

# Chapter 1

## Introduction to GeomInt2



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### 1.1 Project

GeomInt2 is the follow-up project to the joint project “Geomechanical Integrity of Host and Barrier Rocks—Experiment, Modelling and Analysis of Discontinuities (GeomInt)”. The results of GeomInt made essential contributions to the analysis of the origin and development of discontinuities in clay, salt and crystalline rocks.

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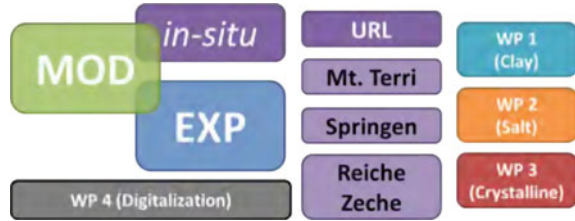
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**Fig. 1.1** General project structure

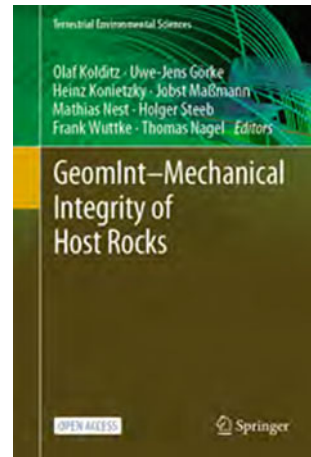


Discontinuities are considered in many forms, be it as volumetrically distributed damage macroscopically representing fissures in the rock microstructure, discontinuities that can form anew at phase interfaces as well as discrete cracks or fracture networks. The pathways created or extended by these discontinuities entail the risk of migration of fluid phases from deep to near-surface geological layers and must therefore be taken into account in geotechnical safety analyses.

The main result of the primarily methodology-oriented joint project GeomInt is the development of a broad experimental and numerical platform for laboratory and field analysis, and prediction of discontinuities in important reservoir and barrier rocks. Model comparisons for damage and fracture processes driven by different physical phenomena provide indications for the optimal application areas of the numerical methods. The follow-up project GeomInt2 aims to demonstrate the practical applicability of the developed experimental-numerical instruments under real conditions at the site scale. In addition, knowledge gaps that still exist will be closed through in-depth tests on a smaller scale and in-depth model developments for specific process components.

At the core of GeomInt2 was an interdisciplinary consortium of partners from universities, state and private research institutions with complementary, long-standing experience in the analysis of geosystems that has proven itself in the previous project. New insights were elaborated, especially in understanding the effects of discontinuities on underground geosystems. In this context, the focus of experimental investigations shifted significantly to the implementation and evaluation of in-situ experiments in various underground research laboratories (URLs). For the efficient numerical simulation of coupled mechanical, thermal and hydraulic processes in the formation and development of discontinuities on the scale under consideration, the models and algorithms were further refined in GeomInt2. To enable the analysis of larger and more complex systems, high-performance computing (HPC) methods were added as a new aspect. The descriptive presentation of structural, experimental and model results in a real context (e.g. URLs) is to take place within the framework of an integrated visual data analysis approach (virtualisation). Figure 1.1 is a graphic illustration of the GeomInt2 project.

The project results aim at improved understanding of the processes, the used methods and the application-oriented systems for realistic time and length scales in order to make the planning and realisation of geotechnical uses of the subsurface safer, more reliable and more efficient. Another important advantage of GeomInt2 is the

