oil recovery applications. In addition, I have studied fluid-fluid and fluid-rock interactions, as well as the migration behavior of nanoparticles through porous media to understand the displacement of residual oil due to nanoparticle in injection water.

Do you think that the work you are doing now can help changing the oil and gas industry?

The search for new technologies to extract oil in a more economical and environmentally friendly way is, in my opinion, very important. First, because the world population is expected to reach about 10 billion by 2050, which means that the demand for energy will increase. Today, most of the energy consumption comes from combustion of hydrocarbons. However, the discovery of new oil fields has been scarce, and the existing fields face abandonment with more than 50% of original oil in place trapped in the reservoir after primary and secondary oil production stages. Second, protecting the environment is an obligation for any of today's activity in order to provide a healthy life for us and for future generation. Thus, the application of silica particles for oil recovery is a valuable addition to the greenish environment that today's society requires from the activities of oil companies and is expected to play a major game change in near future.

How did you end up in Trondheim?

In search of a doctoral position, I came across the Norwegian Program for Capacity Development in Higher Education and Research for Development in the Energy and Oil Fields. I submitted my application and I was fortunate to be granted a position to continue my studies as a doctoral student at PoreLab, NTNU division.

What about the future, where do you see yourself in 5 years?

Well, I think that research is exciting. My goal is to gain deep experience in the oil and gas industry, especially in enhanced oil recovery and related areas. I believe I can achieve this with my ongoing research and practical training.

I am also very excited to enter the oil industry sector and take on some responsibilities in the years to come and potentially even lead some projects. I was fortunate to work as a lecturer at the university and would love, after spending some years in the industry, going back and teach at the university.

PORELAB AND THE NJORD CENTRE

At the University of Oslo, PoreLab is organized under the auspices of the Njord Centre for studies of the Physics of the Earth.

Njord, named for the Nordic god of sea, wind, and fertility, is a cross-disciplinary geoscience-physics Centre at the Faculty of Mathematics and Natural Sciences. Its mission is to advance the understanding of transformation processes in Earth- and man-made porous materials. The Centre's research focuses on the fundamental physics of geologically relevant processes including: transport and reactions in deformable porous media, fracturing and fragmentation processes, interface dynamics during geophysical flows, and intermittency and pattern formation in geological systems far from equilibrium. The research is directly relevant to a wide range of applications, including transport of water, pollutants and hydrocarbons in porous and fractured rocks, carbon sequestration and storage, avalanche dynamics, earthquakes and other geohazards.

Njord was officially established on January 1st, 2018 and is an umbrella organization including the Oslo node of PoreLab and researchers from the first-generation Norwegian Centre of Excellence (CoE) PGP ("Physics of Geological Processes", running in the period 2003-2013). Njord is directed by Bjørn Jamtveit, Professor at the section of Physics of Geological Processes at UiO and associate member of PoreLab.

The Njord Centre was established to promote collaborations between the two groups, which have traditionally had a significant scientific overlap. *"There is an obvious and considerable potential for increased synergies between physics and geoscience at UiO by merging PGP and the PoreLab node at UiO onto a joint organizational platform"*, says Knut Jørgen Måløy, Professor at the department of Physics at UiO and Deputy Director for PoreLab. The fact that the PGP approach is driven more by basic geology while the PoreLab approach is motivated more by basic physics problems, means that the two groups bring different and complementary competence to the collaboration. *"Through curiosity-driven research near the interface between physics and geoscience, we hope to advance the frontier of knowledge about the behavior of Earth-like systems at far-from equilibrium conditions"*, says Njord's Director Bjørn Jamtveit.

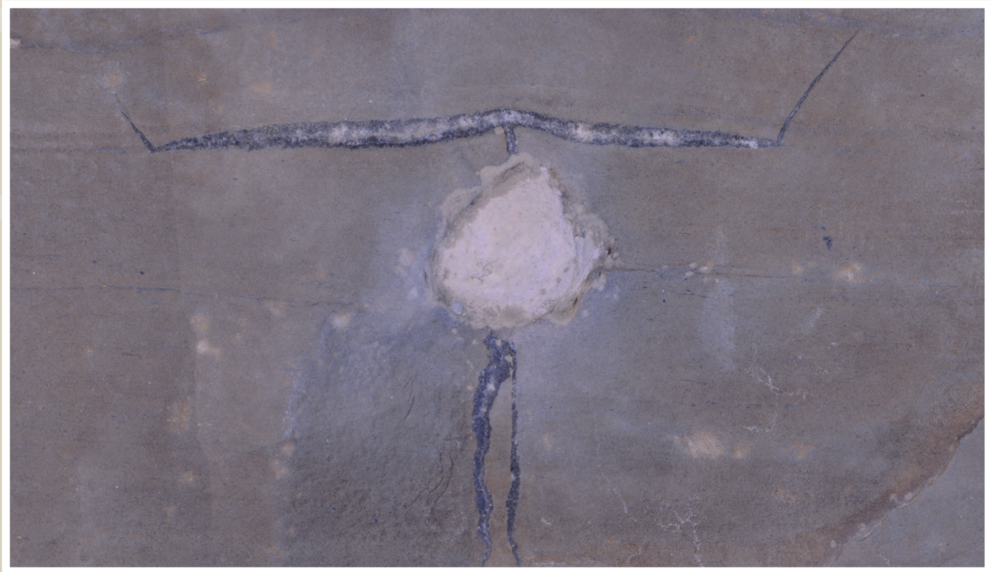
The two groups have independent scientific leadership but a joint budget that funds two postdocs and common activities such as seminars. The funding for the joint activity comes from the Faculty of Mathematics and Natural Sciences at UiO as well as from overheads from individually funded projects.

«Njord allows us to increase the interactions and raise visibility of the collaboration between the Departments of Geosciences and Physics at UiO", says François Renard, Professor at the section of Physics and Geological Processes at UiO and associate member at PoreLab. *"The main motivation is to develop common research projects and to be competitive concerning interdisciplinarity"*. As an example, François Renard mentions a new four-year project called *"MODIFLOW: Modelling flow across scales"* and funded under the Equinor's Akademia program. *"In this project we will model fluid flow when rocks are breaking, and hereby gather competences across geology and physics"*, explains François Renard. Gaute Linga, a researcher at Njord, is one of the post-doctorates jointly funded. He receives his funding both from the MODIFLOW project and from PoreLab.

Luiza Angheluta-Bauer, Associate Professor in condensed matter physics at UiO and associate member of PoreLab, appreciates the different collaborations within Njord. *"The bridge between PGP and PoreLab is very convenient"*, she says, *"It raises more opportunities for discussions, sharing ideas and developing synergies between the different research activities within Njord"*.

The premises are indeed organized at UiO in order to create the best interactions within Njord. PoreLab UiO is situated at the 3rd floor of the Physics building at UiO and the rest of researchers under the Njord umbrella are on the 4th floor. When renovating this part of the building for the two centers last year, the employees asked specifically that the renovations take into account the easy accessibility between the two floors through a dedicated staircase. Employees from both centers meet daily for chats, coffee breaks, lunches, meetings and other events.

However, collaboration between PoreLab and PGP does not just happen at the level of the offices. Exchange happens as well in the laboratories even as both PGP and PoreLab have their own laboratory facilities at UiO. *"We use similar techniques in the laboratories"*, says Dag Kristian Dysthe, Professor in condensed matter physics at UiO and associate member of PoreLab, *"We have a long history of overlap between employees from PGP and PoreLab, it is natural for us to exchange instruments and discuss each other's experiments"*.



During field work in Svalbard, researchers discovered a cross-section in a stone rock very similar to the Njord's logo.

Picture courtesy: Frank B.B. Guldstrand

WORKSPACE ENCOURAGES INTERACTION

Interdisciplinarity is at the core of PoreLab. The center gathers scientists from five departments at NTNU and UiO: The Departments of Physics, Chemistry, Geoscience & Petroleum, Civil & Environmental Engineering, all at NTNU, and the Department of Physics at UiO.

"True interdisciplinarity is to gather a diverse group of scientists around a well-defined problem", says PoreLab's director Alex Hansen before adding: *"A component necessary to succeed with this kind of interdisciplinarity is that we sit together on a daily basis"*. It can be a challenge to gather scientists from all corners of a university! After the decision in 2016 to merge NTNU and three university colleges, NTNU is still going through the process of establishing a unified university by reorganizing the workspace. This made the process to gather all NTNU scientists from PoreLab in one dedicated place even harder. We were lucky to have the overwhelmingly support of the involved Deans at NTNU, Olav Bolland at the Faculty of Engineering and Øyvind Gregersen at the Faculty of Natural Sciences.

In May 2018, PoreLab scientists from the four involved departments at NTNU move to the second floor of the Petroleum Technical Center, S.P. Andersens vei 15B, nearby Gløshaugen campus in Trondheim. Laboratories from the Department of Geoscience & Petroleum are our close neighbors, making the location ideal for those sharing their time between the laboratories and their offices.

However, in the beginning, only half of the second floor was reserved for PoreLab and we quickly felt its limitation. In February 2019, PoreLab gained the entire second floor. The location could not be better. We now have the capacity to offer workspaces not only to NTNU employees, but also to our large number of visitors, more than 40 in 2019 at PoreLab NTNU. Some of them stay just for a day, while others join us for much longer, up to a year or more. A large common area, including a dining area and lounge, is the hub for our joint activities, lecture series, Journal Club, workshops, lunches, coffee breaks, Christmas dinner and other celebrations. This common area is also equipped with video conferencing tools, an interactive whiteboard, microphones and speakers, and good internet connection, so that we can host events simultaneously in Trondheim (NTNU) and Oslo (UiO). Fully equipped offices open out to the common area, which makes it unavoidable not to meet colleagues and engage oneself in inspiring discussions around the latest hot research topic. Offices are either individual, for the administrative leader and professors, or double for researchers, postdocs and PhDs. Two meeting rooms, that fit up to ten people each, are equipped with video conference systems and a larger room with several workplaces is reserved for master students.

UiO also made tremendous efforts to offer PoreLab a key location where employees can innovate, collaborate and inspire. When PoreLab was established as a CoE at UiO, it was decided that we would have our own office space on the 3rd floor of the West Wing of the Physics building, Sem Sælands vei 24. The renovation and preparation of these offices began in January 2019. While this work was carried out, PoreLab shared offices with their Njord colleagues in the PGP group on the 4th floor of the Physics building. Building and renovation work dominated the 3rd floor for many months but were finished in mid-June 2019. On September 27, 2019, we at PoreLab UiO celebrated our new offices with a small «housewarming» party.

The new PoreLab office space has a stunning reception area and a comfy kitchen. The offices are a mix of individual offices for the administrative coordinator and professors, and shared offices for researchers, postdocs, PhDs and some master students. In addition, there are two seminar rooms: Room V313, named Celsius, fits 12+ people, and is used for meetings and small workshops; room V316, Kelvin, fits up to 40 people and is used for teaching, seminars and conferences. Kelvin is also equipped with a video conference system, which will eventually allow for seamless transfer of seminars, conferences and joint teaching between UiO and NTNU. Group leaders Knut Jørgen Måløy and Eirik Grude Flekkøy, are very happy with the new offices, which feel more and more like home.

1. PoreLab NTNU: S.P. Andersens vei 15B, Trondheim
2. Cozy sitting area down the hall at PoreLab NTNU
3. Common area at PoreLab NTNU
4. Meeting room at PoreLab NTNU
5. Seminar room V316, Kelvin, at PoreLab UiO
6. Shared offices at PoreLab UiO
7. Reception area at PoreLab UiO.
8. The Physics building at UiO


8


7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ABOUT SUPPORT AND COORDINATION

"Tend to the people and they will tend to business". This quote from John C. Maxwell, though initially written for leadership, could be the mantra of the administrative and technical support at PoreLab. A broad spectrum of support is indeed essential when developing a large Centre of Excellence.

