CSD ANNUAL REPORT

CENTER FOR MODELING OF
COUPLED SUBSURFACE DYNAMICS

UNIVERSITY OF BERGEN
Center for Modeling of Coupled Subsurface Dynamics

Contents

DIRECTOR'S COMMENTS

In its second year of operation, activities in CSD are flourishing. By the end of 2022, 34 people were formally associated with CSD this year. Importantly, we have recruited five new PhD students and one postdoc. With these new members of our team, we have reached 18 early career researchers affiliated with our researcher training program. We can also welcome Jakub Both as a new PI in the center. He leads the externally funded project "Gradient flow modelling of multi-phase flow in deformable porous media", which is an international research mobility project with collaborators from French research institutions.

This year, we have continued our weekly seminars, which are important for both internal communication and network building. PhDs and postdocs have presented ongoing work and we have also had several international guests. Our annual meeting at Solstrand was held in March and gave us a great opportunity to discuss center research activity and interact across the different projects. In September, we set aside a day for our early career researchers to discuss different aspects of career development. Central to the day was interactive work with self-assessment as well as steps to develop a career development plan.

A highlight this year has been the porous media exhibition at the Bergen University Museum to which CSD members Jan M. Nordbotten and Martin Fernø have made central contributions. A core theme of the exhibition is CO2 storage in porous formations. Through video, interviews, text and images, it shows how different disciplines contribute to the successful implementation of subsurface CO_2 storage.

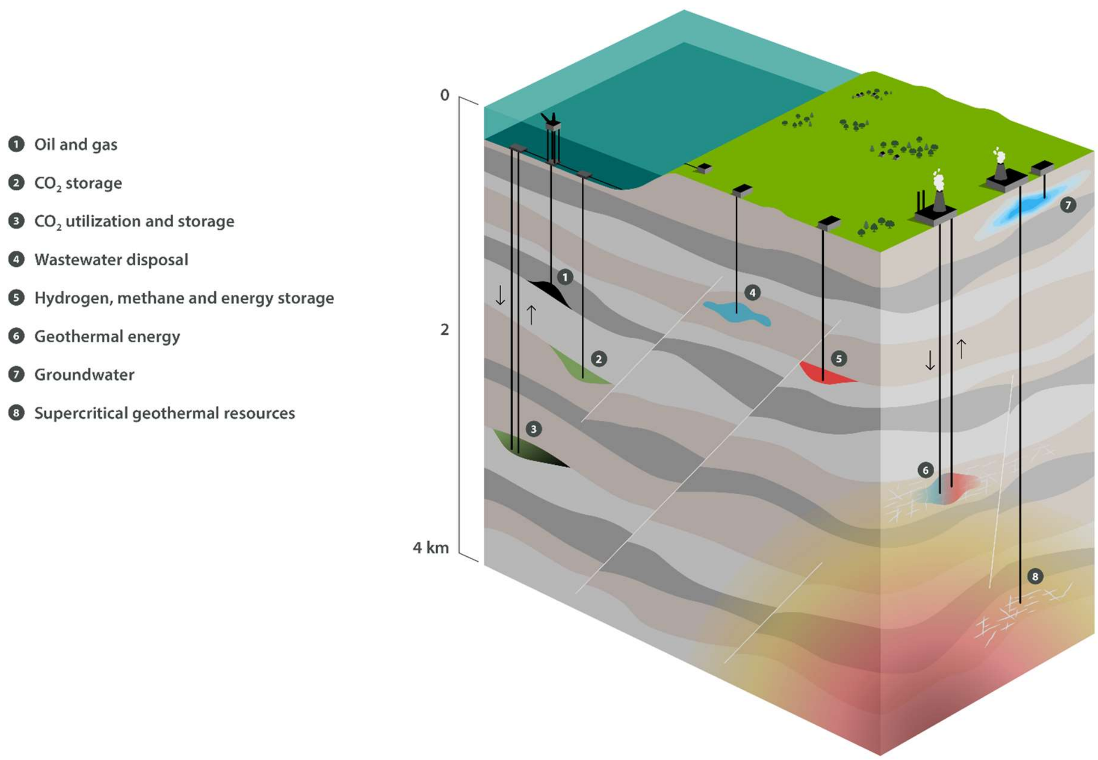
The activity in CSD is made possible by a fantastic team, and I would like to thank all CSD members for their contributions to the CSD activities this year.

Inga Berre
Center Director

ABOUT THE CENTER

In recent years, the surface manifestations of human fluid injection and production have become increasingly apparent. Production of hydrocarbons and geothermal energy, extraction of groundwater, subsurface energy storage, CO_2 sequestration and wastewater disposal all involve massive subsurface extraction and/or injection of fluids. The Center for Modeling of Coupled Subsurface Dynamics (CSD) develops basic knowledge on how the subsurface deforms because of fluid injection and production.

CSD's primary objective is to develop fundamental knowledge and educate next generation researchers to understand how subsurface fluid injection and extraction results in deformation, fault reactivation and fracturing. The center targets critical and fundamental research questions through mathematical and numerical modeling and data analysis.



Injection and production of fluid in the subsurface.

VISTA PROJECTS

Mathematical framework for handling complex geometries (P1.1)

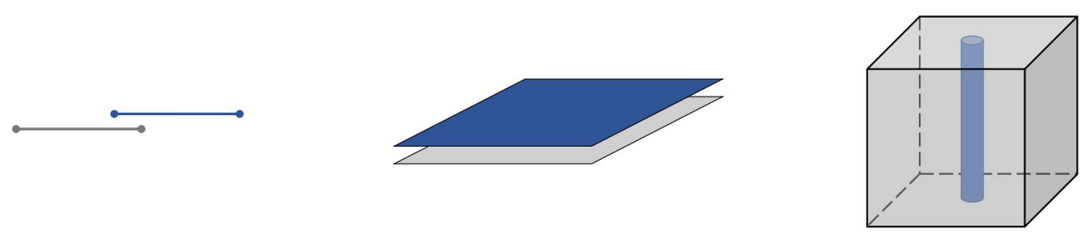
Duration	2021-2025
PI	Jan Martin Nordbotten
Team	Daniel Førland Holmen, Jon Eivind Vatne, Einar Iversen

The goal of this project is to further close the gap between theoretical developments and efficient computational tools in the context of quasi-2D structures complex fault and fracture networks and quasi-1D structures such as wells.

