ITN Enigma

15 PhD positions in the EU Horizon 2020 Marie Skłodowska-Curie MSCA-ETN Project ENIGMA (EU Training Network for In situ imaGing of dynaMic processes in heterogeneous subsurfAce environments, Project GA 722028)

Applications are invited for 15 PhD positions ("Early Stage Researchers") to be funded by the Marie-Sklodowska-Curie Innovative Training Network (ITN) "ENIGMA - EU Training Network for In situ imaGing of dynaMic processes in heterogeneous subsurfAce environments" within the Horizon 2020 Programme of the European Commission. ENIGMA is a consortium of high profile universities, research institutions and companies located in France, Spain, Germany, Switzerland, Belgium, Denmark, Sweden, USA and UK.

Number of positions available: 15 PhD positions
Exceptional opportunities for promising young students on the following cutting edge topics.
Discussion possible at main scientific meetings (AGU, EGU)

Research Fields
Geophysics – Hydrology - Hydrogeology – Hydrogeophysics - Biogeochemistry and microbiology – Soil physics

Keywords
Dynamic processes imaging - Water resources – Hydrosystems - Subsurface coupled flow and transport modelling – Critical Zone – – Numerical Modelling – inverse problem – In Situ Imaging and Experiment – Heterogeneous Porous and Fractured Media

Career Stage
Early Stage Researcher (ESR): these are 3-year PhD position open for graduated students (Master or equivalent).

Scientific research topics:
There will be strong collaboration between the various ESR and the different partners of the ENIGMA network.

- Mixing and chemical reaction hotspots in saline-freshwater mixing zones
- Imaging flow dynamics and resulting reactivity in the transition zone between streams and riparian aquifers
- Closing the observational gap between the hyporheic and meander scale
- Flow and transport in fracture networks: reducing uncertainty of DFN models by conditioning to geology and geophysical data
- Monitoring spatio-temporal water redistribution in the subsurface with seismic methods
- Active DTS methods to quantify subsurface flow distribution and dynamics
- Multi-scale thermal imaging of groundwater upwelling in stream valleys
- Monitoring water storage changes with a new portable absolute quantum gravimeter
- Geophysical signatures of spreading and mixing
- High resolution imaging of transport processes with GPR full-waveform inversion
- Joint heat and solute tracer test inversion for imaging preferential pathways
- Spectral induced polarization monitoring for in-situ quantification of biochemical reactions
- Fully coupled hydrogeophysical inversion of 3D tracer tomography using temporal moments and Ensemble Kalman Filtering
- Geologically constrained joint inversion of hydraulic, tracer and ERT data for process visualization
- Integration of dynamical hydrogeophysical data in a multiple-point geostatistical framework

This project has received funding from European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement N°722028

See a description of the PhD opportunities at the end of the document

Public Abstract ENIGMA:

ENIGMA will **train a new generation of young researchers in the development of innovative methods for imaging process dynamics in subsurface hydrosystems**, in order to enhance understanding and predictive modelling capacities. The term imaging refers to the spatial representation of subsurface heterogeneity, fluxes, chemical reactions and microbial activity, through the integration of data and approaches from geophysics, hydrology, soil physics, and biochemistry. **The integration of six industrial partners** in the consortium (two as full partners and four as associated partners) as well as **a national geological survey and a water management agency** is an important asset to enhance intersectorial exchanges and ensure that new technological developments are transferred and validated by industrial and institutional actors. **The active participation of two high-profile US partners**, leading research in innovative environmental sensors and novel subsurface modelling techniques, will further strengthen the research and training activities of ENIGMA.

