Chapter 5

Data Management

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Data management includes the development and use of architectures, guidelines, practices and procedures for accurate managing of data during the entire data lifecycle of an institutional unit or a research project defined as different information units such as numbers, alphabetic characters, and symbols that are particularly formatted and can be processed by computer. The data in the project is provided by various actors which can be GeomInt partners, their legal representatives, employees, and external partners. GeomInt Data is provided at GeomInt data management portal (DMP).

In GeomInt project the partners work in very close cooperation. Project-owned and connected infrastructures are synergetic used (as illustrated in Fig. 5.1). In addition to the rock mechanics laboratories of the partners CAU, IfG and TUBAF with partly unique equipment data from ongoing experiments in the underground laboratories

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Fig. 5.1 Network diagram to illustrate synergies and dependencies in the GeomInt network in connection with the infrastructure elements and numerical methods in the project

are accessed. An essential element of the GeomInt project is the simulation and software development structures illustrated in Fig. 5.1. With regard to the use of the simulation platform OpenGeoSys, the development of which is coordinated by the UFZ and in whose further development the GeomInt partners BGR, CAU, IfG and TUBAF are involved, the simulation and development infrastructures located at the UFZ, including version management, is available to these partners.

The collaborative work requires data management structures and guidelines. Therefore, the first step was to set up a document that includes a user agreement and a data management plan which is the basis for data management in the project.

5.1 User Agreement and Data Management Plan

The GeomInt project partners agreed to set up a user agreement which includes specifications for data structures including metadata, data formats, access authorization for data, the possible publication of data, as well as the handling of the data after the

end of the project and outside the project. A first version of this user agreement was created six months after the start of the project.

The user agreement includes guidelines and definitions for the following aspects

- Which data will be generated in the project and has to be managed?
- How will data be provided and exchanged?
- What are the rights of use for the partners and for third parties?
- How to cite data?
- How to supervise the compliance of the user agreement?

As part of the user agreement, a data management plan, which is a formal document that describes how project data is managed during the research period and after completion of the project, was developed. The goal of a data management plan is to consider the aspects of data management (metadata creation, data preservation and analysis) before the start of the project. Following points are discussed in the GeomInt data management plan:

1. Generation and management methods (data infrastructure, external data, data integration, data formats, quality control, user groups, data processing stages, versioning, documentation and meta data, geocoding)
2. Data Legal Management
3. Data exchange and provision, citation rules
4. Short-term storage and data management (storages, data transfer, backup, security)
5. Long-term storage (characteristics, metadata and documentation, responsibility)
6. Resources (organizational roles and responsibilities for data management).

5.2 GeomInt Data

The project results include specific data from laboratory and in-situ experiments, software components and data sets from numerical simulations (i.e. model and result files). An estimation of the extent of the data generated in GeomInt could not be made before the project. Therefore, the data management concept had to be flexible. This uncertainty was mainly due to the fact that the evaluation of test and calculation results may lead to a change in test and calculation planning and may even lead to additional experiments or simulation calculations.

The availability of experimental and numerical data generated in the project, including existing metadata, is realized on an internal area of the Geomint homepage. The UFZ is responsible for the project data and has many years of experience in data management regarding the cooperative development of open source software (OpenGeoSys) as well as the acquisition, storage and processing of data from experiments on different scales, exploration and monitoring campaigns, numerical simulations and scientific 3D visualizations.

The UFZ has sufficient capacities and modern data management systems for data storage, which are available as a central data infrastructure for the research network. Specifically, data sets are managed by means of an ORACLE database. Access is via a web portal, where each data record must be provided with metadata before uploading. The metadata standard used is compatible with the INSPIRE Directive 2007/2/EC and also regulates the rights for access, use and transfer of the data. A tape system is also available for the long-term storage of very large amounts of data. For the provision of exploration and monitoring data, geo-services mentioned in the GDI-DE are used as far as possible. Since such services for complex modelling and simulation data do not exist so far, the provision is done via a data research portal, where data can be found by means of stored metadata.