A PoreLab support team was established as soon as PoreLab was born. Its role? To make it easier for academics to develop their research activities. Diversified in skills and background, these dedicated employees help organizing workshops and seminars, welcome guests, contribute to a good flow of information across institutions, report to the financing divisions, ensure that contracts and legal documents are applied, keep track of economical and investments matters, help in the recruitment process for new employees, deliver services in connection with the applications process and make sure that the laboratories are operational. They are administrators, technicians and researchers, well acquainted with multidisciplinary and professionalized research support.

Some work full time for PoreLab, others part-time depending on their role.

Srutarshi Pradhan, researcher at the department of Physics at NTNU, is working part-time with coordination work. He is helping scientists in the preparation of applications and research proposals for different funding schemes such as RCN, ERC or internal university's calls. Since the beginning of PoreLab, Srutarshi attended several workshops on H2020 and ERC grant proposals, then shared his knowledge with his colleagues at PoreLab. In the beginning of 2019, he organized proposal presentation sessions for all proposals to be submitted by PoreLab to the RCN, H2020 and ERC calls. This was a thorough but extremely efficient process since not less than five new PoreLab related projects were granted funding by the Research Council of Norway early in 2020. At the Physics Department at UiO, Magdalena Edvardsen is the contact person for external funding opportunities, providing assistance with project applications and reports.

Eivor Maria Onsum Gundersen at NTNU and Anita Reime at UiO are PoreLab's accounting officers, controlling the economy and working with budgets for the Center.

Mihailo Jankov is a senior engineer at PoreLab UiO. *"My role is 2 folds"*, he explains, *"I make sure that the laboratories at PoreLab are safe and operational"*. Mihailo's activities span from the maintenance of small equipment, purchase of consumable and equipment, follow-up of the orders, and as well guidance of the students in the laboratories. *"PoreLab is a friendly and inspirational environment"*, he says, *"it can be stressful from time to time due to tight schedules, but it is so rewarding when you see that people are counting on you and that you deliver"*.

Hedda Susanne Molland, who is the deputy for Nina Mino Thorud currently on maternity leave, coordinates research support, organization of events, public communication, administration of human resources and financial overviews for PoreLab UiO. *"This is complex work, we are many here and each researcher is unique and has their own special needs"*, she says, *"However, it is fulfilling to have the overview of such a large and diverse group"*.

PoreLab has researchers coming from 19 different countries: Norway, Germany, the Netherlands, Austria, United Kingdom, France, Italy, Spain, Serbia, Turkey, Iran, Yemen, Algeria, Mozambique, India, China, Korea, Brazil and USA. Developing a shared culture, across nationalities, gender and background, is an essential objective for the Center.

"We have no intention of stopping in 2027", says Marie-Laure Olivier, administrative leader for PoreLab, *"we build PoreLab to last, and the center is not just about excellent research, we work to raise a family"*.

Clockwise from top left: Nina Mino Thorud, Anita Reime, Srutarshi Pradhan, Marie-Laure Olivier, Eivor Maria Onsum Gundersen, Magdalena Edvardsen, Mihailo Jankov and Hedda Susanne Molland

PORELAB GRADUATE SCHOOL

TRAINING THE NEXT GENERATION OF RESEARCH LEADERS

Training of Master and PhD students, as well as Postdoctoral researchers, is a core activity at PoreLab. An essential part of NTNU's and UiO's mission as universities, is student and researcher education. PoreLab is a valuable contributor in this respect. It is our ambition at PoreLab, to create an interdisciplinary and international training ground for our juniors.

Third PoreLab Junior Forum at UiO on March 21st.

We give a range of workshops and seminars at the center. Most of the lectures and seminars are held simultaneously in Oslo and Trondheim. The PoreLab Journal Club meets every week to discuss scientific literature, where a PoreLab member chooses and presents either a brand new or a classical paper. The presented paper is then peer-reviewed by the group, and the junior members can experience the review process. In the lecture series, our own and visiting researchers give talks on a weekly basis. They present their work, share their ideas and get feedback from the audience.

Third PoreLab Junior Forum at UiO on March 21st

COURSES AT PORELAB

PoreLab offers a range of courses open for all students at our host universities. FYS4465/FYS9465 at UiO or KJ8210 at NTNU: Theory and simulation of flows in complex media. FYS4420/FYS9420 at UiO: Experimental techniques in condensed matter physics. PG8605 at NTNU: Dual porosity reservoirs or TPG4565 at NTNU: Petroleum Engineering, specialization course.

Fourth PoreLab Junior Forum at NTNU on October 25th

PORELAB JUNIOR FORUM

The PoreLab Junior Forum is a gathering for all PhDs, PostDocs and early career researchers at PoreLab. The Junior Forum has established itself as an important platform for integration of junior members from both PoreLab hubs (Oslo and Trondheim). The group meets twice a year. The 3rd PoreLab Junior Forum took place at the University of Oslo on March 21st, 2019, while the 4th PoreLab Junior Forum was organized at NTNU in Trondheim on October 25th. Introduction of new members, project presentations, presentations from visitors coming from industries or research institutes, discussions around internal PoreLab topics, lab tours, and of course social time are on the agenda of these events.

The Junior forum is particularly important to PoreLab, because it serves to bind two hubs in Oslo and Trondheim together. It is important to make it clear, particularly to the newest members, that although the center has two physical locations, it is indeed a single center, and collaboration between the groups should not be hindered by physical distance.

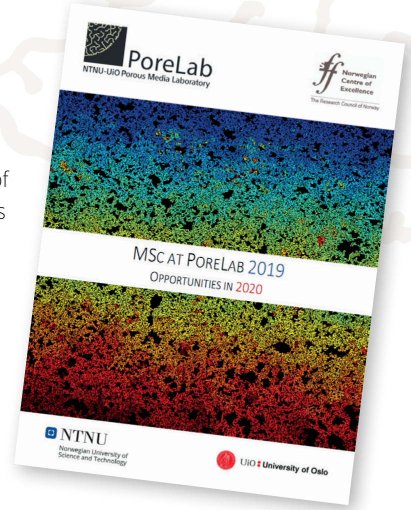
PoreBuzz in Trondheim

THE POREBUZZ AND THE JUNIOR CLUB

The PoreBuzz at PoreLab NTNU and the Junior Club at PoreLab UiO were established by the Juniors themselves. These series of informal events aim to strengthen connection within the group and to integrate new Juniors, especially the master students and guests. The hottest research topics in the field, as well as pizza, are on the menu of these convivial and relaxing events. The Junior Club at UiO is gathering the Juniors both from PoreLab UiO and the Njord center.

PORELAB MASTER STUDENTS 2019

A dedicated catalogue presents our suite of excellent Master students. The aim of this catalogue is to provide an overview of the projects performed by our Master students in 2019 and inspire new students to join the team. We show as well that PoreLab is an international community. Master students at PoreLab do not only come from NTNU and UiO, but also from our international partners. You find names, project titles and name of supervisors in the table below.



NAME	TITLE MASTER THESIS	SUPERVISORS
Stig-Martin Liavåg	Modeling nanoparticle transport in a pore network model	Ruth Catharina de Lange Davies, Magnus Aa. Gjennestad and Signe Kjelstrup
Simon Birger Byremo Solberg	Energy-efficient designs of systems: from nature to industry	Signe Kjelstrup and Elisa Magnanelli
Salem Akarri	Pore-scale investigation of the impact of silica-based nanofluid on residual oil	Ole Torsæter
Christina Rong Anfinsen	Identification of two-phase flow regimes	Carl Fredrik Berg
Patience Ankah	Experimental study of porosity, permeability and wettability and the effect of mineralogy on these properties	Ole Torsæter
Muhammad Iffan Hannanu	Lattice Boltzmann modeling for two-phase flow in a microfluidic chip with realistic pore structure	Carl Fredrik Berg and Thomas Ramstad
Marie B. Løvereide and Ilgar Azizov	Low-salinity EOR in carbonates	Carl Fredrik Berg and Ole Torsæter
Mohamed A. F. A. Omran	Experimental investigation on oil recovery from water flood and polymer-coated silica nanoparticles base nanofluids using the same pore structure	Ole Torsæter
Beatrice Baldelli	Simulations and means of characterization of gravity-stabilized flow on a self-affine surface	Eirik Grude Flekkøy and Knut Jørgen Måløy
Hilmar Yngvi Birgisson	Density driven CO_2 advection diffusion	Knut Jørgen Måløy and Eirik Grude Flekkøy
Joachim Falck Brodin	A new vision for 3D experiments on flow in porous media	Knut Jørgen Måløy and Marcel Moura
Ivar Svalheim Haugerud	Symmetry and reversibility in hydrodynamic dispersion	Eirik Grude Flekkøy, Knut Jørgen Måløy and Gate Linga
Cristian Camilo Garcia Castaño	Micromodel investigation of spontaneous emulsification in low salinity water flooding	Ole Torsæter
Giulio Fossati	Computing coupling coefficient effects in a proton exchange membrane fuel cell using non-equilibrium thermodynamics	Signe Kjelstrup and Andrea Casalegno
Francis Mujica	A digital investigation into the impact of diagenesis above and below the oil-water contact	Lesley A. James, Carl Fredrik Berg, Derek Wilton
Mao Qiangqiang	Relationship between grain packing and single phase transport properties	Carl Fredrik Berg
Edgar Javier Rueda Rueda	A pore-scale study to evaluate the efficiency of nanoparticle-assisted polymer flooding	Ole Torsæter and Rosângela Barros Zanoni Lopes Moreno

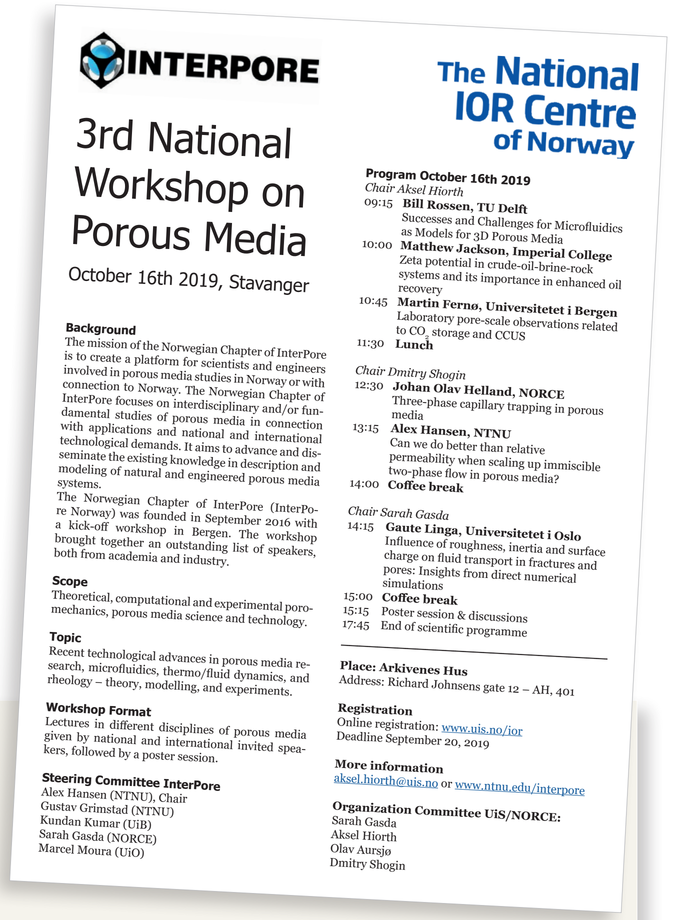
PORELAB AND THE INTERPORE NETWORK

InterPore is the International Society for Porous Media where PoreLab is an institutional member. A national chapter of InterPore was established to benefit all of Norway's research in the field. PoreLab has also added to the development of the central organization. Both activities are described here:

INTERPORE NORWAY

PoreLab is a major contributor to InterPore Norway. The close cooperation between PoreLab and InterPore Norway led to the organization of annual national workshops.