In 2022 we had significant progress towards the project goal. Notably, we developed an internal "road-map" document (Nordbotten, Keilegavlen, Stefansson (2022), Representing fractures, wells and their intersections, CSD internal technical note) for coupling of 3D porous media with both 2D and 1D structures (separately and in intersection) meant to guide both the theoretical and computational developments within the CSD. This technical note was presented to the CSD board and constitutes the fulfillment of a key Milestone from the CSD research plan.

This project has pursued the theoretical part of the roadmap. In particular, Daniel Førland Holmen was recruited for a PhD position in the project, with a background in algebraic geometry. He spent a research visit with Dr. Wietse Boon at Politechnico Milano, and together we developed a general theory for geometrically overlapping models. While the theory is quite general, we elaborate two examples of particular relevance for the CSD: The structure of dual-permeability models (as often used to model flow in fine-scale fractured rocks), and precisely the inclusion of wells as quasi-1D objects in a porous domain.

Also in collaboration with Dr. Boon, we published in 2022 a major theoretical work, providing a fully consistent mixed-dimensional model for large deformation poromechanics, including contact mechanics and friction (Boon and Nordbotten, 2022). In this work we also develop a well-posedness results based on arguments from the theory on evolutionary equations with maximal monotone operators. This year also saw the completion and publication of our first a posteriori error analysis for such problems.



Conceptualization of some of the overlapping geometries permitted within the context analyzed in this project (figure from Boon et al., 2022).

Publications

Boon, W. M. & Nordbotten, J. M. (2022), Mixed-dimensional poromechanical models of fractured porous media, Acta Mechanica. https://doi.org/10.1007/s00707-022-03378-1

Varela, J., Ahmed, E., Keilegavlen, E., Nordbotten, J. M., & Radu, F. A. (2022), A posteriori error estimates for hierarchical mixed-dimensional elliptic equations, Journal of Numerical Mathematics. https://doi.org/10.1515/jnma-2022-0038

Simulation tool for fully dynamic Biot equations (P1.2)

Duration	2022-2026
PI	Florin Adrian Radu
Team	Kundan Kumar, Morten Jakobsen

Development of efficient solvers for flow in deformable porous media, described by the linear, quasi-static Biot model has received huge attention in the last decade. To include seismicity, the fully dynamic, non-linear Biot-Allard model must be considered, i.e., the acceleration of the porous medium and the process history have to be included. In this activity, higher-order space-time finite element, splitting solvers, which are energy preserving (a very important feature for waves), will be designed, implemented and analyzed based on our previous work [30]– [35]. The resulting model will be tested and calibrated based on geophysical methods.

We continued to study the convergence of higher order Galerkin schemes (space-time elements) for a linear version of the dynamic Biot model. When the PhD student associated to this project will be employed, we will continue with the implementation and analysis of a more general dynamic Biot model.

End of November 2022, F.A. Radu and E. Storvik gave a compact course on ‘Efficient solvers for linear or nonlinear coupled problems’ at the Federal Army University of Hamburg, Germany.

Publications

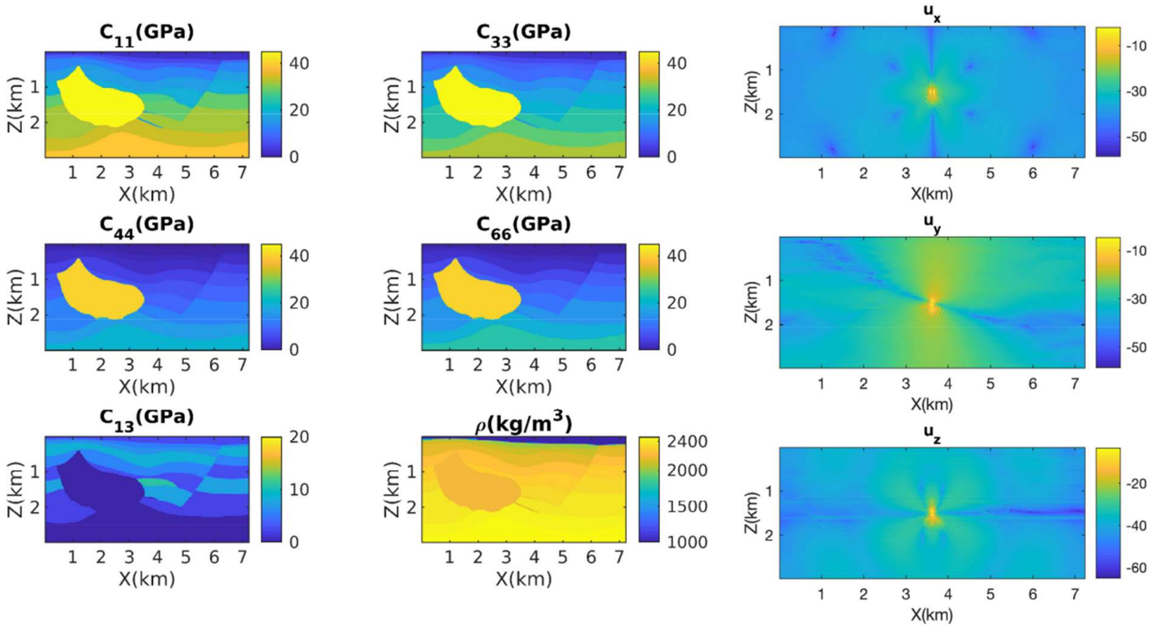
Illiano, D., Both, J.W., Pop, I.S., Radu, F.A. (2022), Efficient solvers for non-standard models for flow and transport in unsaturated media, ROMAI Journal, 18 (1), pp. 31-73.

Storvik, E., Both, J. W., Nordbotten, J. M., & Radu, F. A. (2022). Cahn–Hilliard–Biot system and its generalized gradient flow structure. Applied Mathematics Letters, 126, 107799.