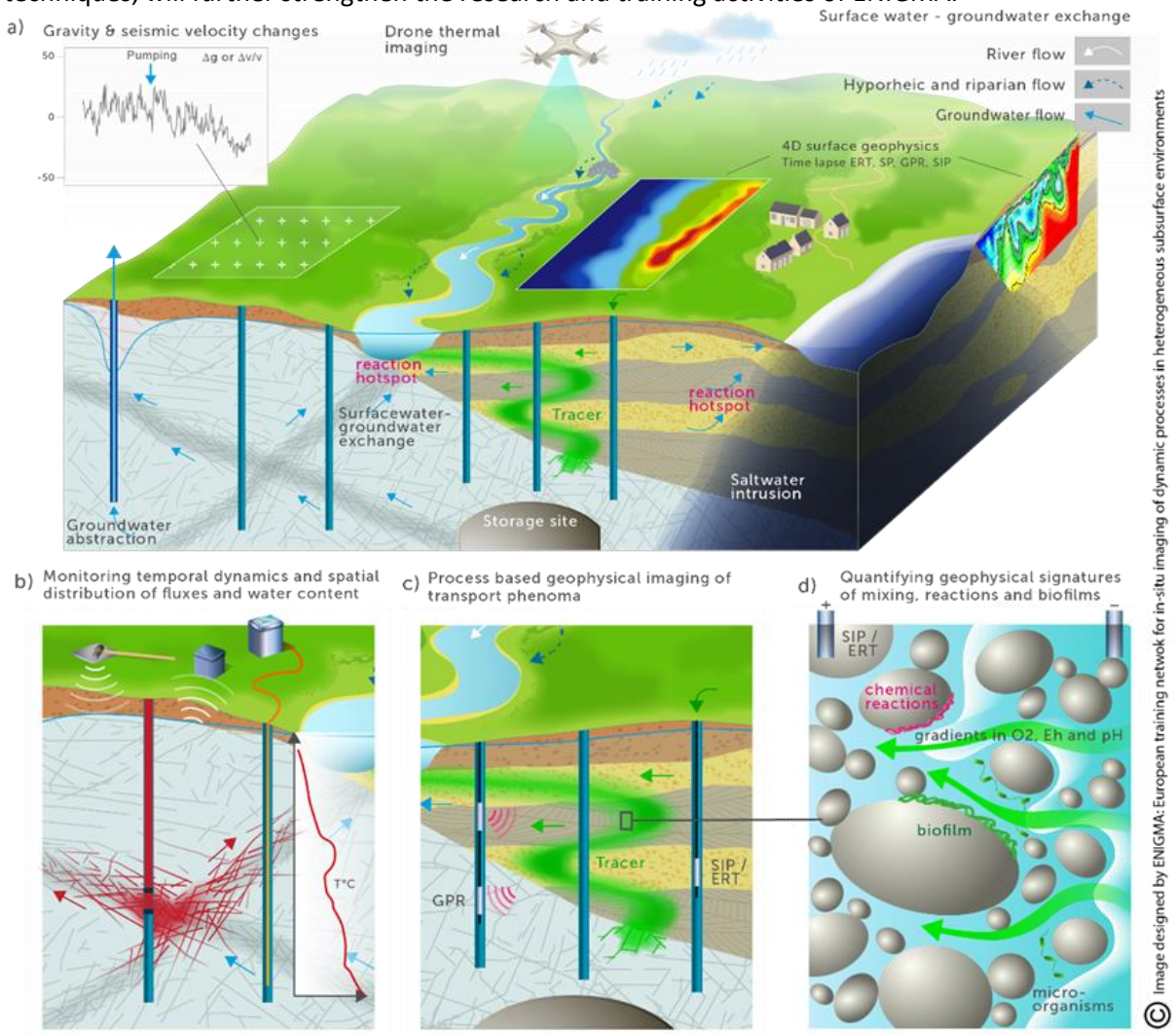

Figure 1: Illustration of the novel approaches developed in ENIGMA for imaging dynamic processes in the subsurface

This project has received funding from European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement N°722028

Benefits and salary

The successful candidates will receive an attractive salary in accordance with the MSCA regulations for early stage researchers. The exact salary will be confirmed upon appointment and is dependent on the country correction factor (to allow for the difference in cost of living in different EU Member States). The salary includes a living allowance, a mobility allowance and a family allowance (if married). The guaranteed PhD funding is for 36 months (i.e. EC funding, additional funding is possible, depending on local supervisor).

For instance, for the ESR in France the annual salary will be :

41 425,20€ + 7,200€ (for mobility allowance) + €6,000 (for family allowance, if eligible); this is before any applicable tax and/or deductions.

In addition to their individual scientific projects, all fellows will benefit from further continuing education, which includes internships and secondments in this high level network, a variety of training modules and courses as well as active participation in workshops and conferences.

