



# WORKSHOP

## **Microfluidic approaches for geological applications and Investigations of the deep biosphere within a carbon cycle context**

March 16 & 17 2020

*ICMCB, UMR5026, CNRS, Université de Bordeaux, Bordeaux INP,  
87 avenue du docteur Albert Schweitzer, 33600 Pessac, France.*



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## **Invited speakers**

## OLIVER Gina

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### -----Short bio-----

Dr. Gina Oliver received her undergraduate degree in Geology at California State University, Long Beach and was recruited as a graduate student by Dr. Karyn Rogers at Rensselaer Polytechnic Institute in 2014. At RPI, she worked with Dr. Rogers and Dr. Cario in building a high temperature and pressure microbial cultivation laboratory, and tested the effects of elevated growth pressures of a model extremophile, *Archaeoglobus fulgidus*. She finished her PhD in Geology in 2019 and has since been teaching Oceanography in Southern California and pursuing her own business ventures in advancing sustainable agriculture.



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### Abstract

#### ***Exploring microbial growth under deep biosphere pressure conditions using a model extremophile, Archaeoglobus fulgidus***

Elevated pressures are a common environmental parameter throughout the deep biosphere where microbial growth drives biogeochemical and energy cycles. Here a model extremophile, *Archaeoglobus fulgidus*, was used to determine how elevated pressure affects growth and physiology of deep-sea and subsurface microorganisms. *A. fulgidus* is an anaerobic, hyperthermophilic archaeon that cycles carbon and sulfur through various metabolic strategies in high temperature and pressure environments including deep-sea hydrothermal vents, deep geothermal wells, and deep oil reservoirs. *A. fulgidus* growth was tested over a range of elevated pressures for one heterotrophic metabolism (lactate oxidation coupled to sulfate reduction) and one autotrophic metabolism (CO<sub>2</sub> fixation coupled to thiosulfate reduction via H<sub>2</sub>) and the affect of sample decompression on *A. fulgidus* heterotrophic growth patterns was explored using various high hydrostatic pressure cultivation techniques. In this study, *A. fulgidus* grew exponentially from 0.1 - 60 MPa for this heterotrophic metabolism and growth was inhibited at 70 MPa. Under certain heterotrophic conditions and cultivation techniques, *A. fulgidus*' optimal growth rate was observed at 20 MPa, displaying preference to increasing pressure conditions. Yet, depending on the number of times microbial samples were decompressed and repressurized, *A. fulgidus* growth rates reflected various degrees of sensitivity and tolerance to increasing pressures as optimal growth rates were observed at 0.1 MPa. Furthermore, *A. fulgidus* biofilm production was observed in certain heterotrophic conditions from 0.1-50 MPa under high-pressure batch cultivation conditions due to both low calcium concentrations in the growth medium and the presence of a nucleation site. For this autotrophic metabolism, *A. fulgidus* cell densities and growth rates were similar from 0.1-40 MPa, showing tolerance to pressure for this metabolism, and growth was inhibited at 60 MPa. Here, *A. fulgidus* continues carbon, sulfur, and energy cycling up to ~4-6 km below sea level (equivalent to 40-60 MPa). As a whole, these results show that elevated pressures and decompression affect microbial growth and that high-pressure growth patterns in one species can fluctuate depending on the specific environmental conditions as *A. fulgidus* showed sensitivity, tolerance and even preference to increasing pressures. These results exemplify the importance of studying extremophiles found in the deep biosphere and are especially relevant to scientific endeavors in carbon sequestration in the subsurface, modern and ancient biogeochemical modeling, biotechnology, and the origin and evolution of life.

## ROMAN, Sophie

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### -----Short bio-----

Sophie Roman is an Associate Professor at University of Orléans (France). She is interested in understanding the underlying physics of multiphase and reactive flows in porous media that is of great importance in many areas of applied science and engineering including hydrogeology, reservoir engineering and CO<sub>2</sub> sequestration. She earned her Ph.D in Fluid Dynamics from the National Polytechnic Institute of Toulouse (France) did postdoctoral research in nanofluidics at the University of Montpellier (France) and in the department of Energy Resources Engineering at Stanford University (USA). More specifically, her work investigates the use of microfluidics as a powerful tool for simulating and investigating transport phenomena in porous media.