Microseismic imaging using rock physics-based full-waveform inversion (P1.3)

Duration	2021-2025
PI	Morten Jakobsen
Team	Ujjwal Shekhar, Morten Jakobsen, Einar Iversen, Inga Berre, Florin A. Radu

Microseismic imaging includes localization of microseismic events and characterization of their source mechanisms as well as determination of the (anisotropic-elastic) background model. This is a highly ill-posed inverse problem. However, the degree of ill-posedness can potentially be reduced if one makes use of all the information contained in the full waveforms and employs rock physics models in this context. Synergies between active and passive seismic methods can also be useful here. However, seismic and microseismic full-waveform inversion in general anisotropic elastic media is computationally expensive and memory demanding. During 2022, we have therefore developed a fast and accurate integral equation (IE) method that can be used to compute microseismic waveform data in general (fractured) anisotropic elastic media as functions of the parameters of the source; including the source location, the ignition time and the moment tensor. This IE method is based on a FFT-accelerated Krylov subspace method for solving the large-scale linear system that results after discretization. We have verified that our (frequency domain) IE method is consistent with the finite difference time domain (FDTD) method and is suitable for large-scale 3D modelling in fractured porous media and related anisotropic elastic media. We think our new IE method can be attractive as the forward model in future systems for microseismic imaging in complex rock formations. Also, we have started to develop methodology for simultaneous estimation of microseismic source parameters and the background velocity model using a Gauss-Newton consistent scattering approach. Having submitted a paper about the fast IE method for microseismic waveform modelling in December 2022, we now plan to focus more exclusively on microseismic imaging problems.



Left: The Hess model – a strongly scattering VTI medium. Right: Displacement field due to an explosive moment tensor source at 10 Hz for the Hess model.

Solvers for mixed dimensional flow and mechanics on the fractured-matrix interface (P2.1)

Duration	2021-2025
PI	Kundan Kumar
Team	Inga Berre, Ivar Stefansson, Nadia S. Taki, Jan M. Nordbotten

Description: The goal is to develop mathematical model and solution approaches to rupture dynamics including advanced friction laws in the presence of fluids. The project will consider the evolution of spontaneous ruptures embedded in an elastic deforming body, governed by contact mechanics (rate-and-state friction laws). The particularity in the description is accounting for the fluid flow. The resulting model is based on coupled differential equations of different dimensions: Biot- Allard in the matrix coupled to flow (on 3D) on the fracture surface as well as friction laws on the fracture interfaces (2D surface embedded in 3D domain). We will propose a novel scheme that exploits the different time scales for the rate- and state-dependent friction laws, the mechanics and the flow. Numerical schemes based on splitting of multiphysics will be developed and analyzed to ensure convergent and efficient solution schemes.

Activities 2022: The project consists of several multi-physics effects coupled together, we considered the following sub-problems to understand the complexity and interaction of the fewer effects. Linear elasticity including normal forces and friction and rate and state friction model – without considering the flow has been discussed in [Taki]. Multi-rate scheme (different time stepping schemes for the different physical effects) for coupled mechanics and flow – without considering the friction and contact forces has been discussed in [Almani].

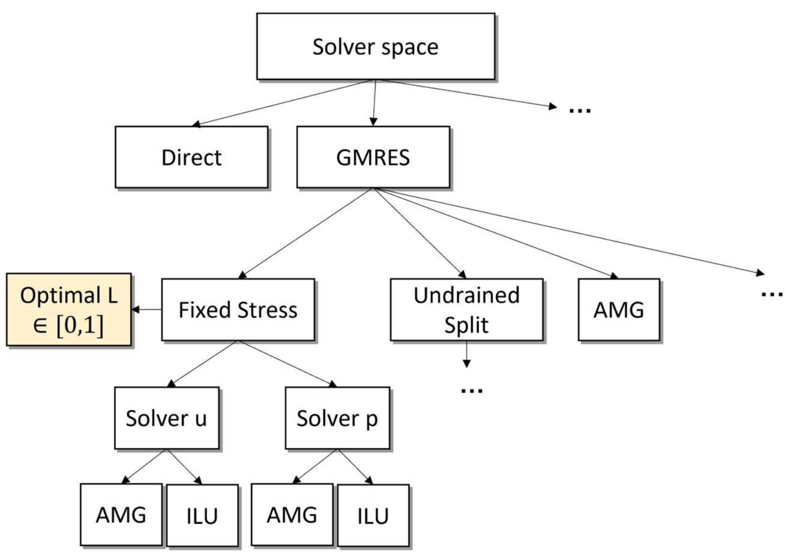
Simulation technology for injection-related fault and fracture reactivation and induced seismicity (P2.2)

Duration	2021-2025
PI	Eirik Keilegavlen
Team	Inga Berre, Einar Iversen, Volker Oye, Ivar Stefansson, Yuri Zabegaev

The project aims to develop simulation technology for injection-induced fault reactivation, accounting for interaction between rock and fluid mechanics. The approach is based on the open-source simulation tool PorePy, which is built on explicit representation of faults, and includes thermo-hydro-mechanical effects. The main research tasks are to adapt the framework to account for advanced fracture behavior including permeability increases and friction laws, and to adapt discretizations and linear and non-linear solvers to facilitate efficient simulations.

Work on the solvers commenced with the recruitment of Yuri Zabegaev to a PhD position in mid-August. The goal is to automatize selection and tuning of linear solvers for multiphysics problems, and thereby relieve users of simulation software of a task which is of paramount importance for computational efficiency, but which also can be tedious and challenging. The approach taken is to consider the solver selection as an optimization problem which can be treated with machine learning techniques. Initial experiments on poromechanical models indicate that the methodology can automatically derive at solvers that are comparable to tailored solvers.

There has also been much activity on improving the simulation software PorePy. This includes improved discretization methods for fluid flow in media with changing permeability, as is relevant for fault deformation as well as reactive flow, and an expansion of PorePy's ability to represent advanced constitutive laws. These activities are expected to be beneficial for future activities within subproject as well as in the wider CSD center.



Decision tree for constructing linear solvers in a poromechanical simulation.