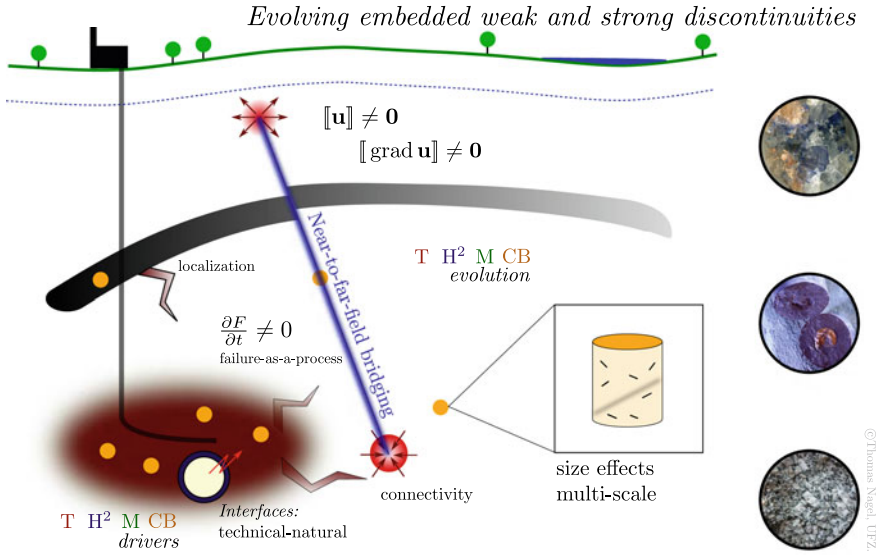
**Fig. 1.2** GeomInt book

transferability of the experimental-numerical concepts and methods to other geotechnical applications such as deep geothermal energy, energy storage, repository problems, methods for hydraulic stimulation, conventional and unconventional resource extraction or tunnelling. GeomInt2 intensified the internationalisation started in the previous project by cooperation with complementary research projects (e.g. DECO-VALEX 2023 and the Mont Terri project) (Fig. 1.2).

The work packages mentioned in Fig. 1.1 were closely linked to the URLs Mont Terri (WP1/WP2), Springen (WP2) and Reiche Zeche (WP3) in continuation of the first project phase. The sample material for the geotechnical laboratories in Freiberg (TUBAF), Kiel (CAU) and Leipzig (IfG) originated from these URLs. Data from in-situ experiments in Mont Terri (BGR) and the Springen pit (IfG) were incorporated into the modelling platform of the GeomInt project coordinated by the UFZ, in which all project partners participated. So-called Model EXperiments (MEX) were defined as a synthesis tool, in which experimental and modelling work were systematically combined from the beginning of phase one (Kolditz et al. 2021a, b). This integration formed the basis for the continuation of the project and the application of its results to site-scale problems in phase 2.

## 1.2 Approach

The research approach of GeomInt2 continues following the general concept of discontinuities in geosystems as illustrated in Fig. 1.3. Discontinuities in geological media—being a general feature in various host rocks such as salt, clay and crystalline rocks—occur at various scales. New fractures can be initiated by elevated fluid pressures, temperatures, and/or mechanical stresses in conjunction with geotechnical applications (TH<sup>2</sup>MCB drivers Fig. 1.3). Existing joints or faults can be reactivated

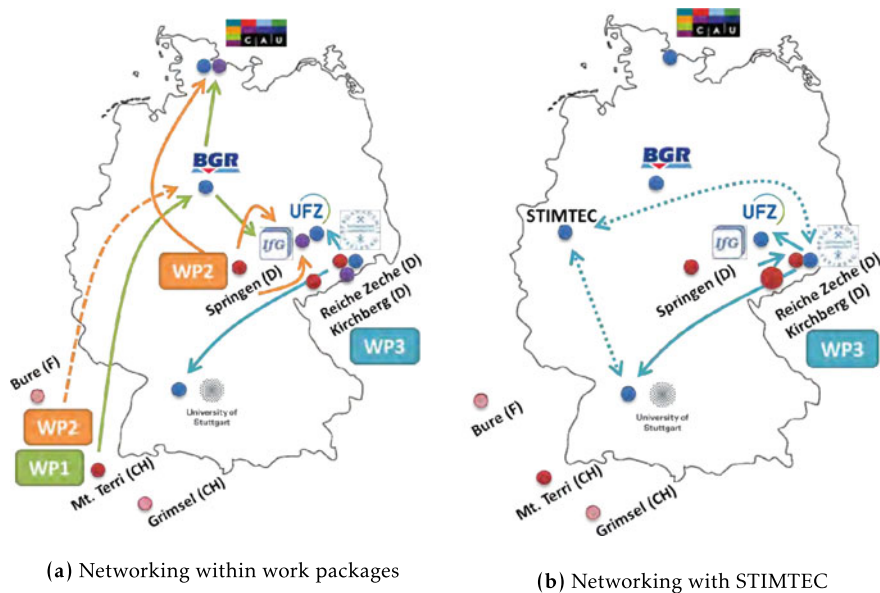


**Fig. 1.3** Graphical abstract of the GeomInt project: geological reservoir-barrier systems and geomechanical integrity (Nagel et al. 2021)