As software components are part of non-commercial, scientific program platforms and are open source products (e.g., OpenGeoSys), they are hosted by the responsible partner via established source code hosting services (e.g. GitHub) and is publicly available. A possible public access to project data, which goes beyond the status quo as described in technical publications, as well as the handling of the data after the end of the project is regulated in the cooperation agreement or in the cooperation contract between the project partners.

The handling of data obtained from the in-situ experiments in the underground laboratories through synergies with other projects is also regulated separately (access authorisation for these data, storage location, publication, handling of the data after the end of the project). Such an approach is necessary because specific parts of these data can be used for the scientific purposes of GeomInt, but they are generated in other projects with partly other partners.

5.3 GeomInt DMP

In this section, exemplary data sets of every project partner are described. A table of these data sets including description and link are available only for project partners at the website (Fig. 5.2). Some data sets can be found on the UFZ data investigation portal <https://www.ufz.de/drp/>. These data sets are uploaded to the data management portal at UFZ (DMP@UFZ).

The GeomInt data management system (DMS) is organised in three sections (Fig. 5.3):

- Experimental data (Fig. 5.3 left),
- Simulation data (Fig. 5.3 right),
- and data connected to URLs (Fig. 5.3 bottom right).

Table 5.1 summarizes the MEX related data concerning experiments and simulations. A selection will be described in the following sections.

The following codes (and related input files) are used (see Chap. 7 for detailed code introductions).

GEOMINT Geomechanische Integrität von Wirts- und Barrieregesteinen – Experiment, Modellierung und Analyse von Diskontinuitäten

Projekt Publikationen Veranstaltungen Intern

GeomInt Datenübersicht

Formulare für Metadaten:

- Formular für Tabelle auf Website
- Formular für UFZ-Datenmanagementportal und Tabelle auf Website

Datenübersicht für:

- Experimentielle Daten
- Simulationsdaten
- Mont Terri Kontext

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GEFÖRDET VOM

Bundesministerium
 für Bildung
 und Forschung

Fig. 5.2 GeomInt DMS portal <https://www.ufz.de/geomint/index.php?de=46799>

Software Codes

- LEM: In-house developed MATLAB In-house code available in executable P-file format.
- DEM: Commercial code by Itasca Ltd.
- SPH: In-house code.
- OGS (OpenGeoSys): <https://www.opengeosys.org/releases/>.
- HDF: In-house code.

Experimentelle Daten

Institut / Mitarbeiter	Teil-projekt	Beschreibung	Datentyp/-format	Link
CAU Kiel Frank Wutthe, Amir Shoarian Sattari	AP1 und AP2	The experimental data for WP1 and WP2	ASCII-files and Excel	https://nextcloud.fg.uni-kiel.de/index.php/s/E7JZ98c5Q3o3NMt
Institut für Getriebe-mechanik GmbH	AP2 (MEX 2-2)	Reduzierung von Permeabilitäten durch Riss-schließung in Steinsalz	Excel	https://www.ufz.de/record/dmp/archive/758/
TUBAF Thomas Fröh-wert, Daniel Pötsch-ke	AP3 (MEX 3-1)	CNL direct shear test. Scan data of surface A+B, rock parameter and results of shear test	ASCII-files	https://www.ufz.de/record/dmp/archive/7443/
TU Freiberg, Thomas Fröh-wert und Daniel Pötsch-ke	AP3 (MEX 3-1)	CNL direct shear test. Scan data of surface A+B, rock parameter and results of shear test, graphic of result	ASCII-files, jpg	https://www.ufz.de/record/dmp/archive/7925/
TU Freiberg, Thomas Fröh-wert und Daniel Pötsch-ke	AP3 (MEX 3-2)	CNS direct shear test. Scan data of surface A+B, rock parameter and results of shear test, photos of surface at three levels, graphic of result	ASCII-files, jpg, png	https://www.ufz.de/record/dmp/archive/7924/