On-line Recruitment Procedure

All applications proceed through the on-line recruitment portal on the ENIGMA website www.enigma-itn.eu. Candidates apply electronically for one to maximum three positions and indicate their preference. Candidates provide all requested information including a detailed CV. During the registration, applicants will need to prove that they are eligible, according to the ESR definition, mobility criteria, and English language proficiency (see below). The selection procedure will be distributed on 3 different sessions.

Deadlines for application will be: January 23rd 2016, March 25th 2017, June 25th 2017 to prepare discussion by the selection committee on respectively January 30th 2017, March 30th 2017, July 7th 2017.

The selected candidates will be interviewed by the supervisors. In order to facilitate their travel, selected candidates will have their travels funded to meet the supervisor (paid by the prioritized supervisor). The final decision on appointment will be made by the selection committee. The selected ESRs are to start their research as quickly as possible.

Applicants need to fully respect three eligibility criteria:

Early-stage researchers (ESR) are those who are, at the time of recruitment by the host, in the first four years (full-time equivalent) of their research career. This is measured from the date when they obtained the degree which formally entitles them to pursue a doctorate, either in the country in which the degree was obtained or in the country in which the research training is provided, irrespective of whether or not a doctorate was envisaged.

Conditions of international mobility of researchers: Researchers are required to undertake trans-national mobility (i.e. move from one country to another) when taking up the appointment. At the time of selection by the host organization, researchers must not have resided or carried out their main activity (work, studies, etc.) in the country of their host organization for more than 12 months in the 3 years immediately prior to their recruitment. Short stays, such as holidays, are not taken into account.

English language: Network fellows (ESRs) must demonstrate that their ability to understand and express themselves in both written and spoken English is sufficiently high for them to derive the full benefit from the network training.

This project has received funding from European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement N°722028

Description of the 15 PhD positions available:

Applicants can already contact the supervisors.

ESR1-PhD: **Mixing and chemical reaction hotspots in saline-freshwater mixing zones**
Objectives: Quantify the impact of flow heterogeneity and variable fluid density on the mixing efficiency of waters of different chemical composition or temperature, and the creation of reaction hotspots at the saltwater-freshwater interface
Expected Results: Mixing across the SW-FW (saltwater freshwater) interface has been the subject of long debate, as it affects karst development, exchange reactions (including mobilization of Radium, used for quantifying nutrients fluxes into the ocean), and biochemical processes. Our conjecture is that mixing is hindered by stable salinity but enhanced by sea level fluctuations, and seasonal variations of temperature and inland recharge. Monitoring these, coupled to field experiments and numerical modelling, should provide new insights into mixing and freshwater displacement in coastal aquifers and subsequent geochemical reactions. This ESR will collaborate with ESRs 9 and 12 on the development and use of novel techniques for the characterization of transport and flow heterogeneity as well as reaction monitoring, which will feed into new theoretical approaches for the identification of mixing and reaction hotspots. These approaches are based on (i) quantification of flow heterogeneity and fluid deformation, (ii) identification of flow strain and stress centers, which drive concentration gradients and mixing, (iii) the development of mixing and reaction diagnostics to explain and predict observed reaction patterns.

Supervisors: **CSIC Barcelona** / Co-Supervisors: CNRS Rennes, UNIL Lausanne, ACA Barcelona
Contact : Marco Dentz, marco.dentz(at)idaea.csic.es, Jesus Carrera. jesus.carrera(at)idaea.csic.es

ESR2-PhD: **Imaging flow dynamics and resulting reactivity in the transition zone between streams and riparian aquifers**