Exploring the subsurface using a generalization of Dix' classic time-to-depth mapping method (P2.3)

Duration	2021-2025
PI	Einar Iversen
Team	Morten Jakobsen, Inga Berre, Jokhongir Khayrullaev

The goal of the project is to develop methodology and software for exploring the subsurface, based on a generalization of Dix' classic time-to-depth mapping method. Whereas the classic approach assumes a one-dimensional subsurface, the generalized Dix method is applicable to variations of velocity in three dimensions. The subsurface structures are assumed to yield weak lateral velocity variations and weak effective anisotropy. Recruitment was a main activity in 2022. On 12 September Jokhongir Khayrullaev started on a three-year PhD position related to this project. By December 2022 Khayrullaev was accepted as a PhD student at the Faculty of Mathematics and Natural Sciences, University of Bergen.

The main points of the project plan represent three work packages:

- Implement and test the generalized Dix method in a controlled environment, using kinematic information from synthetic seismic data. The focus is on stability and to include a regularization approach — the latter is needed to obtain output on a regular grid in the depth domain.
- Replace the improved generalized Dix method by an artificial neural network (ANN). Simplicity, good generalization performance, and low computation cost are important criteria for the ANN model.
- Develop a novel common-angle time migration approach, where the output is amplitude-versus-angle (AVA) gathers in the time domain. In this way, AVA gathers will be obtained quite early in the seismic processing sequence, at a stage where a detailed model of the subsurface is not yet known, and to a reasonable computation cost. The methodology is based on the generalized Dix method in combination with higher-order dynamic ray tracing.

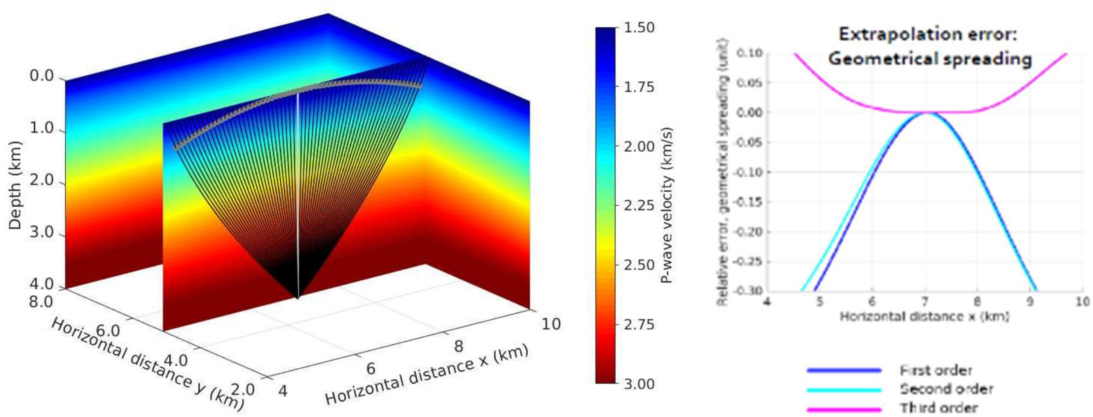


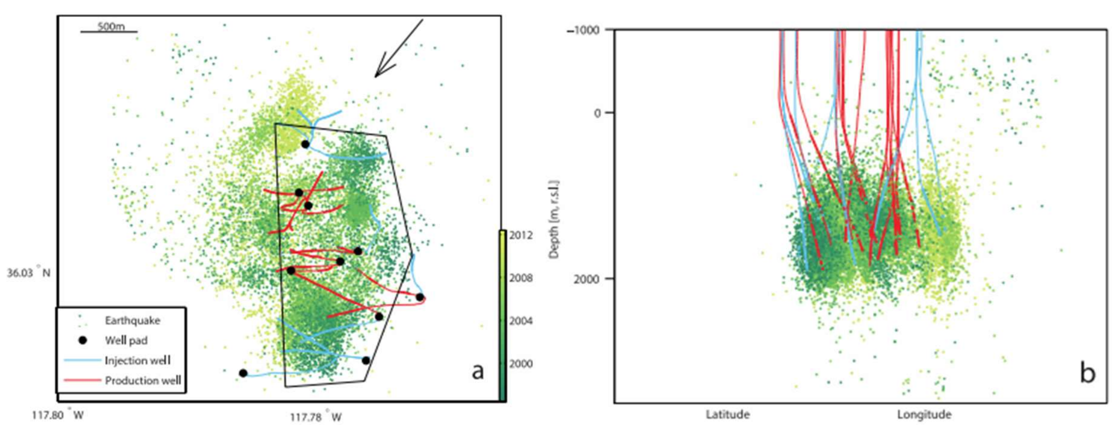
Illustration of higher-order dynamic ray tracing. Left: A 3-D anisotropic model with rays simulated from a buried source. Standard rays (black) to receivers at the surface and a selected ray (grey) for dynamic ray tracing. Right: Extrapolation error in geometrical spreading with the conventional dynamic ray tracing method (blue) and with higher orders (cyan, magenta).

Interpretation of fluid-induced seismicity patterns (P2.4)

Duration	2021-2026
PI	Volker Oye
Team	Joern Kaven, Inga Berre, Eirik Keilegavlen

Within this project we investigate how geothermal production and related fluid re-injections are correlating with the spatial and temporal evolution of earthquake clusters. We will work with data from the COSO geothermal field in Southern California. The data contains injection and production data, i.e. masses flowing in and out of certain wells and pressures monitored at the well heads. We will obtain these data over a period of several years and can hence observe long-term effects of variations in injection and production at the geothermal field. Alongside, we will get earthquake waveform data that is recorded with local borehole sensors and allows to provide precise locations for earthquake and microearthquakes that occurred locally at the geothermal site. The earthquake data will be provided for the same time interval.

The geothermal production and injection impose changes in the pressure and temperature in the subsurface. These changes are associated with stress field changes in the solid-rock matrix, and if certain thresholds are exceeded, microearthquakes occur that are relaxing the stress field suddenly, predominantly at weakness zones or pre-existing fracture zones. In this project, we will not only re-locate the seismicity to better delineate such fault and fracture zones and volumes, but also determine the type of the fractures through fault plane solutions. Such methods generally require high-quality data from many sensors, however, we try to apply new methods that will jointly invert focal mechanisms and take advantage of relative focal mechanisms. As such we will be able to increase the number of analyzed focal mechanisms and can better determine the in-situ stress field at depth, and also potential changes of the stress field direction over time. This will provide relevant input on stress field modelling as is envisioned within P2.2.