Simulationsdaten

Institut / Mitarbeiter	Teil-projekt	Beschreibung	Datentyp/-format	Link
CAU Kiel Frank Wutthe, Amir Shoarian Sattari	WP1 und WP2	The numerical data for WP1 and WP2	ASCII-files and Excel	https://nextcloud.fg.uni-kiel.de/index.php/s/5a5Mn6TgYcr4n
UFZ / Keita Yoshioka	WP1 (MEX 0-1a)	Input files for ogs simulation for Model exercise 2	OGS input file	https://www.ufz.de/record/dmp/archive/7706/
Universität Stuttgart - Institut für Mechanik (Bauwesen) / Patrick Schmidt	Veröffent-lichung zu Reichen Zeche Riss Charakteri-sierung- StimTech Kooperation (MEX 3-3)	Komplizierte Version um experimentelle Step-Rate Tests, durchgeführt an der Reichen Zeche, zu reproduzieren	Komplizierte Version inklusive Input- und Vernetz-ungsdateien	https://galilei.sr.uni-stuttgart.de/galilei/schmidt/geoint
Mont Terri Kontext				
Universität Stuttgart - Institut für Mechanik (Bauwesen) / Patrick Schmidt	Veröffent-lichung zu Reichen Zeche Riss Charakteri-sierung- StimTech Kooperation (MEX 3-3)	Mont Terri Kontext	Parameter- files in ASCII and compu- tational grid in binary	https://www.ufz.de/record/dmp/archive/7471de/

Fig. 5.3 GeomInt DMS portal: Data areas for experimental, simulation and URL related information

Table 5.1 MEX data management

MEX WP	TOP	EXP	MOD				
			LEM	DEM	FEM	HDF	FFS
0-1a	Bending fracture test	LIT	✓	✓	✓		
0-1b	Bending fracture test (aniso)						
0-2	Humidity controlled bending	Concept					
1-1a	Swelling of clay						
1-1b	Swelling of clay						
1-2	Shrinkage of clay						
1-3	Desiccation of clay						
1-4	CD/LP experiment						
2-1a	Pressure driven percolation						
2-1b	Pressure driven percolation						
2-2	Healing / closure						
2-3	Compressible fluids						
2-4	URL Springen						
3-1	CNL test						
3-2	CNS test						
3-3	Cyclic loading						

Table 5.2 MEX 0-1a: Data overview

Type	Spec.	Owner	Access	Comment
EXP	LIT	[1]	Restricted	Literature available via UFZ
MOD	LEM	CAU	Open	Executable MATLAB P-file
			Open	Input files will be uploaded
MOD	DEM	IfG	Restricted	Input files available
MOD	FEM	UFZ	Open	Branch to be merged into OGS
			Open	Input files available

Input files

Input files

- LEM: In-house documentation
- DEM: Itasca Ltd. (user’s manuals)
- SPH/HDF: In-house documentation
- OGS (Benchmarks): <https://www.opengeosys.org/docs/benchmarks/>
- HDF: In-house documentation.

5.3.1 MEX 0-1a: Bending Fracture Test

Participating institutions of MEX 0.1a (see section 4.1): CAU, UFZ, IfG*¹ (Table 5.2).

¹IfG as a user of commercial codes has specific data management rules.

Fig. 5.4 The load versus CMOD from the lattice simulation

Fig. 5.5 The load versus CMOD from the VPF simulation results

CAU (LEM)

The required LEM code and the input variables of the three-Point fracture toughness test on the Rockville Granite samples are uploaded to the IfG (Kiel) NextCloud server. The data is accessible through the following link: <https://nextcloud.ifg.uni-kiel.de/index.php/s/pRmBPJ9gK5Se6ci>.