Objectives: Identify and characterize the space and time patterns of exchange between streams and their riparian zone and the resulting potential for solute turnover by jointly using novel and advanced tracing, imaging, and modelling techniques
Expected Results: This ESR project aims at understanding the links between physical controls (e.g. stream stage, subsurface hydraulic conductivity and heterogeneity) and biogeochemical process patterns (space and time patterns of reactivity) in riparian aquifers. At the River Selke TERENO field site, the natural EC contrasts between stream water and groundwater can be used to trace stream water intrusion into the riparian aquifer. Temporal dynamics of stream-groundwater exchange will be derived by analysis of time series of conservative solutes like EC measured in the stream and piezometers in the riparian aquifer. In close conjunction, spatial infiltration into the riparian aquifer will be imaged using ERT surveys that are optimized for the detection of natural EC contrasts. Using the identified patterns of water and solute fluxes and additional measurements of O2, NO3 in the stream and piezometers with varying distance to the stream will enable a mapping of the turnover capacity for reactive solutes in the riparian aquifer. A synthesis of the observations will be achieved using a reactive transport model to replicate flow and reactivity patterns. The systematic joint evaluation of temporal dynamics and spatial patterns of flow and reactivity with state of the art imaging and sensing methods and models is a novel approach to investigate reactive potential of riparian aquifers. Collaborations on geophysical and thermal imaging techniques are planned with ESRs 6, 7, 12, 13.
Supervisors: **UFZ Leipzig** / Co-Supervisors: UCPH Copenhagen, UNINE Neuchâtel
Contact : Jan Fleckenstein jan.fleckenstein(at)ufz.de

This project has received funding from European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement N°722028

ESR3-PhD: **Closing the observational gap between the hyporheic and meander scale**

Objectives: (1) Expand existing tracer methods with Argon 37 to cover characteristic times relevant to the hyporheic and meander scale, (2) Integrate these data into high resolution simulations to characterize exchange processes across scales

Expected Results: The ESR project aims at providing and integrating field and modelling approaches to overcome the conceptual and observational gaps between hyporheic exchange across different spatial and temporal scales. This is indispensable for understanding and quantifying biogeochemical turnover. While current tracer methods provide information on short time scales (1-10 days, Radon) or large time scales (>100 days tritium/helium) observational gaps for the feedback mechanisms between the different scales exist. The natural tracer Argon 37 (used to detect underground nuclear bomb tests) closes this gap but has so far never been employed in this context. Numerical models will allow quantifying exchange fluxes and processes across the different spatial and temporal scales. These models will be based on a high-resolution characterization of the streambed and will integrate tracer data (222Rn, 37Ar, 3H/3He) covering all the relevant time scales through stochastic inversion. The Emme site will be used to develop these approaches.

Supervisors: **UNINE Neuchâtel** / Co-Supervisors: UFZ Leipzig, GEOTH Heiligenstadt

Contact : Philip Brunner philip.brunner(at)unine.ch

ESR4-PhD: **Flow and transport in fracture networks: reducing uncertainty of DFN models by conditioning to geology and geophysical data**

Objectives: Develop and test a general framework to condition discrete fracture network (DFN) models to geological mapping and geophysical data in order to reduce the uncertainty of fractured rock properties and flow patterns.

Expected Results: Predicting geological and hydrological structures and their impact on flow and mechanical processes is a major challenge for a large number of hydrological and geotechnical applications in fractured hard rock systems. This is mostly achieved by deriving DFN models from field and core mapping, and pumping tests. Conditioning the DFN models with geophysical imaging techniques is still largely unexplored although very promising to overcome the lack of actual 3D fracture data. The ESR aims at developing a methodology for geophysical conditioning of DFN models, by profiting from the complementary expertise of the Rennes group in DFN modelling, and of the Lausanne group in GPR imaging in hard rock environments. The DFN conditioning method will be applied to field-scale tracer experiments conducted at the Äspö Hard Rock Laboratory. The ESR will benefit from the important fracture database that has been acquired for twenty years at Äspö by SKB. Flow measurements with fibre-optic DTS in collaboration with ESR 6 will be used to validate hydrological prediction of the newly developed DFN. Data produced in this project on fracture, flow, transport and geophysics will constitute a unique dataset, made available to the community to understand flow and transport patterns in fractured media. The methodology will offer a new approach for SKB to assess confinement properties of the bedrock barrier around canisters for nuclear waste disposal.