The two first workshops of the Norwegian chapter were organized respectively in October 2017 in Trondheim and in November 2018 in Oslo. The third one was held on October 16th, 2019, in Stavanger. Alex Hansen held a presentation on *"Can we do better than relative permeability when scaling up immiscible two-phase flow in porous media"* and Gaute Linga, postdoc at PoreLab UiO, presented the topic: *"Influence of roughness, inertia and surface charge on fluid transport in fractures and pores: Insights from direct numerical simulations"*. Three PoreLab members belong to the InterPore Norway steering committee: Alex Hansen (chair), Gustav Grimstad and Marcel Moura.



INTERPORE

The National IOR Centre of Norway

3rd National Workshop on Porous Media

October 16th 2019, Stavanger

Background
The mission of the Norwegian Chapter of InterPore is to create a platform for scientists and engineers involved in porous media studies in Norway or with connection to Norway. The Norwegian Chapter of InterPore focuses on interdisciplinary and/or fundamental studies of porous media in connection with applications and national and international technological demands. It aims to advance and disseminate the existing knowledge in description and modeling of natural and engineered porous media systems.
The Norwegian Chapter of InterPore (InterPore Norway) was founded in September 2016 with a kick-off workshop in Bergen. The workshop brought together an outstanding list of speakers, both from academia and industry.

Scope
Theoretical, computational and experimental poromechanics, porous media science and technology.

Topic
Recent technological advances in porous media research, microfluidics, thermo/fluid dynamics, and rheology – theory, modelling, and experiments.

Workshop Format
Lectures in different disciplines of porous media given by national and international invited speakers, followed by a poster session.

Steering Committee InterPore
Alex Hansen (NTNU), Chair
Gustav Grimstad (NTNU)
Kundan Kumar (UiB)
Sarah Gasda (NORCE)
Marcel Moura (UiO)

Program October 16th 2019
Chair Aksel Hiorth
09:15 **Bill Rossen, TU Delft**
Successes and Challenges for Microfluidics as Models for 3D Porous Media
10:00 **Matthew Jackson, Imperial College**
Zeta potential in crude-oil-brine-rock systems and its importance in enhanced oil recovery
10:45 **Martin Fernø, Universitetet i Bergen**
Laboratory pore-scale observations related to CO_2 storage and CCUS
11:30 **Lunch**

Chair Dmitry Shogin
12:30 **Johan Olav Helland, NORCE**
Three-phase capillary trapping in porous media
13:15 **Alex Hansen, NTNU**
Can we do better than relative permeability when scaling up immiscible two-phase flow in porous media?
14:00 **Coffee break**

Chair Sarah Gasda
14:15 **Gaute Linga, Universitetet i Oslo**
Influence of roughness, inertia and surface charge on fluid transport in fractures and pores: Insights from direct numerical simulations
15:00 **Coffee break**
15:15 Poster session & discussions
17:45 End of scientific programme

Place: Arkivenes Hus
Address: Richard Johnsens gate 12 – AH, 401

Registration
Online registration: www.uis.no/ior
Deadline September 20, 2019

More information
aksel.hiorth@uis.no or www.ntnu.edu/interpore

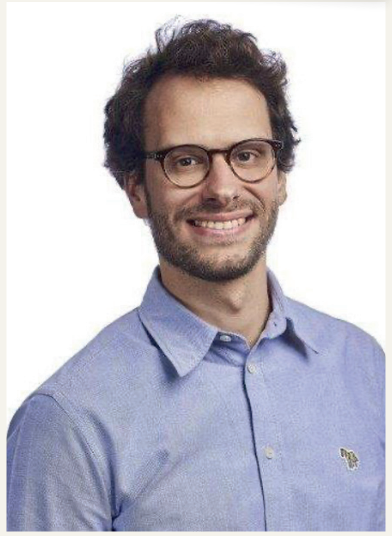
Organization Committee UiS/NORCE:
Sarah Gasda
Aksel Hiorth
Olav Aursjø
Dmitry Shogin

INTERPORE-PORELAB AWARD FOR YOUNG RESEARCHERS

The close cooperation between InterPore and PoreLab has led to the creation of the InterPore-PoreLab award for Young Researchers. The award, allocated for the first time in 2018, is given in recognition of outstanding contributions to fundamental research in the field of porous media.

The 2019 winner of the InterPore-Porelab award for Young Researchers is **Tom Bultreys**, Research fellow at the department of Geology from Ghent University, Belgium. Tom has contributed significantly to the field of pore-scale imaging and modeling. During his PhD, he developed a multi-scale network model to describe rocks with a very wide range of pore sizes. New concepts were developed, which have already found commercial applications. In his subsequent work at Imperial College, Bultreys worked on the validation and calibration of pore-scale network models. He developed a methodology to compare model and image experimental results on a pore-by-pore basis, providing a much richer basis of comparison than had been possible hitherto with simply the comparison of average results. His work laid the framework for a proper validation of models.

"I am extremely honored and humbled to accept this award. Interpore has played an enormously important role in my research career and will continue to do so. That makes this award all the more valuable and special to me"
- Tom Bultreys, 2019 winner of the InterPore-PoreLab Award for Young Researchers.



11TH ANNUAL MEETING INTERPORE, 2019

PoreLab was largely represented at the 11th Annual Meeting of the International Society for Porous Media (InterPore) this year with a delegation of 20 members. The 11th Annual Meeting was held on 6-10 May 2019, in Valencia, Spain. PoreLab at NTNU and UiO got not less than 24 abstracts accepted for the conference, both as oral and poster presentations. *"Our advisory board member, Majid Hassanizadeh, told me it was the best science program ever in Interpore. I was proud of all PoreLab contributions,"* said Professor Signe Kjelstrup who attended the InterPore meeting with a few of her students.

From left to right: Subhadeep Roy, Marcel Moura, Marco Sauermoser, Mathias Winkler, Astrid Gunnarshaug, Eivind Bering, Signe Kjelstrup, Srutarshi Pradhan, Olav Galteland, Alex Hansen, Kim Kristiansen, Dick Bedeaux and Santanu Sinha (missing on the picture are: Magnus Gjennestad, Simon Solberg, Knut Jørgen Måløy, Louison Thorens, Gaute Linga, Hamid Khanamiri, Mohammad Hossein Golestan).

Gathering of PoreLab Juniors in Valencia.

THE INTERPORE STUDENT AFFAIRS COMMITTEE, SAC

The Student Affairs Committee, or SAC, aims to attract, involve and include more PhD students and postdocs in the InterPore organization. The main goal is to improve the dialogue between the existing community, students and young professionals by organizing educational, career and social oriented activities. The SAC activities are open to participants from all career stages, from the early student to the experienced researcher/professor.

The Committee consists of up to six young researchers from the global porous media community. Three PoreLab PhD students and one researcher were members of the SAC already in 2018 and pursue their mandates in 2019: Dr. Marcel Moura (Chair), PhD candidates Olav Galteland (Vice-Chair), Seunghan Song (Secretary and Communication Advisor) and Marco Sauermoser (Events Director).

In response to the excellent participation in the previous years, the SAC organized a set of activities during the 2019 InterPore meeting in Valencia:

- A career development event where four established professionals were invited to share their personal views and experiences.
- A social night out
- An Interactive game on the topic *"the Climate Challenge"*, where participants were invited to reflect on the crucial trade-off between long-term sustainability and short-term economic growth.

INTERPORE Student Affairs

PORELAB IN THE MEDIA

The members of PoreLab are accessible to media and are encouraged to contribute their comments on issues of public concern whenever their expertise is applicable. PoreLab has gotten quite a bit of media coverage since the start.

Here are a few stories the PoreLab scientists have participated in during 2019.

April 23, 2019 – Eirik Flekkøy invited to the Norwegian TV program, "Brille" on TV Norge

Professor Eirik Grude Flekkøy was invited on April 23rd, 2019 to participate on the famous Norwegian TV program, "Brille", on TV Norge. "Brille" is a studio-based quiz program combining humor and science and presented by Harald Eia. The experience with the flying chain fountain was performed on stage and Eirik explained the mechanism of this phenomenon as well as to other physical phenomena: a ping-pong ball flying in the stream of a hair-dryer and the tide phenomenon.

May 11, 2019 – Alex Hansen speaks about Open Science at the Frontiers Forum

June 19, 2019 – Alex Hansen was invited to NRK radio for youth on June 19 after his talk at the NTNU festival "The Big Challenge". The program was about "NTNU-forsker lærer oss noe nytt"

SOCIAL MEDIA

Visit our website **www.porelab.no** where you find daily updated information on our researchers, scientific findings, happenings, studies and many more. Follow us on Twitter as well!

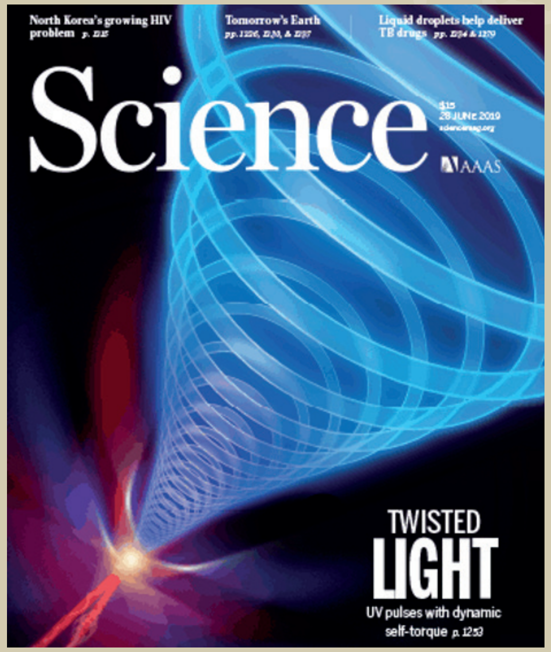
May 3, 2019 – Gemini – Grunnforskning kan gi bedre varsel før ras.


Gemini.no

Grunnforskning kan gi bedre varsel før ras

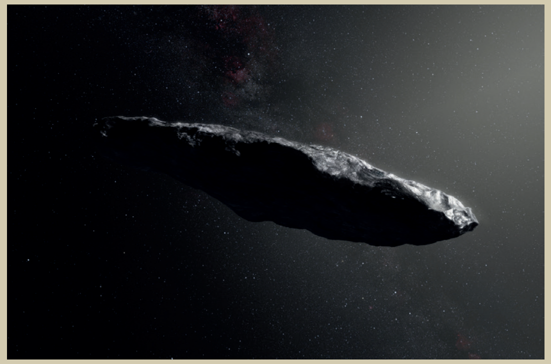
PoreLab studerer porøse medier, teoretisk. Men drømmen er blant annet at resultatene kan forutsi leirras.

June 28, 2019 – PoreLab publication on Labquakes selected as the Editor's choice in the Journal Science.



October 29, 2019 – PoreLab researcher Marcel Moura was a special guest at the Brazilian radio "Cultura". He was interviewed in relation with recent oil spills along the Brazilian coasts.

November 19, 2019 – The theory that the interstellar object 'Oumuamua is a fractal cluster consisting of dust is published in Astrophysical Journal Letters.

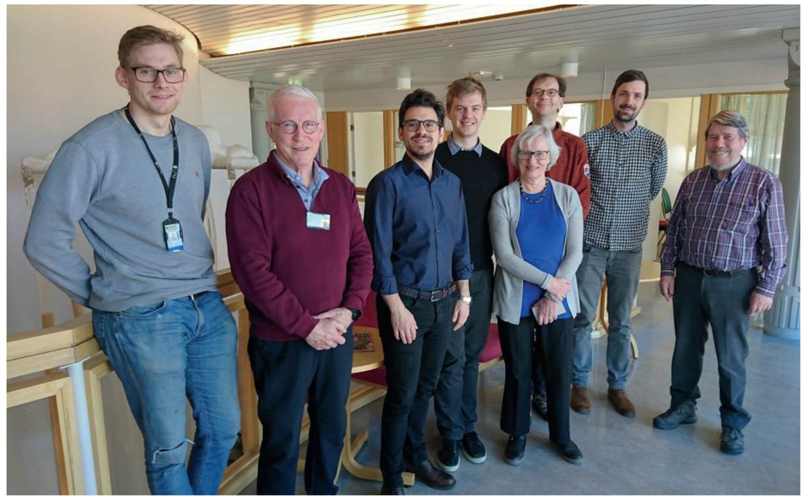


GUEST RESEARCHERS AT PORELAB

Since PoreLab was born, we had the great privilege to host a number of guest researchers for shorter or more extended periods. These guests have provided PoreLab with important new research insights, friendship, and lively discussions in return for access to PoreLab's activities. Most of them gave lectures and workshops were organized when international delegations visited us.