The uploaded protected MATLAB file in a *.p format requires a MATLAB version with a built-in Voronoi Tessellation and Delaunay Triangulation functions. The input variables are prepared in a single file for the simulation of the fracture toughness in Rockville Granite. Figure 5.4 shows the relation between the load versus CMOD as described in Sect. 4.1.

UFZ (FEM-VPF)

The source code can be found in OpenGeoSys project on github and the input files for the three point bending test performed on the Rockville Granite samples have been uploaded. The files include the unstructured finite element mesh files in `vtu` format and an OGS input file in `xm1` format. As homogeneous properties such as Young's modulus are assigned into the computational domain, the spatially constant material properties are specified in the OGS input file rather than in the mesh file. The load and crack mouth opening displacement computed from the simulations are shown in Fig. 5.5 as described in Sect. 4.1.

Table 5.3 MEX 0-1a (CAU)

Data label	GeomInt CAU Bending fracture test, Granite
URL (Numerics)	https://nextcloud.ifg.uni-kiel.de/index.php/s/pRmBPJ9gK5Se6ci
Subject	LEM simulation of bending fracture test (Granite)
Type of data	Executable MATLAB P-file, input parameters
Data quality	Quality assured data
Status of data	Unprocessed data
Data format	txt, MATLAB executable P-file
Creators	Kiel University, Institute of Geomechanics and Geotechnics, Ludwig-Meyn-Straße 10, 24118, Kiel
Source/Origin	In-house code
Publisher	Kiel University, Institute of Geomechanics and Geotechnics, Ludwig-Meyn-Straße 10, 24118, Kiel
Rights holders	Kiel University, Institute of Geomechanics and Geotechnics, Ludwig-Meyn-Straße 10, 24118, Kiel
Contributors	Kiel University, Institute of Geomechanics and Geotechnics: Amir Shoarian Sattari, Frank Wuttke
Time/period of creation	2018–2019
Language of the content	English
Update policy	Stored data is final
Access permissions	Full access

MEX 0-1a (UFZ) will be also provided as an OGS benchmark case at: https://www.opengeosys.org/docs/benchmarks/phase-field/pf_tpb/.

Meta Data Overview (According to Dublin Core)

See Tables 5.3, 5.4 and 5.5.

5.3.2 MEX 0-1b: Three-Point Fracture Toughness Test, Opalinus Clay

Participating institutions of MEX 0-1b (see Sect. 4.2): CAU, UFZ (Table 5.6).

CAU Kiel

The experimental results of the three-point fracture toughness test on the Opalinus Clay samples are uploaded to the IfG (Kiel) NextCloud server. The data is accessible through the following link: <https://nextcloud.ifg.uni-kiel.de/index.php/s/pJxp2eNEJb6PfIS>.

The data set, which includes the time, applied force (N) and the displacement of the sample at the loading point (mm), is provided in a *.txt file. The crack mouth opening displacement (CMOD), which is determined from the image processing technique (Sect. 2.2.2), is given in a *.xlsx file. The data includes the time and the calculated CMOD (mm).

Table 5.4 MEX 0-1a (UFZ)

Data label	MEX 0-1a (UFZ)
URL	http://www.ufz.de/record/dmp/archive/7706
Subject	OGS-VPF simulation of bending fracture test (crystalline rock)
Type of data	Data set (structured data in a defined format)
Data quality	Quality assured data by benchmarking
Status of data	Processed data
Data format	OGS files
Creators	Yoshioka, Keita
Source/Origin	Open source
Publisher	Helmholtz Centre for Environmental Research UFZ
Rights holders	Helmholtz Centre for Environmental Research UFZ
Contributors	Yoshioka, Keita
Time/period of creation	2019–2020
Language of content	English
Update policy	To be merged to OGS benchmarks (see below)
Access permissions	Free access

Table 5.5 MEX 0-1a (IfG)