Supervisors: ITASCA / Co-Supervisors : CNRS Rennes, UNIL Lausanne, SKB Sweden

Contact: Caroline Darcel c.darcel(at)itasca.fr, Philippe Davy, philippe.davy(at)univ-rennes1.fr

ESR5-PhD: **Monitoring spatio-temporal water redistribution in the subsurface with seismic methods**

Objectives: Estimate water content in the vadose zone/aquifer continuum and its evolution over time from active and passive seismic wave methods. Assess the coeval changes of water content and estimated velocity information from seismic records. Evaluate the sensitivities of these proxies to hydrodynamic parameters

Expected Results: The seismic signal is related to mechanical properties that partly depend on porosity and saturation. The behaviour of shear (S) and pressure (P) waves in the presence of water is partially decoupled, such that the ratio of their propagation velocities Vp/Vs is strongly linked to water saturation. Both Vp and Vs can be recovered by analysing both first arrival and surface waves, hence allowing for estimation of water content variability over decametric spatial scales. Seismic noise interferometry has recently emerged as a promising tool to monitor Vs continuously. We will monitor the subsurface with 3D continuous seismic noise interferometry from a dense network that is referenced to time-lapse active methods and soil moisture observations. Controlled experiments will be carried out (infiltration test, pumping test) to focus on infiltration processes and to enable quantitative comparisons with GPR. Developments will be carried out on Ploemeur site and further applied on Krauthausen and LSBB sites. The full wealth of seismic signals is still underexploited,

This project has received funding from European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement N°722028

particularly the temporal evolution of dispersion and attenuation related to wave-induced fluid flow. The experimental approach is here an opportunity to prepare adequate field data to tackle these challenging questions in further work. Finally, we will evaluate the potential of iDAS (Distributed Acoustic Sensing) for continuous monitoring of subsurface water content over long distances.
Supervisors: **CNRS Rennes**/ Co-Supervisors: UNIL Lausanne, SKB Sweden
Contact : Laurent Longuevergne, laurent.longuevergne(at)univ-rennes1.fr and Ludovic Bodet, ludovic.bodet(at)univ-rennes1.fr

ESR6-PhD: **Active Fiber-Optic DTS methods to monitor subsurface flow dynamics**
Objectives: Combining active and passive DTS methods for quantifying flow distribution in i) borehole applications under periodic and interference hydraulic tests and ii) in-situ buried cable in heterogeneous sandy aquifers, saline wedges and hyporheic zones.
Expected Results: Fiber Optic Distributed Temperature Sensing (FO-DTS) is an innovative tool that allows continuous temperature monitoring with an excellent spatial resolution. Recent applications demonstrate the utility of passive FO-DTS for characterizing flows and monitoring thermal tracer tests in heterogeneous media. Passive methods are however often limited to qualitative information about flow distribution. Active methods, which consists in using heated cables or local thermal sources showed very promising results to quantify distributed flow velocities. The first objective of the ESR will be to adapt these recent developments in various hydraulic conditions (cross-borehole interference tests, periodic hydraulic tests and ambient conditions) to develop an innovative hydraulic tomography approach in fractured media (Ploemeur and Äspö sites) based on distributed data on flows and temperature changes. The second objective of the ESR will be to develop similar active DTS methods in buried cables within saturated porous media in order to quantify in-situ fluxes within sandy aquifers (Hermalle site), saline wedges (Argentona site) and/or within the hyporheic zones (River Selke site). The obtained data and the results of inversion will be compared and combined with data and/or inversion scheme developed by ESR 2, 3, 4, 7, 11 and 14
Supervisors: **CNRS Rennes**/ Co-Supervisors: CSIC Barcelona, OSU Oregon, SILIXA
Contact: Olivier Bour olivier.bour(at)univ-rennes1.fr

ESR7-PhD: **Multi-scale thermal imaging of groundwater upwelling in stream valleys**
Objectives: Quantifying spatial and temporal variable groundwater upwelling in stream valleys by multi-scale thermal imaging
Expected Results: The ability of stream networks to drain landscapes depends on hydrologic connectivity across spatial scales from streams, riparian zones to the regional catchment. In combination with temporal changes (seasonal rainfall, temperature) this leads to spatial and temporal heterogeneity in groundwater upwelling in stream valleys through stream beds, riparian zones, and near hill slopes. The challenge is to develop a multi-scale thermal imagery method, where airborne and ground-based methods can quantify where, when, and how much groundwater escapes to stream valleys with special attention to how temperature-controlled changes in hydraulic parameters affect water storage/wetness/flooding/upwelling and direct seepage to streams. The ESR student will; (1) exploit current state-of-the art thermal imaging technologies and statistical methods/metrics for analysis of temperature signals to assess the use of temperature as a tracer for regional studies of groundwater upwelling and (2) integrate data in catchment-scale 3D heat-flow models to understand landscape and climate effects on spatio-temporal thermal and flow heterogeneity. HOBE observatory catchment will be used and the imaging and modelling techniques will be tested at TERENO river Selke and Emme sites. The innovative aspect is to investigate if thermal imaging is a feasible method for mapping upwelling at the scale of stream networks and linking these to temporal changes in hydraulic parameters, possible hot-spots of reactivity (ESR2) and water storage change observations from absolute quantum gravimeters (ESR8).
Supervisors: **UCPH Copenhagen**/ UNINE Neuchâtel, UFZ Leipzig
Contact : Peter Engesgaard pe(at)ign.ku.dk