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### Abstract

#### ***Microfluidics to Improve Mechanistic Understanding of Multiphase and Reactive Flow Processes***

There is strong interest in imaging and numerical modeling of coupled processes in geological porous media, i.e. multiphase flow and reactive transport processes, at the pore scale with application to reservoir engineering, subsurface hydrology, CO<sub>2</sub> sequestration. The hydro-geochemical dynamics at the pore scale, however, remain relatively unknown but influence macroscale behaviors considerably. Here, we investigate pore-scale mechanisms using microfluidic experiments. Such micromodels have the pore network pattern and pore sizes of a real rock or idealized medium. Importantly, these micromodels permit direct, high-magnification, time-lapse observations of fluid movement through pores, as well as visualization of the evolution of the pore space due to dissolution or precipitation. High resolution data analysis includes particle image velocimetry, fluid-fluid interface tracking, water film thickness measurements, and quantification of mineral dissolution and precipitation using confocal Raman spectroscopic techniques. In this work, we discuss the recent progress we made in the understanding of coupled hydro-geochemical processes at the pore scale. Our observations bring new insights for the modelling of multiphase flow and reactive transport processes at various scales of interest.

## DUPRAZ, Sébastien

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### ----- Short bio -----

Dr. Sébastien DUPRAZ has worked on several projects coupling microbiology and geochemistry. He was Head of the Biogeochemistry Unit in BRGM between 2014 and 2017 and is currently the Experimental Platforms Development Officer for the Laboratory Directorate of BRGM and Vice-Chairman of the ECCSEL RICC (ECCSEL ERIC Research Infrastructure Coordination Committee). His former interdisciplinary formation has given him the opportunity to specialize in interfaces between microorganisms and environmental mineralogical deep environments, namely on interactions with gas. His research has focused mainly on the geological storage, including CCS (former member of the Joint Task Force Biomass-CCS ZEP / EBTP, CPER Ardenay project, ULCOS-TGRBF project), as well as the fundamental processes of biomineralization.



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### Abstract

#### ***From biodissolution to bioprecipitation, microorganisms influence in microporous media***

The influence of microbes in the chemistry and permeability of poral environment is essential to optimize the great majority of the processes that are applied to the subsurface. As biological catalyst, they might help exchanges at the mineral-fluid interface but can also create gradients and passivation layers that will, to the contrary, prevent reactions expected formerly. In this presentation, we will describe how the microbial metabolisms can alter different processes that are involved in industrial activities within the subsurface. A specific focus will be given to the biodissolution and bioprecipitation activities and some recent project that were performed on these subjects at the BRGM facilities.

## PANNACCI, Nicolas

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### ----- Short bio -----

Nicolas Pannacci is a physicochemical and petrophysicist engineer at IFP Energies Nouvelles. He received a PhD degree in Physics and Material Sciences from Université de Nice-Sophia Antipolis and Ecole des Mines de Paris after holding a Master in Physics. From 2006 to 2009, he joined Microfluidics MEMS and Nanostructure lab at ESPCI, for a postdoctoral position. He has been in charge of the development of the microfluidics activity at IFP Energies Nouvelles. His researches focus on simulation and experimental approaches of interfacial phenomena and complex fluids transport in porous medium for EOR and biotechnology projects.



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### Abstract

#### ***Capillary trapping and foam flows studies in a model porous medium***

The use of micromodels (2D transparent model porous medium) is discussed to help the understanding of diphasic flows in the framework of Geosciences projects. Two experimental studies are reported as an illustration. The first deals with capillary trapping and untrapping of oil phase after waterflooding. Ongoing work on gas flow invading a porous matrix is also reported. A focus is given on the case of the behavior of a foam invading a highly heterogeneous medium in term of permeability (naturally fractured rocks).

## STERPENICH, Jérôme

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### ----- Short bio -----

Jérôme Sterpenich is Professor at Université de Lorraine. He develops his research in GeoRessources lab, mainly focused on fluid/rock interactions especially in the context of geological storage. He is also the head of the Carnot Institute Icél working to develop the research in partnership with private companies.