Data label	MEX 0-1a (IfG)
URL	
Subject	DEM simulation of bending fracture test (crystalline rock)
Type of data	Data set (structured data in a defined format)
Data quality	Quality assured data by benchmarking
Status of data	
Data format	
Creators	Nest, Mathias
Source/Origin	Commercial code
Publisher	Institut für Gebirgsmechanik IfG
Rights holders	Institut für Gebirgsmechanik IfG
Contributors	Nest, Mathias
Time/period of creation	2019–2020
Language of content	English
Update policy	
Access permissions	Limited access

Table 5.6 MEX 0-1b: Data overview

Type	Spec.	Owner	Access	Comment
EXP	Ben	CAU	Open	Output files are uploaded
MOD	LEM	CAU	Open	Executable MATLAB P-file
			Open	Input files available
MOD	FEM	UFZ	Open	Branch to be merged into OGS
			Open	Input files available

Fig. 5.6 The load versus crack mouth opening displacement (CMOD) response of the Opalinus Clay

The required LEM code and the input variables of the three-Point fracture toughness test on the Opalinus Clay samples are uploaded to the IfG (Kiel) NextCloud server. The data is accessible through the following link: <https://nextcloud.ifg.uni-kiel.de/index.php/s/ZBFN2rSZ99kPY9M>.

The uploaded protected MATLAB file in a *.p format requires a MATLAB version with a built-in Voronoi Tessellation and Delaunay Triangulation functions. The input variables are prepared in two different files for a parallel and perpendicular embedded layer orientations. Figure 5.6 shows the comparison between the experimental and numerical data as described in Sect. 4.2.

UFZ

The input files for OGS, which were used to simulate the three point bending test performed on the orthogonal and parallel laminations of Opalinus Clay samples, have been uploaded. The files include the unstructured finite element mesh files in vtu format and OGS input files in xml format. Also in the mesh files, the material properties are defined per element. Particularly for the orthogonal and the parallel Lamentations in the samples are represented through a contrast in the fracture tough-

Fig. 5.7 The load versus crack mouth opening displacement (CMOD) response simulations for orthogonal and parallel lamination by VPF

ness in the samples and can be found in the mesh files. The load and crack mouth opening displacement computed from the simulations are shown in 5.7 as described in Sect. 4.2.

MEX 0-1b (UFZ) will be also provided as an OGS benchmark case at: https://www.openeosys.org/docs/benchmarks/phase-field/pf_tpb_ani/.

Meta Data Overview (According to Dublin Core)

See (Tables 5.7 and 5.8)

Table 5.7 MEX 0-1b (CAU)

Data label	GeomInt, MEX 0-1b, CAU, Bending fracture test, Opalinus Clay
URL (Experiments)	https://nextcloud.ifg.uni-kiel.de/index.php/s/pJxp2eNEJb6PfS
URL (Numerics)	https://nextcloud.ifg.uni-kiel.de/index.php/s/ZBFN2rSZ99kPY9M
Subject	Bending fracture test, Opalinus Claye
Type of data	Experimental data, executable MATLAB P-file, input parameters
Subject	Bending fracture test, Opalinus Clay
Type of data	Experimental data, executable MATLAB P-file, input parameters
Data quality	Quality assured data
Status of data	Unprocessed data
Data format	txt, xlsx, MATLAB executable P-file
Creators	Kiel University, Institute of Geomechanics and Geotechnics, Ludwig-Meyn-Straße 10, 24118, Kiel
Source/Origin	In-house code
Publisher	Kiel University, Institute of Geomechanics and Geotechnics, Ludwig-Meyn-Straße 10, 24118, Kiel
Rights holders	Kiel University, Institute of Geomechanics and Geotechnics, Ludwig-Meyn-Straße 10, 24118, Kiel
Contributors	Kiel University, Institute of Geomechanics and Geotechnics: Amir Shoarian Sattari, Frank Wuttke
Time/period of creation	2018–2019
Language of the content	English
Update policy	Stored data is final
Access permissions	Full access