This project has received funding from European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement N°722028

ESR8-PhD: **Monitoring water storage changes with a new portable absolute quantum gravimeter**

Objectives: Field assessment of absolute gravity surveys to quantify water storage in both saturated and unsaturated zone

Expected Results: Gravity measurements are pertinent to monitor water balance from local to basin scale. This technique can provide an estimation of the water storage spatial variability at kilometer scale with an integration scale of about 100 m. µQuans is developing a new absolute quantum gravimeter (AQG), fast and transportable (sensor ~30 kg). The AQG is a real technological breakthrough compared to current portable gravimeters, which provide relative measurements. It will allow a more efficient and precise mapping of gravity in space and time. The ESR student will perform the field validation of the first AQG against the most accurate gravimeters located at fixed stations (superconducting gravimeters available at H+ Larzac and LSBB sites). AQG will be used in to estimate the contribution of different water storage reservoirs (saturated vs unsaturated) in complement to vertically resolved complementary measurements (ERT, RMP, borehole logging). Coupled soil moisture and gravity measurements are planned at the HOBE observatory (ESR 7) as both techniques complementary for water mass balance.

Supervisors: **µQuanS** / Co-Supervisors : UM Montpellier, UCPH Copenhagen

Contact : Bruno Desruelle bruno.desruelle(at)microquans.com and Cédric Champollion cedric.champollion(at)umontpellier.fr

ESR9-PhD: **Geophysical signatures of spreading and mixing**

Objectives: Upscale transport processes to scales resolved by geophysics and test spreading and mixing theories

Expected Results: Geophysical time-lapse inversions provide upscaled estimates of temporal changes in bulk properties that may provide constraints on dispersion (spreading), but they have never been used to-date to infer statistics of mixing, which controls (fast) chemical reactions. We suggest that simultaneous acquisition of geophysical data and concentration fields by means of millifluidic experiments will enable novel and fundamental insights that will ultimately influence hydrogeophysical research at the field scale. Millifluidic experiments in artificial media of varying complexity (developed by ESR 12) will provide high-resolution images of the concentration field during tracer experiments. Simultaneous acquisitions of geophysical data (representing effective upscaled properties at the scale of the sample) in the form of electrical resistance and self-potential (i.e., the electro-diffusive contribution) will be influenced by pore scale and meso scale heterogeneities of the salinity and liquid phase. These combined data sets will be used to develop new theory and experimentally demonstrate how spreading and mixing of solutes in heterogeneous porous media, manifest themselves in geophysical data. These findings can then be used to make inferences about the statistics (not the actual salinity distribution) of spreading and mixing in porous media.

Supervisors: **UNIL Lausanne** / Co-Supervisors: CNRS Rennes, CSIC Barcelona.

Contact : Niklas Linde Niklas.Linde(at)unil.ch

ESR10-PhD: **High resolution imaging of transport processes with GPR full-waveform inversion**

Objectives: Develop GPR full-waveform inversion to image tracer front distributions using time-lapse measurements

Expected Results: Compared to conventional ray-based approaches, GPR full-waveform inversion can return unprecedented high resolution images of the subsurface. The resulting porosity estimates have been shown to agree well with independent estimates from Neutron-Neutron logging data and cone penetration tests data. GPR full-waveform approaches have a huge potential for improving image resolution for time-lapse measurements and measurements in fractured aquifers. Dedicated full-waveform inversion approaches will therefore be developed for i) time-lapse crosshole measurements to image transport processes (gradients of local concentrations) in synthetic and field tracer tests (Krauthausen site) and ii) time-lapse single-hole and cross-hole measurements in fractured aquifers where the full-waveform phase and amplitude changes will be explored to estimate fracture thickness and filling material (Ploemeur site). For both sites, the obtained inversion results will be compared and combined with data obtained by ESR 4,5, 6, 11, 12, 13, 15.