by similar multi-physical reasons as well (TH<sup>2</sup>MCB evolution Fig. 1.3). Fractures are localized and subject to size effects—they thus render a problem inherently multi-scale. Changes in connectivity of existing fracture networks due to evolving discontinuities can qualitatively alter system behaviour and lead to accelerated pathways from repositories to cap or side rocks (near-to-far-field bridging in Fig. 1.3).

*GeomInt2 leveraged both the experimental and numerical framework from the Lab to Field Scale*—which became the subtitle of the present book. GeomInt2 was aimed at improving our understanding of the underlying physical mechanisms and provide methods across different geological settings. The numerical instrumentation has been further developed and tested against experimental results on the field scale in particular from the underground research labs and mines in Mont Terri (CD-A experiment, Opalinus clay), Reiche Zeche (crystalline rock, STIMTEC experiment), and Springen (salt rock, large borehole experiment).

As a result of the GeomInt project so far, a broad experimental and numerical platform has been developed for the investigation of discontinuities due to swelling and shrinking processes (WP1), pressure-driven percolation (WP2) and stress redistribution (WP3). With these phenomena, processes relevant in the most important barrier and reservoir rocks (clay, salt, crystalline) are addressed. A comprehensive validation of the platforms („Proof-of-Concept“) was done by the Model EXperiments (MEX) for the damage and fracture processes driven by different processes. In the continuation of the project, the basic idea—the investigation of the three relevant process types for the formation of pathways in different rock types—is preserved. The proven project structure (WP1-3) is also retained (Fig. 1.4a).



**Fig. 1.4** GeomInt project geography

The emphasis in GeomInt2 is set as follows:

- Experiments: Focus on the evaluation of recent in situ experiments at the Mont Terri (Opalinus clay), Springen (salt) and Reiche Zeche (crystalline) rock laboratories. Selected laboratory experiments are used to specifically fill remaining knowledge gaps (e.g. mechanical anisotropy of clay rocks).
- Modelling: Numerical methods are to be further developed and used for in-situ applications. For the scaling from micro- to macro-scale models, different model approaches are to be specifically linked with each other (e.g. integration of the LEM into the FE method).
- Digitalisation: New developments in the computer sciences, such as high-performance computing and visual data analysis, are to be incorporated into the continuation of the project. This is necessary, on the one hand, to achieve the required scaling of the models to the application scale and, on the other hand, to allow a presentation of the model results in the real context of the underground laboratories.
- Internationalisation: In addition, the international cooperation with the Mont Terri project and DECOVALEX 2023 should be intensified, also in order to strengthen the external impact of the Geo:N project.

Figure 1.4 depicts the project geography of GeomInt2 in direct continuation of the workflows established in phase one of the project between the project partners from the universities of Freiberg (TUBAF), Kiel (CAU) and Stuttgart (UoS) as well

as research institutions BGR, UFZ and the IfG company. The close collaboration established between the GeomInt and STIMTEC projects both working on discontinuities in crystalline rocks linked to the URL “Reiche Zeche” was also continued in the second phase.

The following chapters introduce some important results from the three work packages at the core of the project: WP1 (swelling/shrinkage), WP2 (fluid percolation) and WP3 (stress redistribution) for three types of host rocks, namely, clay, salt and crystalline rocks. Subsequently an introduction to the virtual reality and computation platforms is given, featuring the visualization, HPC and software engineering aspects. Some results are given more emphasis than others. Particularly, simulations on the hydro-mechanical behaviour of Opalinus clay were presented in greater detail. In the other chapters, a shorter presentation was chosen to keep the book concise. However, we point the reader to publications where more information also on the remaining topics addressed in the project can be found. The book closes with a synthesis and outlook.

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