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### Abstract

***Experimental approach to determine thermodynamic and kinetic properties of water/gases/salt systems under geological conditions of P and T.***

Fluids are ubiquitous in geological environment and consequently in geological storages (gases, solid wastes...). Such fluids play an important role for the evolution of such anthropic or natural system because they drive the fluid rock interactions and thus the possible mineral transformations. Moreover, the knowledge of thermodynamic and kinetic properties of water/gases/salt system is essential if we want to predict the geochemical processes in such complex systems. In particular, the solubility of gases in water, their diffusion kinetics in aqueous solutions of different salinities are mandatory to feed the geochemical codes used to predict the evolution of the system with time. If the behavior of non-toxic and non-hazardous gases such as N<sub>2</sub> or CO<sub>2</sub> is well known even under conditions of high PT, this is not the case for exotic gases such as SO<sub>x</sub> or NO<sub>x</sub> for example. In this talk, we propose to develop the methodology used in GeoRessources lab to be able to acquire new thermodynamic and kinetic data, especially for hazardous gases. The presentation will be focused on fused silica capillary method coupled with in situ Raman spectrometry.



## ALAIN, Karine\*

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### Short bio

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Current position:

- Research scientist at the CNRS (Laboratoire de Microbiologie des Environnements Extrêmes (LM2E), UMR 6197 (UBO-CNRS-Ifremer), Institut Universitaire Européen de la Mer (IUEM), Plouzané)
- Director of the Sino-French Associate Laboratory MicrobSea (LIA 1211)

Topics: cultivating the uncultured microorganisms from marine and extreme habitats, studying novel metabolisms and elucidating functions of phylogenetic branches with few cultured representatives



CV

- 2014 / HDR      Habilitation (Microbiology) to supervise research (HDR), Université de Bretagne Occidentale, Brest, France.
- Since oct. 2007 / CR      Researcher, permanent position at the CNRS (CR). Laboratoire de Microbiologie des Environnements Extrêmes CNRS-Ifremer-UBO UMR6197 (Director : Prof. Jebbar), IUEM, Brest, France.
- 2007 / Post-doc (ATER)      Observatoire Océanologique (Director: Prof. Lebaron), Banyuls s/mer, France.
- 2004-2006 / Post-doc      Max-Planck Institute for Marine Microbiology, dept. of Microbiology (Director: Prof. Widdel), Bremen, Germany. Grants: Alexander von Humboldt + Max Planck Society.
- 2000-2003 / PhD      Université de Bretagne Occidentale, Brest, France – Ifremer (group headed by the Dr. Querellou), Brest, France.

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### Abstract

#### ***Microbial communities from the deep-subseafloor biosphere: state of the art and future challenges***

In recent years, our understanding of the diversity, abundance, physiological state and activities of microbial communities inhabiting deep marine sediments has considerably advanced, resulting in a paradigm shift about the subsurface biosphere. In this presentation, I will provide a review of the state of knowledge about microbial communities living beneath the ocean floor. I will address the issues of the diversity present in these environments, microbial numbers, microbial activities, physiological state, energy sources, physical and chemical limits to life in the subseafloor, and impacts of the subseafloor biosphere on Earth's biogeochemical cycles. In conclusion, I will present the challenges to be taken up in the future to study the nature and functions of life in this unique environment.

## JOSEPH, Pierre

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### ----- Short bio -----

After studies in physics, P Joseph graduated in Paris in 2005 with a PhD dealing with the hydrodynamic boundary condition. After a post-doc in Lyon on super-lubricating surfaces, he was recruited as CNRS researcher at LAAS in Toulouse in 2007, both to build model systems of fluid flow (mimic blood transport, flows in porous media, interaction of nanoparticles with biomembranes) and to make functional lab-on-chips (DNA concentration and separation). He is head of MILE team (15 members) and deputy director of the French national network GDR Microfluidics. The team is carrying on research on microfluidics for health and the environment, taking in particular benefit of high-level platforms for fabrication and for bio-chemical experiments.