Supervisors: **FZ Jülich** / Co-Supervisors: CNRS Rennes, UNIL Lausanne

Contact : Jan van der Kruk j.van.der.kruk(at)fz-juelich.de

This project has received funding from European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement N°722028

ESR11-PhD: **Joint heat and solute tracer test inversion for imaging preferential pathways**

Objectives: 1) Characterize preferential pathways in porous and fractured aquifers at multiple-scales through combined heat and solute tracer tests 2) Assess the impact of preferential pathways and associated uncertainty in model predictions

Expected Results: The characterization of subsurface heat and solute transport is particularly challenging due to the existence of preferential transport paths at multiple scales. The ESR project aims at characterizing the role of preferential pathways (channeling) on transport based on dual-domain modelling approaches. The main innovation is to combine solute and heat tracer tests which have different sensitivities to preferential pathways and matrix diffusion processes. Field experiments will combine multiple wells injection and pumping experiments using solute and heat tracers complemented by DTS and geophysical imaging (GPR and ERT/SIP). Experimental campaigns on two different test sites (alluvial sediments in Hermalle hydrogeophysical site and fractured bedrock overlaid by weathered rocks in India (H+ Hyderabad site)) will be used to assess the added value of the proposed experiments to identify preferential flow paths and their influence on model predictions. Interactions with other ESRs include fibre optic monitoring of temperature and flow (ESR6), model comparison for spreading and mixing (ESR9), GPR (ESR10) and SIP (ESR12).

Supervisors: **ULG Liège** / Co-Supervisors: BRGM Orléans, FZ Jülich

Contact : Alain Dassargues, A.Dassargues(at)ulg.ac.be

ESR12-PhD: **Spectral induced polarization monitoring for in-situ quantification of biochemical reactions**

Objectives: Establishment of quantitative relationships between subsurface biochemical reactions and Spectral Induced Polarization (SIP) signals using laboratory millifluidic imaging and subsequent validation using field measurements.

Expected Results: Recent findings suggest that geophysical methods may provide new opportunities for mapping the subsurface spatial distribution of biochemical reaction rates and biofilm development, although it is still difficult to distinguish between the multiple origins of the measured signals. In a first step, this project aims at disentangling the multiple origins of the SIP signal using a novel experimental approach that combines SIP measurements with well-controlled millifluidic experiments where 2D concentration fields and biofilm distribution can be simultaneously and independently monitored using fluorescence imaging techniques. Experiments will be performed using classical laboratory bacterial strains as well as micro-organisms sampled from the Ploemeur site in direct collaboration with microbiologists of the Rennes ecology department. In a second step, a novel borehole SIP imaging approach will be used to quantify biofilm distribution and development at the Ploemeur site. In collaboration with ESR 5 and 9, these field investigations will provide insights into the interaction between flow distribution, chemical gradients, and biofilm distribution. This is of pivotal importance to understand how biofilms can positively (e.g. bioremediation) or negatively (e.g. bioclogging) affect water quality.

Supervisors: **FZ Jülich**/ Co-Supervisors: CNRS Rennes

Contact : Sander Huisman. s.huisman(at)fz-juelich.de

This project has received funding from European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement N°722028

ESR13-PhD: **Fully coupled hydrogeophysical inversion of 3D tracer tomography using temporal moments and Ensemble Kalman Filtering**
Objectives: Development of fully coupled 3D inversion for in-situ monitoring of salt-tracer tests with ERT and cross-hole GPR
Expected Results: 3-D time-lapse ERT will be used for monitoring of salt tracer experiments and will be combined with GPR imaging of salt-tracer tests (secondment to ULG - University of Liège), transient hydraulic tomography, heat tracer testing (also using natural sources as input signal). Other geophysical surveys may be used to obtain structural information. Fully coupled inversion methods of the hydraulic-geoelectrical system will be developed. The innovation of the ESR project lies in the development of fully coupled 3D-inversion methods for the joint analysis of field-scale tomographic data sets from multiple investigation techniques. In this context, Ensemble-Kalman methods will be adapted as inversion techniques. Field testing requires the extension of experimental concepts for tomographic salt-tracer testing with ERT and GPR monitoring and will be validated at the Lauswiesen site of the University of Tübingen and then applied at other ENIGMA sites (Krauthausen, Hermalle, Selke).
Supervisors: **UT Tübingen** / Co-Supervisors: ULG Liège
Contact : Olaf A. Cirpka olaf.cirpka(at)uni-tuebingen.de