Table 5.8 MEX 0-1b (UFZ)

Data label	MEX 0-1b (UFZ)
URL	https://www.opengeosys.org/docs/benchmarks/
Subject	Bending fracture test, Opalinus Clay
Type of data	Data set (structured data in a defined format)
Data quality	Quality assured data by benchmarking
Status of data	Processed data
Data format	OGS files
Creators	Yoshioka, Keita
Source/Origin	Open source
Publisher	Helmholtz Centre for Environmental Research UFZ
Rights holders	Helmholtz Centre for Environmental Research UFZ
Contributors	Yoshioka, Keita
Time/period of creation	2019–2020
Language of content	English
Update policy	To be merged to OGS benchmarks (see below)
Access permissions	Free access

5.3.3 MEX 1-1: Swelling Process, Red Salt Clay

Participating institutions of MEX 1-1 (see Sect. 4.2): CAU, IfG (Table 5.9).

CAU Kiel

The required LEM code and the input variables for simulating the swelling process of the salt clay are uploaded to the IfG (Kiel) NextCloud server. The data is accessible through the following link: <https://nextcloud.ifg.uni-kiel.de/index.php/s/JmZseQqrsbgWNqC>.

The uploaded protected MATLAB file in a *.p format requires a MATLAB version with a built-in Voronoi Tessellation and Delaunay Triangulation functions. Fig. 5.8 shows the change of hydraulic conductivity with applied linear strains as described in Sect. 4.4.

Meta Data Overview (According to Dublin Core)

See (Table 5.10).

Table 5.9 MEX 1-1: Data overview

Type	Spec.	Owner	Access	Comment
EXP		IfG		Available on demand
MOD	LEM	CAU	Open	Executable MATLAB P-file
			Open	Input files available
MOD	DEM	IfG	Restricted	Please contact IfG

Fig. 5.8 The change of hydraulic conductivity with applied linear strains

Table 5.10 MEX 1-1 (CAU)

Data label	GeomInt—CAU—Swelling process, Red Salt Clay
URL (Numerics)	https://nextcloud.ifg.uni-kiel.de/index.php/s/JmZseQqrsbgWNqC
Subject	Swelling process (Red Salt Clay)
Type of data	Executable MATLAB P-file, input parameters
Data quality	Quality assured data
Status of data	Unprocessed data
Data format	txt, MATLAB executable P-file
Creators	Kiel University, Institute of Geomechanics and Geotechnics, Ludewig-Meyn-Straße 10, 24118, Kiel
Source/Origin	In-house code
Publisher	Kiel University, Institute of Geomechanics and Geotechnics, Ludewig-Meyn-Straße 10, 24118, Kiel
Rights holders	Kiel University, Institute of Geomechanics and Geotechnics, Ludewig-Meyn-Straße 10, 24118, Kiel
Contributors	Kiel University, Institute of Geomechanics and Geotechnics: Amir Shoarian Sattari, Frank Wuttke
Time/period of creation	2019–2020
Language of the content	English
Update policy	Stored data is final
Access permissions	Full access

5.3.4 MEX 1-2: Drying and Wetting Paths of the Opalinus Clay

Participating institutions of MEX 1-2 (see Sect. 4.5): CAU, UFZ (Table 5.11).

CAU Kiel

The experimental results of the drying and wetting paths of the sandy Opalinus Clay are uploaded to the IfG (Kiel) NextCloud server. The data is accessible through the following link: <https://nextcloud.ifg.uni-kiel.de/index.php/s/q6g25nWyWJKqzNB>.

The experimental data (*.xlsx) of drying and wetting paths are uploaded to the server. The data includes the reading number, time (day), stain values in perpendicular and parallel orientations, weight of the sample and measured water content values. Fig. 5.9 shows the change of the strains under the applied suction values.