NAME	POSITION	AFFILIATION	PERIOD
Jingya Zhang	PhD candidate	College of Geosciences, China University of Petroleum, Beijing, China	01.09.18 - 31.08.19
Fernando Bresme	Professor	Department of Chemistry, Faculty of Natural Sciences, Imperial College, London, UK	14.01.19 - 15.01.19
Wojciech Debski,	Professor	Department of Theoretical Geophysics, Polish Academy of Sciences, Poland	18.01.19
Francis Mujica Urbina	Master student	Department of Earth Sciences, Memorial University of Newfounland, Canada	17.01.19 – 21.03.19
Alain Gibaud	Professor	Institut des Molécules et Matériaux du Mans, Université du Maine, UMR CNRS, Le Mans, France	22.01.19 – 03.02.19
Phil Vardon	Professor	Faculty of Civil Engineering and Geosciences, TU-Delft, The Netherlands	24.01.19
Marios Valavanides	Ass. Professor	department of Civil Engineering, University of West Attica, Greece	28.01.19 – 30.01.19
Miguel Rubi	Professor	Department of Fundamental Physics at the University of Barcelona, Spain	01.02.19 – 01.02.20
Shidong Li	Scientist	ICES, Agency for Science, Tech. and Research, Singapore	15.02.19
Santanu Sinha	Researcher	Beijing Computational Science research Center, Beijing, China	01.03.19 – 30.05.19
Verónica Pérez Chávez	Professor	CETYS University, México	01.03.19 – 30.09.20
Fabien Georget	Scientist	Construction Materials Laboratory, Ecole Polytechnique Fédérale de Lausanne, Switzerland	07.03.19 – 08.03.19
Khalil Ferjaoui	PhD candidate	Construction Materials Laboratory, Ecole Polytechnique Fédérale de Lausanne, Switzerland	07.03.19 – 08.03.19
Diego Kingston	PhD candidate	University of Buenos Aires, Argentina	14.03.19 – 17.05.19
Othon Moultos	Ass. Professor	Section for Engineering Thermodynamics, TU Delft, The Netherlands	14.03.19 - 15.03.19
Mate Erdos	PhD candidate	Section for Engineering Thermodynamics, TU Delft, The Netherlands	14.03.19 - 15.03.19
Thijs Vlugt	Professor	Section for Engineering Thermodynamics, TU Delft, The Netherlands	15.03.2019
Benoit Cordonnier	Researcher	Section of Physics of Geological processes, UiO, Norway	18.03.19 – 24.03.19
Giulio Fossati	Master student	Politecnico di Milano, Italia	19.03.19 – 30.09.19
Patrick Huber	Prof. Dr. rer. nat	Institute of Materials Physics and Technology, Hamburg University of Technology, Germany	20.03.19
Kerstin Kirschbaum	Master student	Technische Universität München, Germany	15.04.19 – 15.10.19
Natalya Kizilova	Professor	Faculty of Power and Aeronautical Engineering, Warsaw University of Technology, Poland	17.04.19 – 30.06.19
Marios Valavanides	Ass. Professor	Department of Civil Engineering, University of West Attica, Greece	23.04.19 – 04.05.19
Xin Wang	Professor	Shandong Academy of Sciences, Institute of Oceanography Instrumentation Qingdao, China	30.04.19
Ye Xu	Professor	School of Mechanical Engineering and Automation, Beihang University, Beijing, China	30.04.19
Martin Hendrick	Researcher	University of Neuchâtel, Switzerland	01.06.19 – 30.06.19
Daan Frenkel	Professor	Department of Chemistry, University of Cambridge, UK	02.06.19 – 04.07.19
Alain Zanella	Lecturer	University of Le Mans, LPG, Geology department, Université du Maine, Le Mans, France	04.06.19
Ali Telmadarreie	Research Ass.	University of Calgary, Canada	15.06.19 – 06.07. 19
Majid Hassanizadeh	Professor	Utrecht University, The Netherlands	18.06.19 – 27.06.19
Erika Eiser	Professor	Cavendish Laboratory, University of Cambridge, UK	21.06.19 – 28.06.19
Philipp Rehner	PhD candidate	Institute for technical Thermodynamics and Thermal Process Eng., Univ. of Stuttgart, Germany	01.08.19 – 12.10.19
Quirine Krol	Post-doc	College of Engineering, Montana State University in Bozeman, USA	27.08.19 – 10.11.19
Benoit Coasne	Director	CNRS, Laboratoire interdisciplinaire de Physique, University Grenoble Alpes, France	29.08.19 - 30.08.19
Edgar J. Garcia Castano	Master student	School of Mechanical Engineering, University of Campinas, Brazil	02.09.19 – 31.10.19
Danial Arab	PhD candidate	Department of chemical and petroleum engineering at the University of Calgary, Canada	02.09.19 – 31.01.20
Cristian C. García Castaño	Master student	National Autonomous University of Mexico, UNAM, Mexico city, Mexico	02.09.19 – 24.11.19
Jane Luu	Professor	Draper Laboratory, MIT, Massachusetts, USA	04.09.19 - 07.09.19
Renaud Toussaint	Professor	CNRS research director, experimental geophysics, University of Strasbourg, France	04.09.19 - 11.09.19
David Grégoire	Professor	Institute Universitaire de France, Université de Pau et des Pays de l'Adour, France	09.09.19 – 18.09.19
Bjørn Birnir	Professor	Director of center for complex and nonlinear Science at UCSB, USA	11.09.19 - 14.09.19
Diego Kingston	PhD candidate	University of Buenos Aires, Argentina	13.09.19 – 30.11.19
Peter Daivis	Professor	School of Science cluster, Physics department, RMIT University, Melbourne, Australia	28.09.19 – 06.10.19
Antoine Dop	Master student	ENS Lyon, France	01.10.19 – 30.06.20
Thijs Vlugt	Professor	Section for Engineering Thermodynamics, TU Delft, The Netherlands	04.10.19
Othon Moultos	Ass. Professor	Section for Engineering Thermodynamics, TU Delft, The Netherlands	04.10.19
Sebastián Caro Ortiz	PhD candidate	Section for Engineering Thermodynamics, TU Delft, The Netherlands	04.10.19
Noura Dawass	PhD candidate	Section for Engineering Thermodynamics, TU Delft, The Netherlands	04.10.19
Ahmadreza Rahbari	PhD candidate	Section for Engineering Thermodynamics, TU Delft, The Netherlands	04.10.19
Mate Erdös	PhD candidate	Section for Engineering Thermodynamics, TU Delft, The Netherlands	04.10.19
Remco Hens	PhD candidate	Section for Engineering Thermodynamics, TU Delft, The Netherlands	04.10.19
Hirad Seyed Salehi	PhD candidate	Section for Engineering Thermodynamics, TU Delft, The Netherlands	04.10.19
Remco Hartkamp	PhD candidate	Section for Complex Fluid Processing, TU Delft, The Netherlands	04.10.19
Max Dopke	PhD candidate	Section for Complex Fluid Processing, TU Delft, The Netherlands	04.10.19
Daan Frenkel	Professor	Department of Chemistry, Cambridge University, UK	06.10.19 – 01.12.19
Erika Eiser	Professor	Cavendish Laboratory, Department of Physics, University of Cambridge, UK	06.10.19 – 01.12.19
Nasiru Idowu	Chief engineer	iRock Technologie, Trondheim, Norway	23.10.2019
James Mc Clure	Scientist	Advanced Research Computing, Virginia Tech, USA	24.10.19
Shaltiel Eloul	Post-doc	Department of Chemistry, University of Cambridge, UK	28.10.19 - 05.11.19
Xidong Wang	PhD candidate	School of Geosciences, China Univ. of Petroleum (East China), Qingdao, China	28.10.19 – 28.10.20
Dag Chun Standnes	Professor	Leading researcher at Equinor ASA & adjunct professor at University of Stavanger, Norway	30.10.19
Olivier Rodriguez		Co-founder & Chief Executive Officer at Voxaya	03.12.2019
Jane Luu	Professor	Draper Laboratory, MIT, Massachusetts, USA	12.12.19 - 15.12.19
Santanu Sinha	Researcher	Beijing Computational Science Research Center, Beijing, China	17.12.19 - 20.12.20

On March 7th and 8th, 2019, PoreLab Trondheim organised a workshop with members of the ERICA network. ERICA stands for "Engineered calcium-silicate-hydrates for applications" and is a project of the type MSCA-ITN-ETN – European Training Networks financed by EU H2020. From left to right: Mette Rica Geiker, Alex Hansen, Fabien Georget, Miguel Rubi, Signe Kjelstrup, Petter Hemstad, Klaartje De Weerdt, Srutarshi Pradhan, Dick Bedeaux, Khalil Ferjaoui.
Photo: Marie-Laure Olivier



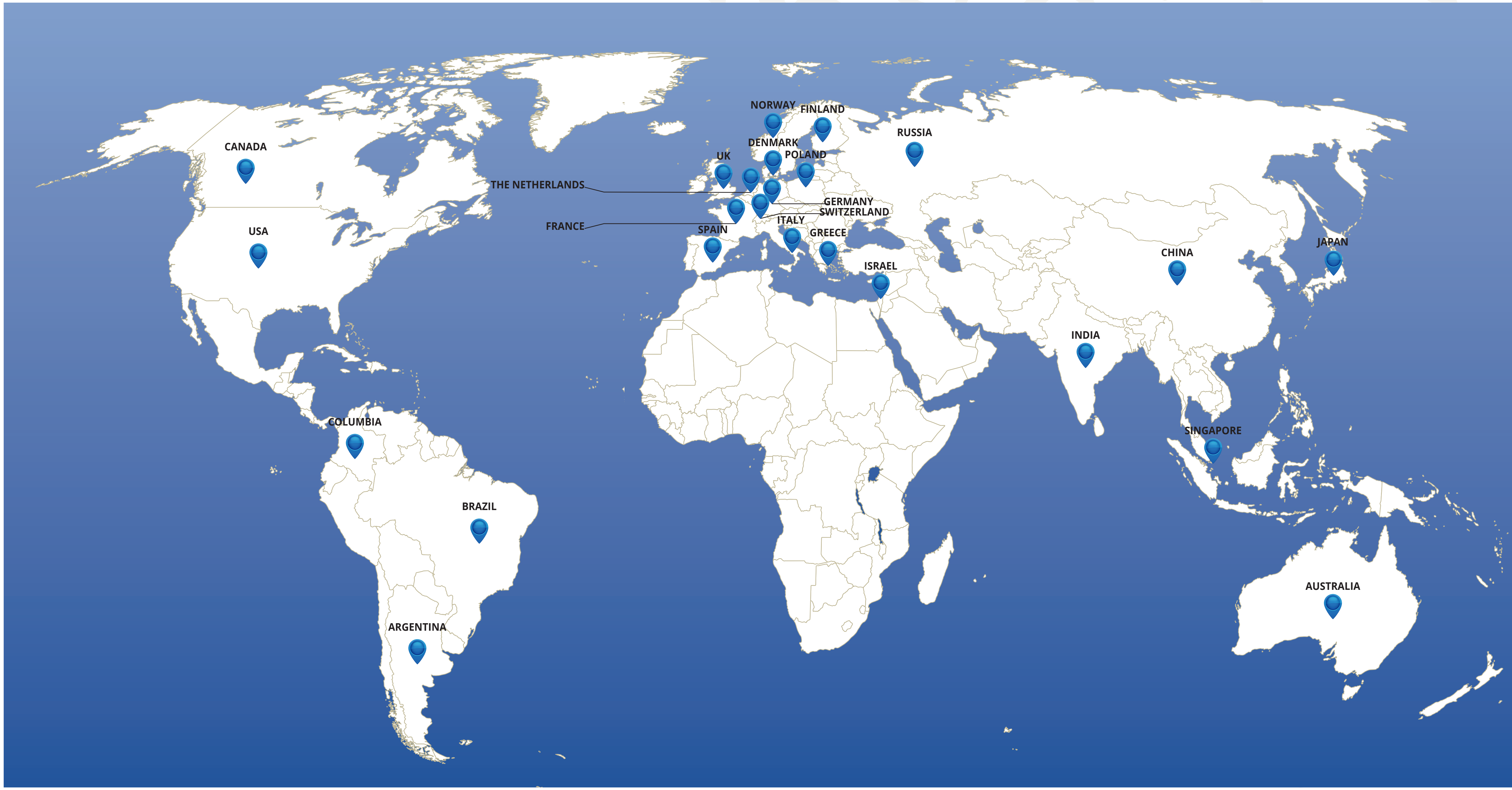
On March 14th and 15th, 2019, a delegation from the Engineering Thermodynamics group from the University of Delft, the Netherlands, visited PoreLab Trondheim. The purpose of the visit was to explore a new definition of the pressure of porous media proposed by Galteland et al., in a new type of porous media, namely zeolites. A purpose was also to investigate possibilities for further collaborations on porous media. From left to right: Olav Galteland, Bjørn Hafskjold, Othon Moultos, Mate Erdös, Signe Kjelstrup, Thijs J.H. Vlugt, Michael Rauter, Dick Bedeaux..
Photo: Marie-Laure Olivier