ESR14-PhD: **Geologically constrained joint inversion of hydraulic, tracer and ERT data for process visualization**
Objectives: (1) Develop effective and efficient methods for the inversion of flow, heat transport, electrical conduction and conservative and reactive solute transport, and (2) Apply these methods to ENIGMA sites
Expected Results: Effective integration of geological understanding into model inversion remains the single most challenging hurdle for reliable groundwater inversion. Thus, the novelty of the procedure lies in including sequential stratigraphy concepts (well known for the Argentona site, where hydraulic tests coupled to heat and conservative and reactive tracer tests will be conducted simultaneously with ERT campaigns). Inversion will be based on optimizing model fit to hard data on state variables (T, h, C, V), of fields conditioned to categorical data (textural information from boreholes) and sequential stratigraphy concepts on continuity and orientation of layers. This will allow testing the validity of geological assumptions. The inversion should provide a detailed visualization of the actual processes occurring in the field, which would allow us to gain understanding on these processes. Specifically, it should allow us to understand Radium mobilization in the freshwater-saltwater mixing zone. The methodology of joint inversion will be developed in collaboration with ESRs 13 and 15.
Supervisors: **CSIC Barcelona** / Co-Supervisors: UCPH Copenhagen, ACA Barcelona
Contact : Jesus Carrera. jesus.carrera(at)idaea.csic.es

ESR15-PhD: **Integration of dynamical hydrogeophysical data in a multiple-point geostatistical framework**
Objectives: 1) Develop a new framework to integrate dynamical hydrogeophysical data sets in multiple-point geostatistical framework 2) Consider prior scenarios validation/falsification using geophysical monitoring data of transport processes.
Expected Results: 4D spatially distributed geophysical data sets, at an hourly or daily temporal resolution, gives new insights on transport processes and hydrogeological parameters distribution in the subsurface. The novelty of this project lies in their integration into inverse modelling techniques, historically developed to deal with sparse well dynamical data (breakthrough curves) or few temporal geophysical data. Furthermore, we will consider, prior to inversion, the validation/falsification of several plausible geological scenarios obtained from aquifer analogs using dynamic hydrogeophysical data. 4D ERT and SIP data contains information on transport processes and preferential flow paths that can help discriminate between various scenarios better than static images. A combination of 3D image analysis on geophysical data, temporal information and multidimensional scaling approach will be integrated in a multi-point geostatistical framework to compare outcomes from proposed scenarios with the observed data to update their conditional probability. The methodology will be developed in collaboration with ESRs 13 and 14. New datasets from technologies developed by ESR6 (DTS) and ESR10 (GPR) will be integrated.
Supervisors: **ULG Liège** / Co-Supervisors: CSIC Barcelona, AQUA Montpellier
Contact: Frédéric Nguyen F.Nguyen(at)ulg.ac.be

This project has received funding from European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement N°722028

This project has received funding from European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement N°722028

Beneficiaries: CNRS Research Centre Rennes, CSIC Research Centre Barcelona, Helmholtz Centre Jülich, Helmholtz Centre for Environmental Research, University of Liège, University of Tübingen, University of Copenhagen, University of Lausanne, University of Neuchâtel, µQuanS, ITASCA Consultants s.a.s.,

Partner Organisations: Stanford University, Oregon State University, University of Montpellier, Bureau des Recherches Géologiques et Minières (BRGM), SILIXA, SKB, Geotechnik Heiligenstadt, Aquale, Agencia Catalana de l'Aigua

General contact for ENIGMA

Enigma.itn(at)gmail.com
enigma-itn_recruitment(at)groupes.renater.fr
enigma-itn_supervisory(at)groupes.renater.fr

This project has received funding from European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement N°722028