Relocated seismicity in the East Flank of the COSO geothermal field, in map view (a) and cross-section view (b). Each of the green dots represents a microearthquake. Lines in red and blue show production and injection wells, respectively. This is one of the datasets that we will further investigate in this project (from Kaven et al, 2014, 39th Stanford Geothermal Workshop).

AFFILIATED PROJECTS

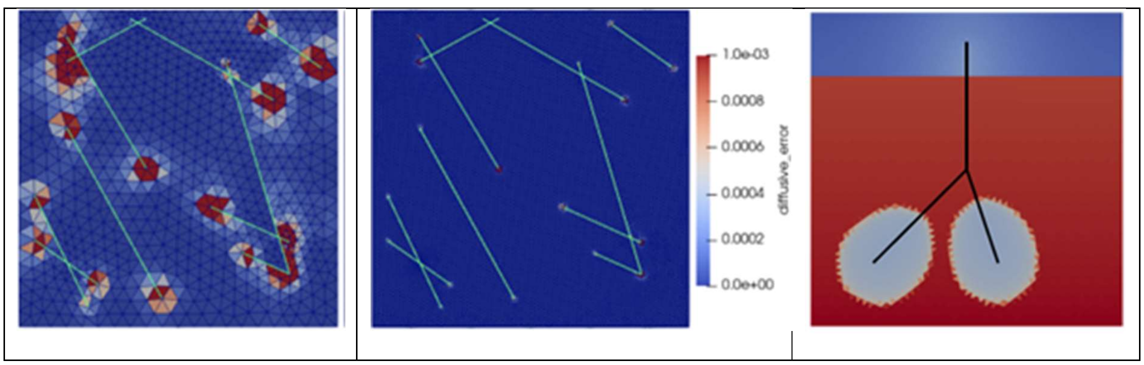
Multi-phase flow in fracture networks (MPFN)

Duration	2019-2022
PI	Eirik Keilegavlen
Team	Adrian Florin Radu, Jan M. Nordbotten, Jhabriel Varela

This was the PhD project of Jhabriel Varela, who defended his thesis in June 2022. The two main research directions of the project were the development of a posteriori error estimates for mixed-dimensional flow problems and modeling and simulation of unsaturated flow in fractured porous media.

The error estimates derived in the project allow computations of how close a numerically computed solution is to the true solution to a problem, without actually knowing the solution. Such techniques can for instance be used to judge the accuracy of computed solution and guide mesh refinement strategies.

The project also developed simulation techniques for flow in unsaturated fractured porous media, as is relevant for instance for water migration into dry soil. Due to capillary pressure effects, fractures can act both as barriers and conductive pathways for the water, depending on the local water saturation. The project developed a mathematical model for this process and a numerical approach which preserves the dual character of fractures, and implemented a simulation model which is able to capture these effects.



Estimated pressure errors in a fractured media for a coarse (left) and fine (middle) grid. Right: Migration of water (blue) into dry soil (red) with fractures (black) serving as the main flow paths.

Publications

Varela, J., Ahmed, E., Keilegavlen, E.., Nordbotten, J. M., & Radu, F. A. (2022). A posteriori error estimates for hierarchical mixed-dimensional elliptic equations. Journal of Numerical Mathematics, accepted.

FracFlow

Duration	2020-2023
PI	Jan Martin Nordbotten
Team	Martin Fernø, Bergit Brattekås, Jakub Wiktor Both, Eirik Keilegavlen.

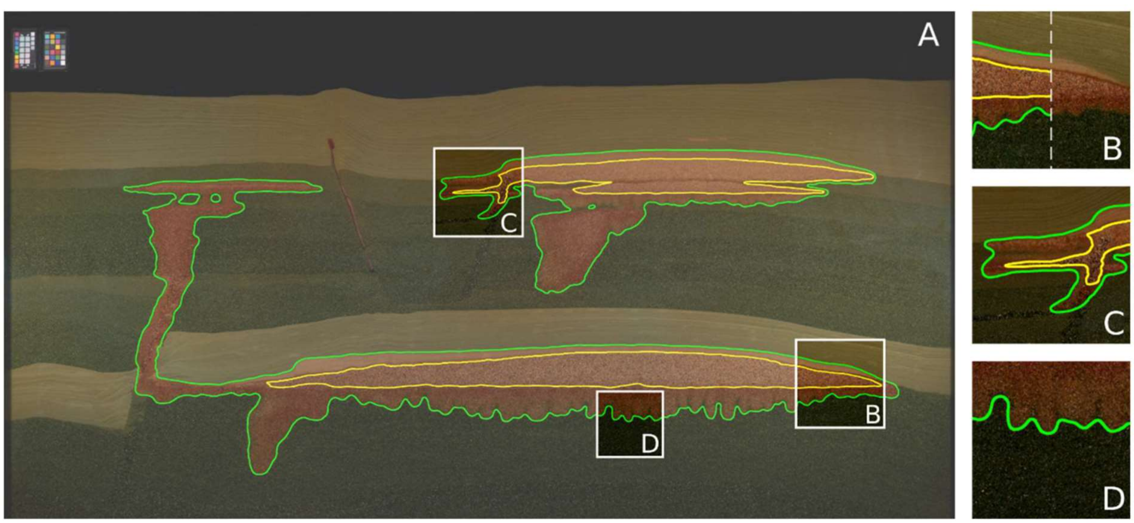
The FracFlow project is an interdisciplinary collaboration between the Department of Physics and Technology and the Department of Mathematics. At the core of the project lies to establish strong cross-disciplinary collaboration to enhance our understanding of fluid flow in thin, quasi-2D structures, such as fractures.

During 2022, the FracFlow team has contributed to developing our understanding the flow in the “FluidFlower” experimental rig, which is a quasi-2D experimental concept at the laboratory scale designed to investigate multiphase flows of geological relevance.

The experimental work is conducted in three different realizations of the FluidFlower rig.

Simultaneously, the FracFlow project has initiated the development of an open-source code for analyzing general images of porous rocks, termed “Darcy-Scale Image analysis”, or DarSIA for short. The DarSIA code is intended to be a bridge between experimental images and mathematical analysis across several different imaging modalities.