Delegation from Virginia Tech with James Mc Clure visiting Equinor and the department of Geoscience and Petroleum, NTNU. 24.10.2019.
Photo: Marie-Laure Olivier

RESEARCH STAY ABROAD FOR PORELAB MEMBERS (AT LEAST 1 MONTH)

NAME	POSITION	INSTITUTION VISITED	PERIOD
Alex Hansen	Professor, PoreLab's director	Beijing Computational Sciences Research Center, CSRS, Beijing, China	07.07-07.08.2019
Alex Hansen	Professor, PoreLab's director	Beijing Computational Sciences Research Center, CSRS, Beijing, China	08.11-11.12.2019
Signe Kjelstrup	Professor	TU Delft and U of Utrecht	January
Dick Bedeaux	Professor	TU Delft and U of Utrecht	January
Renaud Toussaint	Adjunct Professor UiO Directeur de recherche CNRS	Institut de Physique du Globe de Strasbourg, CNRS/University of Strasbourg	11 months total in 2019
Gustav Grimstad	Professor	UCD, Dublin, Ireland	August to the end of the year
Ailo Aasen	PhD candidate	University of Barcelona, Spain	17.03 – 25.06
Louison Thorens	PhD candidate	ENS, Lyon, France	14.04 – 06.09
James Campbell	Post-doc	Swansea University, UK	01.06 -

NATIONAL AND INTERNATIONAL COLLABORATION



USA
Sarah L Codd: *College of Engineering, Montana State University, Bozeman*
Daniel H. Rothman: *Department of Earth, Atmospheric, and Planetary Sciences, Massachussets Institute of Technology*
Jane Luu: *Draper Laboratory, Massachusetts, USA*
Steven Pride: *Energy Geosciences Division, Lawrence Berkeley National Lab*
James McClure: *Virginia Tech*

CANADA
Steven Bryant, Marie Macquet, Steven Bryant, Marie Macquet, Somayeh Goodarzi, Ali Telmadarreie, Ellen Liu, Carter Jordan Dziuba, Ian Gates: *University of Calgary*
Francis Mujica Urbina: *Department of Earth Sciences, Memorial University of Newfoundland*

COLUMBIA
Daniel Barragán: *School of Chemistry, Faculty of Sciences, National University of Colombia*

ARGENTINA
Diego Kingston: *University of Buenos Aires, Argentina*

BRAZIL
Jose Soares Andrade Jr.: *Universidade Federal do Ceara*

NORWAY
Jan Øystein Haavig Bakke: *Schlumberger Stavanger*
Øivind Wilhelmsen, Asbjørn Solheim, Olaf Trygve Berglihn, Torleif Holt, Erik Lindeberg, Dag Wessel-Berg, Vegard Brøtan: *SINTEF*
Bjørn Skjetne: *CEGNOR AS*
Geir Helgesen, Kenneth Knudsen: *Institute for Energy Technology, IFE*
Mario Acquarone, Lars Folkow : *The Arctic University of Norway*
Bernt O. Hilmo: *Asplan Viak AS*
Ellinor B. Heggset, Kristin Syverud: *RISE PFI AS*
Harald Berland, Olav Aursjø: *NORCE Norwegian Research center AS*
Thomas Ramstad: *Equinor Research Center, Trondheim*

DENMARK
Joachim Mathiesen: *Niels Bohr Institute, University of Copenhagen*

GERMANY
Rainer Helmig and Joachim Gross: *University of Stuttgart*
Andrzej Gorak: *TU Dortmund*
Steffen Schlüter: *Helmholtz Centre for Environmental Research, Leipzig*
Frank Richter, *AKKA Technology*

THE NETHERLANDS
Thijs J.H. Vlugt, Ger J.M. Koper, Claire Chassagne, Othon Moultos, Mate Erdos: *Delft University of Technology*
Majid Hassanizadeh: *Multiscale Porous Media Laboratory, Utrecht University*

UK
Bjørnar Sandnes: *Energy Safety Research Institute, College of Engineering, Swansea University*
Fernando Bresme: *Department of Chemistry, Imperial College London*
Daan Frenkel, Erika Eiser: *University of Cambridge, UK*

FRANCE
Sunniva Indrehus: *Pierre and Marie Curie University, Paris 6*
Laurent Talon: *Laboratoire FAST, Université de Paris-Sud, Orsay*
Renaud Toussaint, Tom Vincent-Dospital, Monem Ayaz, Antoine Léo Turquet: *Institut de Physique du Globe de Strasbourg, CNRS, Université de Strasbourg*
Tanguy Le Borgne: *University of Rennes*
Jean-Marc Simon: *University of Bourgogne, CNRS*
Stéphane Santucci, Michael Bourgoin: *Ecole Normale Supérieure de Lyon, UMR CNRS, Lyon*
Osvanny Ramos: *Department of Physics, Claude Bernard University, Lyon*
Francois Renard: *Institut de Physique du Globe de Strasbourg, CNRS/University of Strasbourg*

SWITZERLAND
Martin Hendrick: *Université de Neuchâtel*

SPAIN
Miguel Rubi, Xavier Cartoixa: *University of Barcelona*
Riccardo Rurali: *Theory and Simulation Department, Materials Science Institute of Barcelona (ICMAB–CSIC)*
María Barragán Garciá: *Department of Applied Physics, Complutense University of Madrid*

ITALY
Luciano Colombo: *University of Cagliari*
Pietro Ballone: *Center for Life Nanoscience. Instituto Italiano di Tecnologia*
Giulio Fossati: *Politecnico di Milano*

GREECE
Marios Valavanides: *Dept. of Civil Engineering, University of West Attica*

POLAND
A. Mikkelsen, K. Khobaib, R. Rozynek: *Institute of Acoustics, Faculty of Physics, Adam Mickiewicz University, Poznań*
Natalya Kizilova: *Institute of Aeronautics and applied Mechanics, Warsaw University of Technology*
Wojciech Debski: *Department of Theoretical Geophysics, Institute of Geophysics Polish Academy of Sciences, Warszawa*

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L. Laurson, Mikko Alava: *Department of Applied Physics, Aalto University, Espoo*

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Sergey Abaimov: *Skolkovo Institute of Science and Technology*

ISRAEL
Ran Holtzman: *Hebrew University of Jerusalem*
Itamar Procaccia: *Weizmann Institute, Rehovot*

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Purusattam Ray: *Institute of Mathematical Sciences, Chennai*
Chakrabarti Bikas K.: *Saha Institute of Nuclear Physics, Kolkata*

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Hai-Qing Lin, Rubem Mondaini, Tie-Fu Li, Li-Shi Luo, Santanu Sinha: *Beijing Computational Science Research Center*
Jingya Zhang: *College of Geosciences, China University of Petroleum, Beijing*
Ye Xu: *School of Mechanical Engineering and Automation, Beihang University, Beijing*
Fulong Ning: *China University of Geosciences Wuhan*
Xin Wang: *Institute of Oceanography Instrumentation, Shandong Academy of Sciences, Qingdao*

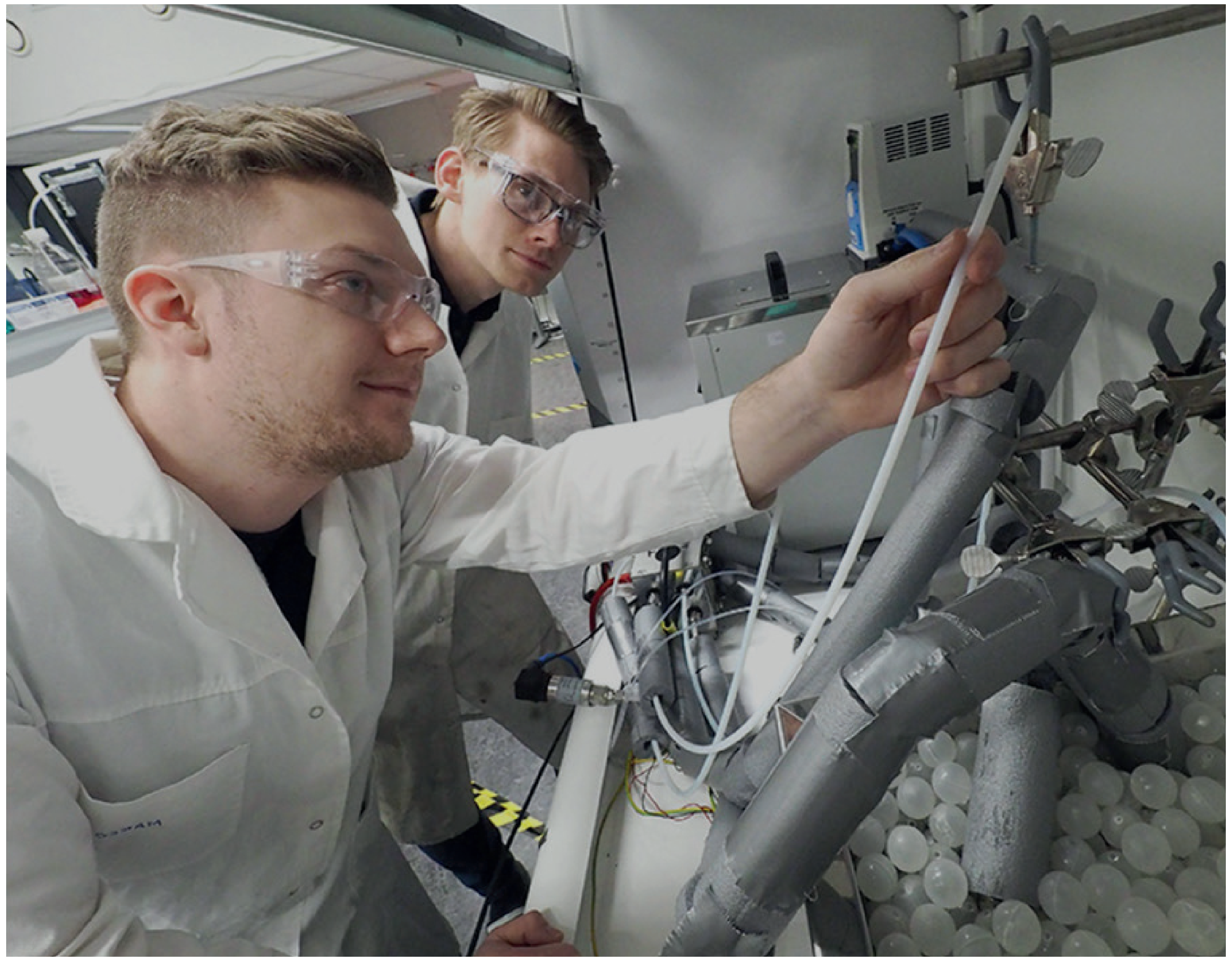
JAPAN
Pieter Krüger: *Graduate School of Science and Engineering, Molecular Chirality Research Center, Chiba University, Chiba*
Tamio Ikeshoji: *National Institute of Advanced Industrial Science and Technology, AIST*
Koji Amezawa: *Institute of Multidisciplinary Research for advanced materials, Tohoku University*
Hironori Nakajima: *Department of Mechanical Engineering, Faculty of Engineering, Kyushu University*
Satoshi Nishimura: *Faculty of Engineering, Field Engineering for the Environment, Hokkaido University*
Yasuhiro Fukunaka: *Research Organization for Nano and Life Innovation, Waseda University, Shinjuku, Tokyo*