<https://www.laas.fr/public/en/mile>

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### Abstract

#### ***Microfluidic models to mimic flows in porous media: salt crystallization, nanoscale flows, clogging***

Microfluidics, controlling fluids in microfabricated chips, is a valuable tool for chemical or biological analysis; these are labs-on-chip. It also allows, thanks to simplified configurations, to dissect and better understand some complex situations encountered in porous natural or industrial environments, or biological systems. The talk will present a few chosen examples of our research in MILE team, based essentially on such model systems. Fluid transport in a porous medium, in particular at the nanoscale, is studied by manufacturing a microfluidic/nanofluidic network, mimicking imbibition, fluid evaporation, the crystallization of salt in a rock, or the clogging of a filtration membrane.

## ROGERS, Karyn

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### ----- Short bio -----

Dr. Karyn Rogers is a geochemist, geomicrobiologist and astrobiologist who works on life in extreme environments, the emergence of life on Earth, and the search for life elsewhere. She received her BS from Harvard University and an MS from Stanford University. She completed her PhD at Washington University in St. Louis and was a postdoctoral scholar at Woods Hole Oceanographic Institute. Dr. Rogers is an Associate Professor at Rensselaer Polytechnic Institute in New York, where she also serves as Director of the Rensselaer Astrobiology Research & Education Center. Dr. Rogers' research combines field work and laboratory experiments to explore the relationships between microbial communities and environmental conditions in extreme ecosystems, and is broadly applied to understanding the nature of the origin of life on Earth, the potential for life throughout the solar system, and the extent of life in modern extreme environments.



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### Abstract

#### ***Imposing Planetary Realities on our Search for Habitability***

The environments of early Earth are an inevitable constraint on the prebiotic chemistry that eventually led to life's emergence, and yet their specific role in the evolution of the prebiotic pathway is poorly understood. In an emerging NASA research program we postulate a new paradigm for the study of life's origins: Only through experimental and theoretical constructs that replicate dynamic early Earth environments can we understand the chemistry that arose during the Hadean; this chemistry is, necessarily, the prebiotic chemistry that laid the foundation for life's emergence. The Earth First Origins Project conceives of the earliest prebiotic chemistry within the context of the fundamental planetary processes that defined the Hadean. As such Hadean environments are instantiated in physical and virtual experimental facilities that enable the exploration of planetary processes and physicochemical conditions and facilitate the identification of the prebiotic pathway(s) that eventually led to life's emergence.

## RANCHOU PEYRUSE, Anthony

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### ----- Short bio -----

Anthony Ranchou-Peyruse (born in 1977) received his PhD in Microbiology from the University of Pau and Pays de l'Adour (UPPA). He joined the IPREM as Professor Assistant at the UPPA at the end of 2009 to develop subsurface microbiology. Prior to joining UPPA, Dr. Ranchou-Peyruse obtained two post-doctoral positions at the Georgia Institute of Technology (Atlanta) and at the University of Rouen. His research interests in microbiology of deep environments include: the isolation of new anaerobic microorganisms to understand the physiological and ecological factors controlling the microbial processes of these particular ecosystems, bioremediation of these environments when impacted by the human activity, the impact of these microorganisms populating these geological reservoirs on human activity (biocorrosion, integrity of the geological reservoir, acidification ...).



Because of the complexity of the ecosystems studied, he favors multidisciplinary approaches and works in close collaboration with molecular biologists, analytical chemists, geologists, imagists, fluid physicists, optics and processes. His field of activity and his thematic interests lead him to collaborate regularly with private partners exploiting the subsurface (Total, TIGF, Storengy).

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### Abstract

*Titre*

## ANDREANI, Muriel

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### Short bio

Full professor at the Université Claude Bernard, Lyon 1, she is working on the various aspects of fluid-rock interactions in the lithosphere (mechanisms, nature, and kinetic of reactions) and their rheological and geochemical implications. Using a structural, petro-geochemical and mineralogical analysis, she is more specialized in oceanic systems (ocean spreading ridges and faults) and CO<sub>2</sub>-water-rock reactions. She combines field work, on land or at sea during oceanographic cruises, with hydrothermal experiments in the lab.



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### Abstract

***Heterogeneity of fluid-rock reactions in CO<sub>2</sub>-enriched environments***