By leveraging the combined experimental results and imaging capabilities, we initiated a double-blind simulation validation study, and contributed the “ground truth” results (see Nordbotten et al., 2022). The forecasting and numerical simulation component of the study was executed in collaboration with the University of Stuttgart.



An image of a FluidFlower experiment, with DarSIA- based segmentation between gas and water phase, and regions of dissolved CO_2 superimposed.

Publications

Nordbotten J. M., M. A. Fernø, B. Flemisch, R. Juanes, M. Jørgensen (2022). Final Benchmark Description: FluidFlower International Benchmark Study. Zenodo. https://doi.org/10.5281/zenodo.6807102

Simulation of governing processes in superheated and supercritical geothermal systems: mathematical models, numerical methods and field data (SiGS)

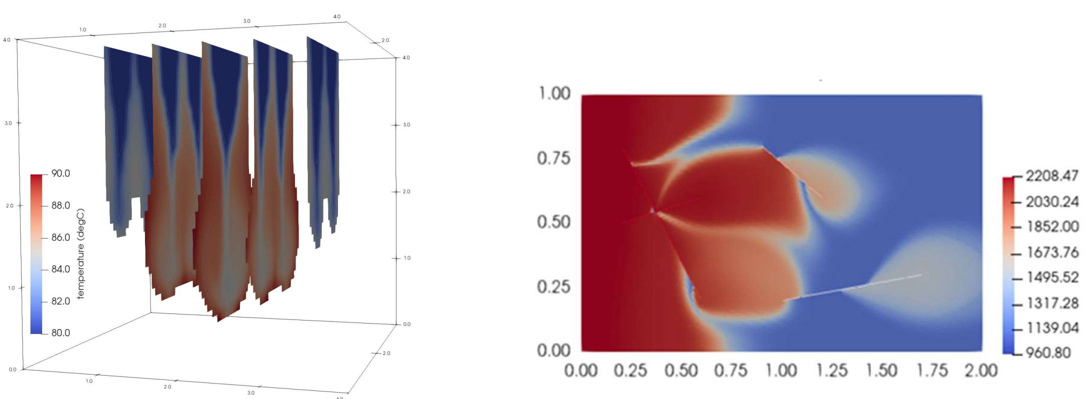
Duration	2020-2024
PI	Eirik Keilegavlen
Team	Shin Irgens Banshoya, Inga Berre, Sæunn Halldorsdottir

The project aims to combine simulation and field data analysis for thermal, hydraulic, mechanical, and chemical (THMC) processes in supercritical geothermal reservoirs. The project focuses on two mechanisms that are critical to understand superheated and supercritical geothermal systems: Heat transport from deep sources towards the geothermal reservoir and thermal stimulation caused by the introduction of cold fluids during drilling or reinjection. Development of simulation technology for multiphysics problems is also a core activity in the project.

This year, the project has studied the formation of pathways for transport of energy from the deep roots of geothermal systems. Simulations studies indicate that fractures which propagate due to a combination of fluid flow, transport of thermal energy, and rock mechanical effects, may form efficient pathways for fluid flow and transport of energy towards the shallower parts of the subsurface. This can be important not only in regimes where the temperature varies rapidly with depth, as are found in volcanic areas, but also in regions with relatively weaker temperature variations.

The project has also developed simulation techniques for transport of water-borne chemicals in fractured porous media. This transport may change the chemical composition, leading to mineral dissolution and precipitation which both can alter the flow pattern. These methods can simulate this coupled problem, and also account for the effect of temperature variations on the chemical equilibrium.

The project has also contributed to the development of a new linear solver for calculating pressure fields in fractured porous media. This is expected to enable larger simulations in SiGS and in the wider CSD center.



Left: Temperature profile in propagating fractures under cooling-induced tensile fracturing. Right: Concentration of a precipitated mineral under non-isothermal reactive flow in a fractured porous media.

Quantifying the relation between Carbon Capture and Storage and earthquake risk (CCS-ER)

Duration	2021-2025
PI	Mathilde B. Sørensen
Team	Maren K. Karlsen, Mathilde B. Sørensen, Lars Ottemöller, Corbett Grainger

This project aims to quantify the relation between CCS and seismic hazard and risk, the likelihood of earthquakes, and the risk of these earthquakes causing damage. The project will include a field example, evaluating the hazard and risk for a planned storage site at the Horda platform, off the coast of western Norway. A thorough hazard and risk analysis will help inform industry and policy makers when making decisions towards the UN climate goals, as well as the strategic focus of the Norwegian government on CCS as a future industry.

The project started in October 2021. Activities during 2022 have been focused on developing a baseline probabilistic seismic hazard model for Norway. This includes compiling and quality checking a homogeneous earthquake catalog for Norway, developing a model of seismic source zones, establishing earthquake activity rates for each source zone and identifying ground motion prediction models (describing the level of ground shaking as a function of e.g., earthquake magnitude and distance). The hazard model is still under development. In the beginning of 2023, a workshop was arranged with colleagues from the neighboring Nordic countries working on national seismic hazard models, to assure that the models are consistent across national borders.

The seismic source zonation model to be used in the baseline probabilistic seismic hazard model for Norway.

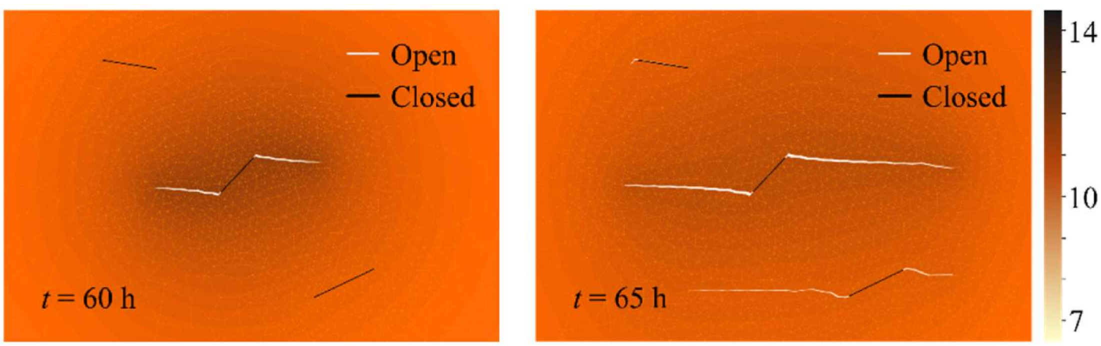
Mathematical and Numerical Modelling of Process-Structure Interaction in Fractured Geothermal Systems (MaPSI)

Duration	2021-2026
PI	Inga Berre
Team	Hau Trung Dang, Omar Duran, Ingrid Kristine Jacobsen, Jakub W. Both, Eirik Keilegalven, Veljko Lipovac, Jan Martin Nordbotten, Florin Radu, Ivar Stefansson

The goal of the MaPSI project is to provide mathematical models and simulation technology required to assess subsurface process-structure interaction in the context of hydraulic and thermal stimulation in development and production of high-temperature geothermal resources.