SINGAPORE
Shidong Li, Nanji Hadia, Yeap Hung Ng, Ludger Stubbs, Qi Hua Ng: *Institute of Chemical and Engineering Sciences (ICES), Agency for Science, Technology and Research*
Hon Chung Lau: *National university of Singapore*

AUSTRALIA
Peter Daivis: *RMIT, Royal Melbourne Institue of Techhnology, Melbourne*
Benjy Marks: *University of Sydney*
Ryan Armstrong: *UNSW, School of Petroleum Engineering, Sydney*

COMPLETED PHDS IN 2019

NAME	DEPARTMENT	DATE	THESIS	SUPERVISORS
Le Xu	Department of Physics, UiO	21 June	*Experimental Observations of Dissolution in Fractures in Circular Geometry*	Knut Jørgen Måløy and Eirik Grude Flekkøy
Reidun Cecilie Grønfur Aadland	Department of Geoscience and Petroleum, NTNU	5 December	*Experimental Study of Flow of Nanocellulose in Porous Media for Enhanced Oil Recovery Application*	Ole Torsæter, Kristin Syverud
Bahador Najafaziar	Department of Geoscience and Petroleum, NTNU	13 December	*HyGreGel: A new class of gel systems for water diversion by in-depth reservoir placement*	Ole Torsæter, Torleif Holt and Jan Åge Stensen.
Monem Ayaz	Department of Physics, University of Oslo and Department of Physics and Engineering, University of Strasbourg	16 December	*Experimental and numerical investigation of cluster morphologies and dynamic during biphasic flow in porous media*	Renaud Toussaint, Gerhard Schafer, Knut Jørgen Måløy
Jonas Tøgersen Kjellstadli	Department of Physics, NTNU	17 December	*Local versus Equal Load Sharing in the Fiber Bundle Model*	Alex Hansen and Asle Sudbø

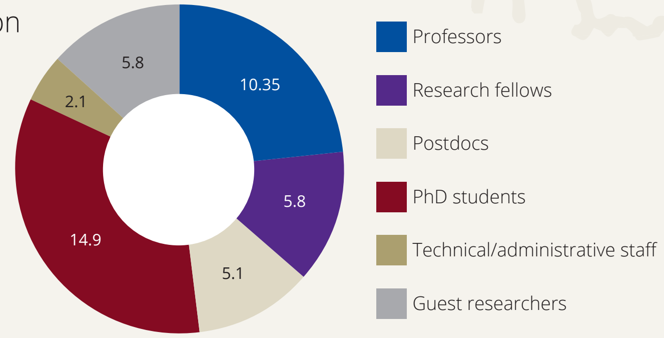


PhD candidates Marco Sauermoser and Olav Galteland are setting up a fuel cell test station in order to investigate new flow field plate designs.
Photo: Per Henning

FACTS AND FIGURES 2019

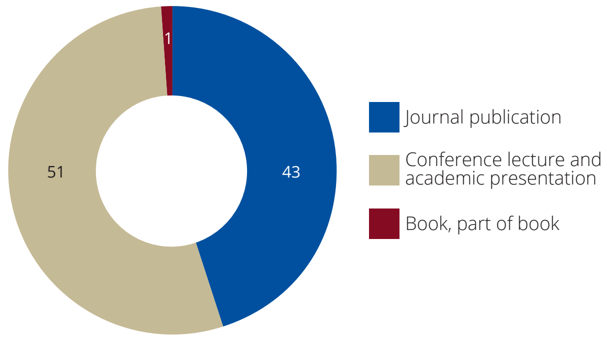
PORELAB STAFF categorized by position

PoreLab staff equals 44,1 man-years in 2019.
The pie chart on the right shows the categorization of our staff by position. In addition, 17 master students were hosted by PoreLab in 2019.



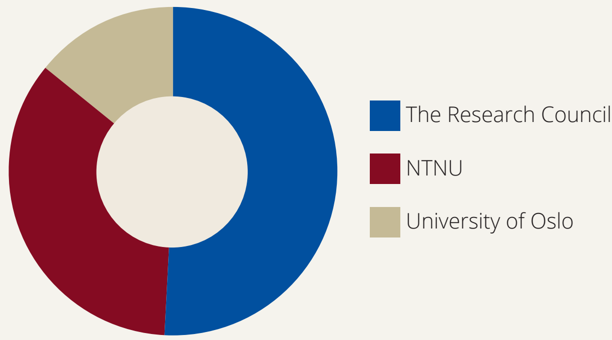
PUBLICATIONS in 2019

- 43 Journal publications
- 51 Conference lectures and academic presentations
- 1 book or part of book



FUNDING in 2019

FUNDING (1000 NOK)	AMOUNT	PERCENTAGE
The Research Council	15 247	51 %
NTNU	10 668	35 %
University of Oslo	4 192	14 %
TOTAL	30 107	100 %



PORELAB MEMBERS

PoreLab Executive Board

Øyvind Gregersen
Dean
NV faculty, NTNU

Erik Wahlström
Head of Department
Department of Physics, NTNU

Sveinung Løset
Professor, Department of Civil and Environmental Engineering, NTNU
Vice Dean Research and Innovation
Faculty of Engineering, NTNU
(From 31 October 2019)

Jøran Idar Moen
Head of Department
Department of Physics, UiO

Brit Lisa Skjelkvåle
Head of Department
Department of Geosciences, UiO

Ingrid Schjølberg
Vice Dean Research and Innovation
Director NTNU Ocean
IV Faculty, NTNU
(until 31 October 2019)

The Leader Group

Alex Hansen
Director
Professor,
Department of Physics, NTNU

Eirik Flekkøy
Professor,
Department of Physics,
UiO

Knut Jørgen Måløy
Deputy Director
Professor, Department of Physics,
UiO

Signe Kjelstrup
Professor,
Department of Chemistry,
NTNU

Ole Torsæter
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Department of Geoscience and Petroleum,
NTNU

Carl Fredrik Berg
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Department of Geoscience and Petroleum,
NTNU

Marie-Laure Olivier
Administrative leader,
Department of Physics,
NTNU

Scientific Advisory Board

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Emeritus
Professor of Chemistry
Director of Research
Department of Chemistry
University of Cambridge, UK

Anna Korre
Professor of Environmental Engineering
Co-director of Energy Futures Lab
Imperial College London, UK

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University of Amsterdam
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Hamid H. Khanamiri
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N TNU

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Monem Ayaz
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Joachim Falck Brodin
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Michael Tobias Rauter
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Salem Saeed Akarri
Department of Geoscience and Petroleum, NTNU

Davood Dadrasajirlou
Department of Civil and Environmental Engineering,
NTNU

Chuangxin Lyu
Department of Civil and Environmental Engineering,
NTNU

Tom Vincent-Dospital
Department of Physics, UiO
U. of Strasbourg,
France

Researchers and Associates

Srutarshi Pradhan
Researcher,
Department of Physics, NTNU

Bjørn Hafskjold
Professor,
Department of Chemistry,
NTNU

Dick Bedeaux
Professor Emeritus
Department of Chemistry,
NTNU

Øivind Wilhelmsen
Research Scientist
SINTEF Energy Research

Per Arne Rikvold
Researcher,
Department of Physics,
UiO

Ursula Gibson
Professor,
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PUBLICATIONS

The following lists journal publications, books, reports, conference lectures and academic presentations generated in 2019.

JOURNAL PUBLICATIONS

Aadland, Reidun Cecilie Grønfur; Jakobsen, Trygve Dagsloth; Heggset, Ellinor Bævre; Long-Sanouiller, Haili; Simon, Sebastien Charles; Paso, Kristofer Gunnar; Syverud, Kristin; Torsæter, Ole.
High-Temperature Core Flood Investigation of Nanocellulose as a Green Additive for Enhanced Oil Recovery. *Nanomaterials* 2019; Volume 9 (665) p. 1-25 - NTNU

Aleksans, Janis; Koehn, Daniel; Toussaint, Renaud; Daniel, Guillaume.
Simulating Hydraulic Fracturing: Failure in soft versus hard rocks. *Pure and Applied Geophysics* 2019 p. 1-19 - UiO

Berg, Carl Fredrik; Danilova, Anna; Liu, Ming.
Upscaling of polymer adsorption. *Journal of Petroleum Science and Engineering* 2019; Volume 179. p. 655-668 - NTNU

Bila, Alberto Luis; Stensen, Jan Åge; Torsæter, Ole.
Experimental Investigation of Polymer-Coated Silica Nanoparticles for Enhanced Oil Recovery. *Nanomaterials* 2019; Volume 9 (822) p. 1-25 - NTNU SINTEF

Chavez Panduro, Elvia Anabela; Torsæter, Malin; Gawel, Kamila; Bjørge, Ruben; Gibaud, Alain; Bonnin, Anne; Schlepütz, Christian M.; Breiby, Dag Werner.
Computed X-ray Tomography Study of Carbonate Precipitation in Large Portland Cement Pores. *Crystal Growth & Design* 2019; Volume 19 (10) p. 5850-5857 USN NTNU SINTEF

Cheng, Xiaoqian; Kleppe, Jon; Torsæter, Ole.
Simulation study of surfactant injection in a fractured core. *Journal of Petroleum Exploration and Production Technology* 2019; Volume 9 (4) p. 3079-3090 - NTNU

de Miguel, Rodrigo; Rubi, Capaceti Jose Miguel.
Negative Thermophoretic Force in the Strong Coupling Regime. *Physical Review Letters* 2019; Volume 123 (20) NTNU

Farin, Maxime; Mangeney, Anne; De Rosny, Julien; Toussaint, Renaud; Trinh, Phuong-Thu.
Relations between the characteristics of granular column collapses and resultant high frequency seismic signals. *Journal of Geophysical Research (JGR): Earth Surface* 2019; Volume 124 (12) p. 2987-3021 - UiO

Flekkøy, Eirik Grude; Luu, Jane; Toussaint, Renaud.
The interstellar object 'Oumuamua as a fractal dust aggregate. *Astrophysical Journal Letters* 2019; Volume 885.(2) p. L41- UiO

Flekkøy, Eirik Grude; Moura, Marcel; Måløy, Knut Jørgen.
Dynamics of the Fluctuating Flying Chain. *Frontiers in Physics* 2019; Volume 7. p. 1-15 - UiO

Galteland, Olav; Bedeaux, Dick; Hafskjold, Bjørn; Kjelstrup, Signe.
Pressures Inside a Nano-Porous Medium. The Case of a Single Phase Fluid. *Frontiers in Physics* 2019; Volume 7. - NTNU

Gjennestad, Magnus Aashammer; Wilhelmsen, Øivind.
Thermodynamic stability of droplets, bubbles and thick films in open and closed pores. *Fluid Phase Equilibria* 2019; Volume 505. p. - ENERGISINT NTNU

Grimstad, Gustav; Ghoreishian Amiri, Seyed Ali; Nordal, Steinar.
Relations and links between soil mechanics, porous media physics, physiochemical theory, and effective medium theory. *Frontiers in Physics* 2019; Volume 7:41. p. 1-10 - NTNU

Kandhasamy, Sathiyaraj; Haarberg, Geir Martin; Kjelstrup, Signe; Solheim, Asbjørn.
Gas electrodes with nickel based current collectors for molten carbonate electrolyte thermo-electrochemical cells. *Journal of Energy Chemistry* 2019; Volume 41. p. 34-42 - NTNU SINTEF

Kandhasamy, Sathiyaraj; Støre, Anne; Haarberg, Geir Martin; Kjelstrup, Signe; Solheim, Asbjørn.
Thermal Conductivity of Molten Carbonates with Dispersed Solid Oxide from Differential Scanning Calorimetry. *Materials* 2019; Volume 12 (9) - NTNU SINTEF

Kjellstadli, Jonas Tøgersen.
Burst Distribution by Asymptotic Expansion in the Equal Load Sharing Fiber Bundle Model. *Frontiers in Physics* 2019 ;Volume 7. p. - NTNU

Kjellstadli, Jonas Tøgersen; Bering, Eivind; Hendrick, Martin; Pradhan, Srutarshi; Hansen, Alex.
Can Local Stress Enhancement Induce Stability in Fracture Processes? Part I: Apparent Stability. *Frontiers in Physics* 2019; Volume 7. p. 1-7 - NTNU

Kjellstadli, Jonas Tøgersen; Bering, Eivind; Pradhan, Srutarshi; Hansen, Alex.
Can Local Stress Enhancement Induce Stability in Fracture Processes? Part II: The Shielding Effect. *Frontiers in Physics* 2019; Volume 7. NTNU

Kjelstrup, Signe; Bedeaux, Dick; Hansen, Alex; Hafskjold, Bjørn; Galteland, Olav.
Non-isothermal Transport of Multi-phase Fluids in Porous Media. Constitutive Equations. *Frontiers of Physics* 2019; Volume 6. p. 1-12 - NTNU

Kristiansen, Kim; Barragán, V. María; Kjelstrup, Signe.
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Lherminier, Sébastien; Planet, Ramon; Vehel, V Levy Dit; Simon, Gilles; Vanel, Loïc; Måløy, Knut Jørgen; Ramos, Osvanny.
Continuously Sheared Granular Matter Reproduces in Detail Seismicity Laws. *Physical Review Letters* 2019; Volume 122 (21) p. 218501-1-218501-6 - UiO

Li, Shidong; Torsæter, Ole; Lau, Hon Chung; Hadia, Nanji; Stubbs, Ludger P..
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Magnanelli, Elisa; Solberg, Simon Birger Byremo; Kjelstrup, Signe.
Nature-inspired geometrical design of a chemical reactor. *Chemical engineering research & design* 2019; Volume 152. p. 20-29 - ENERGISINT NTNU

Moura, Marcel.
Como limpar uma praia I. *Jornal Vanguarda* 2019 - UiO

Moura, Marcel.
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Moura, Marcel; Flekkøy, Eirik Grude; Måløy, Knut Jørgen; Schäfer, Gerhard; Toussaint, Renaud.
Connectivity enhancement due to film flow in porous media. *Physical Review Fluids* 2019; Volume 4 (9) - UiO

Najafiazar, Bahador; Wessel-Berg, Dag; Bergmo, Per Eirik Strand; Simon, Christian; Yang, Juan; Torsæter, Ole; Holt, Torleif.
Polymer Gels Made with Functionalized Organo-Silica Nanomaterials for Conformance Control. *Energies* 2019; Volume 12 (19) p. 1-28 - NTNU SINTEF

Olsen, Kristian Stølevik; Flekkøy, Eirik Grude; Angheluta, Luiza; Campbell, James; Måløy, Knut Jørgen; Sandnes, Bjørnar.
Geometric universality and anomalous diffusion in frictional fingers. *New Journal of Physics* 2019; Volume 21 (6) - UiO

Patil, Nilesh; Narayanan, Theyencheri; Michels, Leander; Skjønsfjell, Eirik Torbjørn Bakken; Guizar-Sicairos, Manuel; Van den Brande, Niko; Claessens, Raf; Van Mele, Bruno; Breiby, Dag Werner.
Probing Organic Thin Films by Coherent X ray Imaging and X ray Scattering. *ACS Applied Polymer Materials* 2019; Volume 1. p. 1787-1797 - NTNU

Pradhan, Srutarshi; Chakrabarti, Bikas K..
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Pradhan, Srutarshi; Kjellstadli, Jonas Tøgersen; Hansen, Alex.
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Ramstad, Thomas; Berg, Carl Fredrik; Thompson, Karsten.
Pore-Scale Simulations of Single- and Two-Phase Flow in Porous Media: Approaches and Applications. *Transport in Porous Media* 2019; Volume 130 (1) p. 77-104 - NTNU

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Ren, Haonan; Shen, Li; Wu, Dong; Aktas, Ozan; Hawkins, Thomas A.; Ballato, John; Gibson, Ursula; Peacock, Anna.
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Roy, Subhadeep; Hansen, Alex; Sinha, Santanu.
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Rubi, Capaceti Jose Miguel.
Entropic diffusion in confined soft-matter and biological systems. *Europhysics letters* 2019; Volume 127:10001. p. 1-8 - NTNU

Rubi, Miguel; Arango-Restrepo, Andrès.
The Soret coefficient from the Faxèn theorem for a particle moving in a fluid under a temperature gradient. *The European Physical Journal E : Soft matter* 2019; Volume 42.(5)

Schmiedel, Tobias; Galland, Olivier; Haug, Øystein Thorden; Dumazer, Guillaume Henri; Breitkreuz, Christoph.
Coulomb failure of Earth's brittle crust controls growth, emplacement and shapes of igneous sills, saucer-shaped sills and laccoliths. *Earth and Planetary Science Letters* 2019; Volume 510. p. 161-172 - UiO

Song, Seunghan; Lønsethagen, Kristin; Laurell, Fredrik; Hawkins, Thomas A.; Ballato, John; Fokine, Michael; Gibson, Ursula.
Laser restructuring and photoluminescence of glass-clad GaSb/Si-core optical fibres. *Nature Communications* 2019; Volume 10. p. - NTNU

Turquet, Antoine Leo; Toussaint, Renaud; Eriksen, Fredrik Kvalheim; Daniel, Guillaume; Lengline, Oliver; Flekkøy, Eirik Grude; Måløy, Knut Jørgen.
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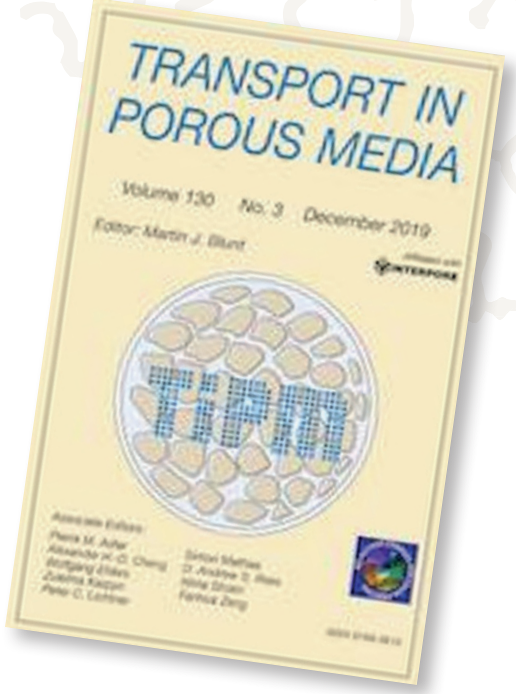

The paper from A. Hansen, S. Sinha, D. Bedeaux, S. Kjelstrup. M. Aa. Gjennestad and M. Vassvik on "Relations between Seepage Velocities in Immiscible, Incompressible Two-phase Flow in Porous Media" *has become the most downloaded paper ever in **Transport in Porous Media**, the main journal in porous media research, since 1986.*

Xu, Le; Szymczak, Piotr; Toussaint, Renaud; Flekkøy, Eirik Grude; Måløy, Knut Jørgen.
Experimental Observation of Dissolution Finger Growth in Radial Geometry. *Frontiers in Physics* 2019; Volume 7.(JULY) p. 1-10 - UiO

Zhang, Jingya; Liu, Guangdi; Cao, Zhe; Tao, Shizhen; Felix, Maarten; Kong, Yuhua; Zhang, Yiying.
Characteristics and formation mechanism of multi-source mixed sedimentary rocks in a saline lake, a case study of the Permian Lucaogou Formation in the Jimusaer Sag, northwest China. *Marine and Petroleum Geology* 2019; Volume 102. p. 704-724 - NTNU

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BOOK, PART OF BOOK AND REPORT

Lyu, Chuangxin; Ghoreishian Amiri, Seyed Ali; Gao, Hao; Ingeman-Nielsen, Thomas; Grimstad, Gustav.
Joint Acoustic and Electrical Measurements for Unfrozen Water Saturation Estimate—A Review. I: Cold Regions Engineering 2019. *American Society of Civil Engineers* (ASCE) 2019 ISBN 9780784482599. p. 26-34 - NTNU

CONFERENCE LECTURES AND ACADEMIC PRESENTATIONS

Aasmundtveit, Knut; Tekseth, Kim Robert Bjørk; Breiby, Dag Werner; Nguyen, Hoang-Vu.
High-energy X-ray Tomography for 3D Void Characterization in Au–Sn Solid-Liquid Interdiffusion (SLID) Bonds. 22nd European Microelectronics and Packaging Conference & Exhibition (EMPC); 2019-09-17 - 2019-09-19 - USN NTNU

Arran, Matthew; Mangeney, Anne; De Rosny, Julien; Farin, Maxime; Toussaint, Renaud.
High-frequency Seismic Signals from Landslides: Insight from Laboratory Flows and DEM Simulations. AGU Fall Meeting; 2019-12-06 - 2019-12-13 - UiO

Bedeaux, Dick.
Nanothermodynamics Session Chairman. Gordon Conference on Micro&Nanoscale Phase Change and Heat Transfer, Pisa, Italy; 2019-02-03 - 2019-02-10 - NTNU

Bedeaux, Dick; Hansen, Alex; Olivier, Marie-Laure; Galteland, Olav; Sauermoser, Marco.
Organisers International Workshop. Nonequilibrium Thermodynamis for Porous Media, PoreLab, NTNU; 2019-10-29 - 2019-10-30 - NTNU

Bedeaux, Dick; Kjelstrup, Signe.
Small System Thermodynamics. Seminar, Department of Chemistry, TUDelft; 2019-01 21 - 2019-01-21 - NTNU

Bedeaux, Dick; Kjelstrup, Signe.
The relation between Hill's Small System Thermodynamics and Gibbs' Thermodynamics for Curved Surfaces. Seminar, Sitges Conference, Spain; 2019-05-26 - 2019-06-01 - NTNU

Bila, Alberto Luis; Stensen, Jan Åge; Torsæter, Ole.
An experimental investigation of surface-modified silica nanoparticles in the injection water for enhanced oil recovery. Annual Symposium of the Society of Core Analysts; 2019-08-26 - 2019-08-30 - NTNU

Bila, Alberto Luis; Stensen, Jan Åge; Torsæter, Ole.
Experimental Evaluation of Oil Recovery Mechanisms Using a Variety of Surface Modified Silica Nanoparticles in the Injection Water. SPE Norway One Day Seminar; 2019-05-14 - 2019-05-14 - NTNU

Bila, Alberto Luis; Stensen, Jan Åge; Torsæter, Ole.
Polymer-coated Silica Nanoparticles for Enhanced Oil Recovery Applications on Berea Sandstone Rocks. 2nd Conference of the Arabian Journal of Geosciences (CAJG); 2019-11-25 - 2019-11-28 - NTNU

Breiby, Dag Werner.
Invited keynote talk: Gearing X-ray microscopy towards environmental challenges. Coherence at ESRF-EBS; 2019-09-09 - 2019-09-13 - NTNU

Breiby, Dag Werner.
Invited talk: Quantitative 4D X-ray microscopy and its future in polymer science. Nordic Polymer Days 2019; 2019-06-05 - 2019-06-07 - NTNU