High-temperature geothermal systems involve multicomponent multiphase processes in porous rock. The model being developed in the project is based on a compositional formulation with pressure, mole fractions of the components and enthalpy as primary variables. A central part of the work is development of new methodology for the required isenthalpic flash calculations to find phase composition, temperature, and partial phase fractions.

Interactions with fluid injection processes and fracture deformation and propagation is another key line of research. In 2022, a model was published which allows investigation of mixed mechanism stimulation of fractured geothermal reservoirs (Dang et al., 2022), i.e., reservoir permeability enhancement through combined fracture slip and dilation and fracture propagation in porous rocks. In addition, work has commenced on new modeling frameworks for fracture mechanics, more advanced friction models and solvers for contact mechanics problems.



Propagation of multiple fractures and evolution of pressure in a 2D porous media during fluid injection into one (central) pre-existing fracture. The white and black color indicates whether the fracture is completely open or mechanically in contact. Figure taken from the paper by Dang et al. (2022).

Publications

Dang, H. T., Berre, I., & Keilegavlen, E. (2022). Two-level simulation of injection-induced fracture slip and wing-crack propagation in poroelastic media. International Journal of Rock Mechanics and Mining Sciences, 160, 105248.

Gradient Flow Modelling of multi-phase flow in Deformable Porous media (GradFlowPoro)

Duration	2022-2023
PI	Jakub W. Both
Team	CSD: Omar Duran, Veljko Lipovac, Erlend Storvik; UiB: Peter von Schultzendorff; Inria Lille: Clément Cancès, Maxime Jonval; University of Nice Sophia Antipolis: Konstantin Brenner

The GradFlowPoro project falls under the Aurora Mobility Programme, ran by the RCN, aiming at establishing new international collaborations between Norway and France, as well as to strengthen European research collaboration under Horizon Europe. As such, short-term visits between the participating partners (with main locations in Bergen and Lille) lie at the heart of the project.

The main objectives of the GradFlowPoro project are the establishment of thermodynamically consistent models for multiphase poromechanics, and the development and mathematical analysis of numerical solution schemes for the derived model formulations.

In May 2022, the GradFlowPoro project was successfully kicked-off by an in-person workshop in Bergen, with all participants present. This provided the young researchers the chance to get to know experts in the field and extend their scientific network. An additional meeting of the two heading members of both sub-teams took place in Lille in October.

The main purpose of the two meetings has been the establishment of a gradient flow formulation of multiphase poromechanics, based on thermodynamic and energetic formulations. Such a formulation has naturally allowed including physical conditions as non-vanishing, variable porosities. In addition, the existence of solutions of this gradient flow formulation have been established using mathematical analysis, in total, addressing the first half of the project goals. Currently, the purely theoretical results are finalized and will be submitted for publication in early 2023.

VISTA CSD RESEARCHER TRAINING PROGRAM

The VISTA CSD Researcher Training Program[1] includes all PhD students and early career researchers affiliated with the center, also those who are employed based on other external and internal funding. The program is focused on transversal skills as well as interdisciplinary technical skills. By the end of 2022, 18 early career researchers have been affiliated with the program.

Participants at the CSD annual meeting 2022.

CSD Annual Meeting

On 29-30 March, 23 CSD team members met at Solstrand to discuss the research plans and progress of research activities under CSD.

CSD Career Development Day

12 September 2022, a career development day was held for early career researchers in CSD. Topics of the day included interactive self-assessment of skills, values and interests, a self SWOT assignment, and the preparation of a career development plan. Jan Arild Skjervheim from Equinor visited the group and was interviewed on his career choices and advice to young researchers.

CSD Seminar

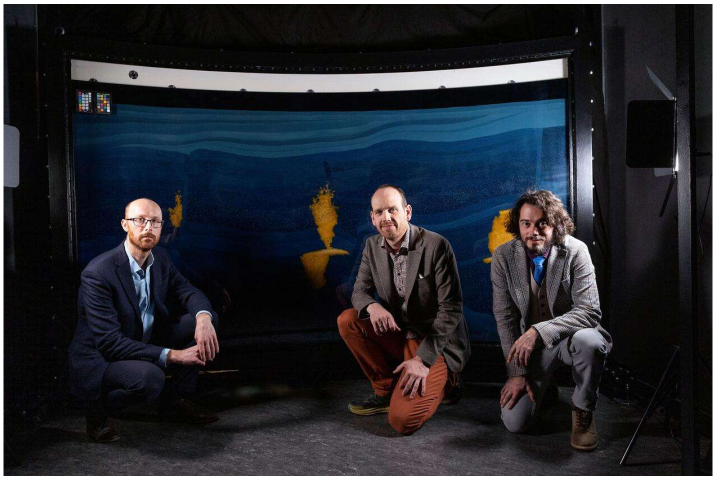
To promote the sharing of scientific knowledge and research results, CSD organizes weekly seminars. Lectures were given at UiB. During 2021, 31 seminars were held, 12 of which were given by external collaborators or guest researchers.

[1]VISTA CSD Training Program, https://www.uib.no/en/vista-csd/145109/researcher-training-program

OUTREACH

The CSD webpages[2] provides general information on the center as well as regular news updates. CSD also has an active Twitter account @csd_uib with more than 140 followers.

The University Museum of Bergen has a major temporary exhibit on “Our porous world” from March 31st 2022 to January 19th 2023. The exhibit displays the complexity of porous media in a broad range of applications, but with a particular emphasis on subsurface applications related to water, energy and CO2 storage. Related to the exhibit, two thematic science days have been organized, including popular science lectures from local and national experts. Furthermore, students from across western Norway have been invited to a specifically designed 4-hour immersive experience, including injecting CO2 into their own A4-paper sizes CO2 storage experiments. This pedagogical program will remain on offer at the museum after the main exhibit ends. The exhibit was curated by the museum in collaboration with Martin Fernø (CSD/Department of Physics and Technology), Atle Rotevatn (Department of Earth Science) and Jan Martin Nordbotten (CSD/Department of Mathematics).



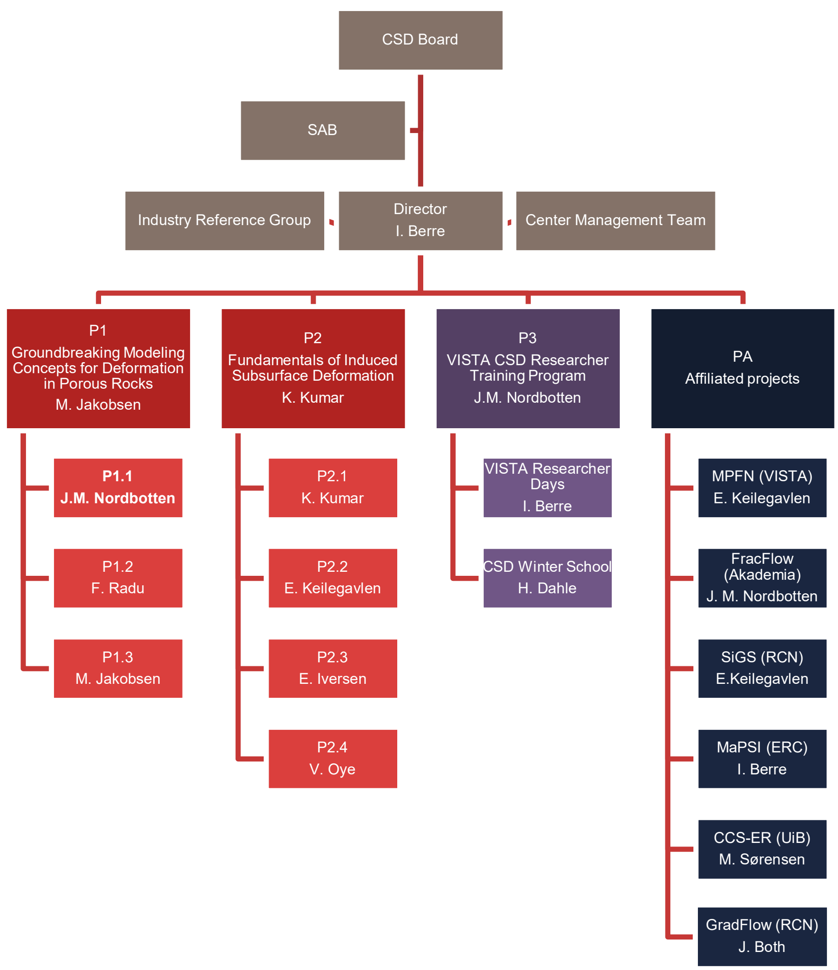
Martin Fernø, Atle Rotevatn and Jan M. Nordbotten with the CO2 storage rig featured at the University of Bergen Museum exhibit on “Our porous world”.

[2]Center for Modeling of Coupled Subsurface Dynamics; https://www.uib.no/en/vista-csd

ORGANIZATION OF THE CENTER

The Board is CSD's formal decision body. The Center Director is supported by the Center Management Team (MT) and the Industry Reference Group. The Scientific Advisory Board (SAB) reports to the CSD Board and gives advice to the Center Director. An overview of the organization structure of CSD is provided in the chart below.

The CSD is organized in four pillars, representing the center's main activities. Three pillars (P1-P3) are funded by the VISTA program, two of which focus on research and the third on researcher training to ensure scientific and transferable skills training for PhD, Postdocs and Master students in the center. Affiliated research projects, which are funded through other grants, are structured in a separate pillar (PA).



Center organization structure.

CSD PIs and project leaders

CSD Principal investigators and project leaders. From left: Jan M. Nordbotten, Jakub W. Both, Helge Dahle, Einar Iversen, Inga Berre, Kundan Kumar, Eirik Keilegavlen, Mathilde Sørensen, Morten Jakobsen, Florin Radu.

The CSD Board

Kenneth Ruud (Chair)

Director General at The Norwegian Defence Research Establishment (FFI)

Anne Marit Blokhus

Professor, Department of Chemistry, University of Bergen

Unni Olsbye

Professor, Department of Chemistry, University of Oslo

Antonella Zanna Munthe-Kaas

Professor and Head of Department, Department of Mathematics, University of Bergen

Atle Rotevatn, Professor and Head of the Department of Earth Science, University of Bergen

Roger Sollie, Academia Program manager at Equinor

Scientific Advisory Board

The task of the CSD Scientific Advisory Board (SAB) is to contribute to realizing the center's main goals and give advice to the center director and host institution. The CSD board has appointed the following Scientific Advisory Board for CSD:

- Prof. Paola Francesca Antonietti, Politecnico di Milano
- Prof. Stefan Buske, TU Freiberg
- Prof. Insa Neuweiler, University of Hannover

SAB will carry out two scientific evaluations of the center, and reports to the CSD board.

Industry reference Group

The CSD industry reference group has nine members:

- Geir Terje Eigestad, Wintershall Dea
- Saeed F. Bolandtaba, Wintershall Dea
- Ketil Hokstad, Equinor
- Leo Eisner, Seismik
- Gunnar Gunnarsson, Orkuveita Reykjavíkur
- Guðjón Helgi Eggertsson, HS Orka
- Lilja Magnúsdóttir, HS Orka
- Anette Mortensen, Landsvirkjun
- Hilmar Már Einarsson, Landsvirkjun

Center Management Team

The center management team consists of Prof. Inga Berre (Center Director), Prof. Morten Jakobsen (P1 Coordinator), Assoc. Prof. Kundan Kumar (P2 Coordinator) and Prof. Jan Martin Nordbotten (P3 Coordinator).

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