Chattopadhyay, Basab; Mürer, Fredrik Kristoffer; Madathiparambil, Aldritt Scaria; Cerasi, Pierre; Chushkin, Yuriy; Zontone, Federico; Gibaud, Alain; Breiby, Dag Werner.
Internal structure of shales by coherent X-ray diffraction imaging. Coherence at ESRF EBS; 2019-09-09 - 2019-09-13 - NTNU SINTEF

Chattopadhyay, Basab; Mürer, Fredrik Kristoffer; Madathiparambil, Aldritt Scaria; Cerasi, Pierre; Chushkin, Yuriy; Zontone, Federico; Gibaud, Alain; Breiby, Dag Werner.
Nanoscale imaging of shale cuttings with coherent X-ray diffraction. NanoNetwork, 10th annual workshop; 2019-06-17 - 2019-06-19 - sNTNU SINTEF

Gunnarshaug, Astrid Fagertun; Kjelstrup, Signe; Bedeaux, Dick; Burheim, Odne Stokke.
Peltier heats of lithium-ion battery electrodes. International workshop on non-equilibrium thermodynamics in porous media, PoreLab, Trondheim, Norway; 2019-08 29 - 2019-08-30 - NTNU

Gunnarshaug, Astrid Fagertun; Kjelstrup, Signe; Bedeaux, Dick; Burheim, Odne Stokke; Vie, Preben Joakim Svela.
Peltier Heats of LiFePO4 electrodes from a Thermoelectric Cell. 236th ECS MEETING, Atlanta, Georgia, USA; 2019-10-13 - 2019-10-17 - IFE NTNU

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Peltier Heat of porous LiFePO4 electrodes in a thermoelectric cell. InterPore 2019; 2019-05-06 - 2019-05-10 - IFE NTNU

Hansen, Alex.
A Statistical Mechanics for Flow in Porous Media. New Trends in Statistical Physics - XXVI Sitges Conference on Statistical Mechanics; 2019-05-27 - 2019-05-31 - NTNU

Hansen, Alex.
A Survey of Recent Results on Immiscible Two-Phase Flow in Porous Media. Seminar; 2019-12-05 - 2019-12-05 - NTNU

Hansen, Alex.
Can we do better than relative permeability when scaling up immiscible two-phase flow in porous media? 3rd National Workshop on Porous Media; 2019-10-16 - 2019-10-16 - NTNU

Hansen, Alex.
Euler Theory for Immiscible Two-Phase Flow in Porous Media. Equinor seminar; 2019 12-16 - 2019-12-16 - NTNU

Hansen, Alex.
Hvorfor porøse medier? Norske fysikkstudenters konferanse; 2019-03-15 - 2019-03-17 - NTNU

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Immiscible two-phase flow in porous media: How adding a little symmetry can go a long way. Winter School on Computational Mathematical Modeling; 2019-03-25 – 2019 03-29 - NTNU

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More and more people lack clean water: Can basic research help? The Big Challenge; 2019-06-16 - 2019-06-19 - NTNU

Hansen, Alex.
SK70 – Signe Kjelstrup. SK70; 2019-08-29 - NTNU

Hansen, Alex.
Sometimes complexity can be brought under control: How we do this for immiscible two-phase flow in porous media. Workshop on Complex Systems; 2019-01-16 – 2019 01-16 - NTNU

Hansen, Alex.
The Physics of Porous Media. Fysikermøtet; 2019-08-07 - 2019-08-09 - NTNU

Hansen, Alex.
The scale-up problem: A search for the missing link between the pore scale and continuum scale. IOR NORWAY; 2019-03-19 - 2019-03-20 - NTNU

Hansen, Alex; Bedeaux, Dick; Kjelstrup, Signe.
Understanding the co-moving velocity. Interpore 2019; 2019-05-06 - 2019-05-10 - NTNU

Hasanzade, Mojde; Alekic, Anel; Breiby, Dag Werner; Akram, Muhammad Nadeem.
Multiplexed LED Recovery using Fresnel Propagation for Fourier Ptychography Microscopy. NanoNetwork, 10th annual workshop; 2019-06-17 - 2019-06-19 - USN NTNU

Hibert, Clément; Talib, Miloud; Noël, François; Gracchi, Teresa; Bourrier, Franck; Brenguier, Ombeline; Desrues, Mathilde; Toe, David; Wyser, Emmanuel; Malet, Jean-Philippe; Jaboyedoff, Michel; Toussaint, Renaud.
Analysis of the dynamics of supervised single-block rockfalls from intra-block accelerometers, seismology and remote sensing. EGU annual meeting; 2019-04-07 - 2019-04-12 - UiO

Jahanbani Ghahfarokhi, Ashkan; Torsæter, Ole.
Modeling Wettability Alteration in Low Salinity Water Flooding. 81st EAGE Conference & Exhibition 2019; 2019-06-03 - 2019-06-06 - NTNU UiO

Kariche, Jugurtha; Meghraoui, Mustapha; Toussaint, Renaud.
Stress transfer and poroelasticity associated to the 2019 Ridgecrest (California) earthquake sequences. AGU Fall Meeting; 2019-12-09 - 2019-12-13 - UiO

Koelemeijer, Paula; Winterbourne, Jeffrey; Toussaint, Renaud; Zaroli, Christophe.
3D printing the world: developing geophysical teaching materials and outreach packages. AGU Fall Meeting; 2019-12-09 - 2019-12-13 - UiO

Li, Shidong; Dan, Daniel; Lau, Hon Chung; Hadia, Nanji; Torsæter, Ole; Stubbs, Ludger P..
Investigation of Wettability Alteration by Silica Nanoparticles through Advanced Surface-Wetting Visualization Techniques.. 2019 SPE Annual Technical Conference and Exhibition.; 2019-09-30 - 2019-10-02 - NTNU

Madathiparambil, Aldritt Scaria; Chattopadhyay, Basab; Mürer, Fredrik Kristoffer; Tekseth, Kim Robert Bjørk; Breiby, Dag Werner.
3D Non-Destructive Imaging of Shales. International Conference on Frontiers of Materials Science; 2019-12-16 - 2019-12-18 - NTNU

Madathiparambil, Aldritt Scaria; Mürer, Fredrik Kristoffer; Chattopadhyay, Basab; Tekseth, Kim Robert Bjørk; Di Michiel, Marco; Cerasi, Pierre; Breiby, Dag Werner.
3D Non-Destructive Imaging of Shale Rocks. NanoNetwork, 10th annual workshop; 2019-06-17 - 2019-06-19 - NTNU SINTEF

Madathiparambil, Aldritt Scaria; Zanella, Alain; Cerasi, Pierre; Chattopadhyay, Basab; Mürer, Fredrik Kristoffer; Tekseth, Kim Robert Bjørk; Gibaud, Alain; Breiby, Dag Werner.
Physical modeling of basin scale fluid generation in source rocks. 3rd National Workshop on Porous Media; 2019-10-16 - 2019-10-16 - SINTEF NTNU

Mürer, Fredrik Kristoffer; Chattopadhyay, Basab; Madathiparambil, Aldritt Scaria; Tekseth, Kim Robert Bjørk; Di Michiel, Marco; Mathiesen, Ragnvald; Olstad, Kristin; Lilledahl, Magnus Borstad; Breiby, Dag Werner.
Orientational imaging of bone and cartilage using small- and wide-angle X-ray scattering. Nordic Workshop on Scattering from Soft Matter (NSSM 2019); 2019-01-08 - 2019-02-09 - NTNU NMBU

Mürer, Fredrik Kristoffer; Chattopadhyay, Basab; Madathiparambil, Aldritt Scaria; Tekseth, Kim Robert Bjørk; Di Michiel, Marco; Mathiesen, Ragnvald; Olstad, Kristin; Lilledahl, Magnus Borstad; Breiby, Dag Werner.
3D imaging of bone and cartilage by X-ray phase-contrast and diffraction computed tomography. NanoNetwork, 10th annual workshop; 2019-06-17 - 2019-06-19 - NTNU NMBU

Mürer, Fredrik Kristoffer; Chattopadhyay, Basab; Madathiparambil, Aldritt Scaria; Tekseth, Kim Robert Bjørk; Di Michiel, Marco; Mathiesen, Ragnvald; Olstad, Kristin; Lilledahl, Magnus Borstad; Breiby, Dag Werner.
3D imaging of bone and cartilage by X-ray phase-contrast and orientational diffraction tomography. ESRF User Meeting; 2019-02-04 - 2019-02-06 - NTNU NMBU

Mürer, Fredrik Kristoffer; Chattopadhyay, Basab; Madathiparambil, Aldritt Scaria; Tekseth, Kim Robert Bjørk; Di Michiel, Marco; Olstad, Kristin; Lilledahl, Magnus Borstad; Breiby, Dag Werner.
3D orientational imaging of bone using X-ray diffraction computed tomography. NTNU Nanosymposium 2019; 2019-10-14 - 2019-10-15 - NTNU NMBU

Måløy, Knut Jørgen; Eriksen, Jon Alm; Flekkøy, Eirik Grude; Toussaint, Renaud; Galland, Olivier; Sandnes, Bjørnar.
Pattern formation of frictional fingers in a gravitational field. In Patterns in Geomechanics; 2019-01-30 - UiO

Måløy, Knut Jørgen; Eriksen, Jon Alm; Flekkøy, Eirik Grude; Toussaint, Renaud; Galland, Olivier; Sandnes, Bjørnar.
Pattern formation of frictional fingers in a gravitational potential. APS meeting Boston; 2019-03-07 - UiO

Noël, François; Wyser, Emmanuel; Jaboyedoff, Michel; Hibert, Clément; Talib, Miloud; Malet, Jean-Philippe; Toussaint, Renaud; Desrues, Mathilde; Bourrier, Franck; Toe, David; Brenguier, Ombeline; Gracchi, Teresa; Derron, Marc-Henri; Cloutier, Catherine; Locat, Jacques.
Real-size rockfall experiment: Applying observed impact dynamics to 3D rockfall simulations on highly detailed terrain models. EGU annual meeting; 2019-04-07 – 2019 04-12 - UiO

Rikvold, Per Arne; Gurfinkel, Aleks.
Interpolating between centrality measures on complex networks using absorbing Markov chains. Complexity Summer Camp; 2019-07-29 - 2019-08-02 - UiO

Rikvold, Per Arne; Gurfinkel, Aleks.
Random-walk based interpolations between centrality measures on complex networks. Biannual meeting of the Norwegian Physical Society; 2019-08-07 - 2019-08-09 - UiO

Sauermoser, Marco; Kizilova, Natalya; Flekkøy, Eirik Grude; Pollet, Bruno; Kjelstrup, Signe.
Seeking minimum entropy production for flow-field patterns and their geometries in fuel cells. Interpore 2019; 2019-05-06 - 2019-05-10 - NTNU UiO

Sauermoser, Marco; Kizilova, Natalya; Kjelstrup, Signe; Pollet, Bruno.
Flow Field Patterns for Proton Exchange Membrane (PEM) Fuel Cells. NTNU Team Hydrogen Annual Workshop; 2019-12-02 - 2019-12-03 - NTNU

Sauermoser, Marco; Kjelstrup, Signe; Kizilova, Nataliya; Pollet, Bruno; Flekkøy, Eirik Grude.
Seeking minimum entropy production for a tree-like flow-field in a fuel cell. Nonequilibrium Thermodynamis for Porous Media, PoreLab, NTNU; 2019-08-29 - 2019-08-30 - NTNU UiO

Vincent-Dospital, Tom; Toussaint, Renaud; Cochard, Alain; Måløy, Knut Jørgen; Flekkøy, Eirik Grude; Santucci, Stephane; Vanel, Loïc.
Hot cracks or cool cracks? A model for the brittle-ductile transition of solids. EGU annual meeting; 2019-04-07 - 2019-04-12 - UiO

Zhang, Jingya; Torsæter, Ole; Khanamiri, Hamid Hosseinzade.
The characteristics of pore-throat structure and two-phase flow in tight sandstone reservoir. ISS2019 - Imaging Summer School 2019; 2019-09-01 - 2019-09-06 - NTNU

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