The required LEM code and the input variables for simulating the drying and wetting paths of the sandy Opalinus Clay are uploaded to the IfG (Kiel) NextCloud server. The data is accessible through the following link: <https://nextcloud.ifg.uni-kiel.de/index.php/s/fDNoPoXpXMqeAsK>.

The uploaded protected MATLAB file in a *.p format requires a MATLAB version with a built-in Voronoi Tessellation and Delaunay Triangulation functions. Fig. 5.10 shows the change of hydraulic conductivity with applied linear strains as described in Sect. 4.5.

Meta Data Overview (According to Dublin Core)

See (Table 5.12).

Table 5.11 MEX 1-2: Data overview

Type	Spec.	Owner	Access	Comment
EXP	DRY	CAU	Open	Output files are uploaded
MOD	LEM	CAU	Open	Executable MATLAB P-file
			Open	Input files available
MOD	FEM	UFZ	Open	Branch to be merged into OGS
	VPF		Open	Input files available

Fig. 5.9 The suction versus linear strains

Fig. 5.10 The change of hydraulic conductivity with applied linear strains, Opalinus Clay

Table 5.12 MEX 1-2 (CAU)

Data label	GeomInt, MEX 1-2, CAU, drying and wetting paths, Opalinus Clay
URL (Experiments)	https://nextcloud.ifg.uni-kiel.de/index.php/s/q6g25nWyWJKqzNB
URL (Numerics)	https://nextcloud.ifg.uni-kiel.de/index.php/s/fDNoPoXpXMqeAsK
Subject	Drying and Wetting Paths (Opalinus Clay)
Type of data	Experimental data, executable MATLAB P-file, input parameters
Data quality	Quality assured data
Status of data	Unprocessed data
Data format	txt, xlsx, MATLAB executable P-file
Creators	Kiel University, Institute of Geomechanics and Geotechnics, Ludewig-Meyn-Straße 10, 24118, Kiel
Source/Origin	In-house code
Publisher	Kiel University, Institute of Geomechanics and Geotechnics, Ludewig-Meyn-Straße 10, 24118, Kiel
Rights holders	Kiel University, Institute of Geomechanics and Geotechnics, Ludewig-Meyn-Straße 10, 24118, Kiel
Contributors	Kiel University, Institute of Geomechanics and Geotechnics: Amir Shoarian Sattari, Frank Wuttke
Time/period of creation	2018–2020
Language of the content	English
Update policy	Stored data is final
Access permissions	Full access

Table 5.13 MEX 1-4: Data overview

Type	Spec.	Owner	Access	Comment
EXP	URL	BGR	Limited	UFZ DMP
MOD	FEM	UFZ	Open	OGS-5, OGS-6 versions
			Open	Input files available

5.3.5 MEX 1-4: CD/LP Experiment (BGR)

Participating institutions of MEX 1-4 (see Sect. 4.7): BGR (Table 5.13).

Link to the data set at UFZ data investigation portal (Download only for project members): www.ufz.de/record/dmp/archive/7471/.

The data set contains all project files that are relevant to reproduce the simulation results described in Sect. 4.7 and its corresponding subsections. For every simulation run with OGS-6, the data set comprises a project file (*.prj), a geometry file (*.gml) and the computational mesh (*.vtu). For simulations run with OGS-5, the project is split into files for boundary conditions (*.bc), initial conditions (*.ic), fluid properties (*.mfp), material properties (*.mmp), solid properties (*.msp), numerical parameters (*.num), output parameters (*.out), process definitions (*.pcs), tabulated functional dependencies (*.rfd), source terms (*.sc), and output parameters (*.out). In addition, separate files are provided for the geometry (*.gli) and the computational mesh (*.msh).

Meta Data Overview (According to Dublin Core)

See (Table 5.14).

5.3.6 MEX 2-1a: Pressure Driven Percolation in Salt

Participating institutions of MEX 2-1a (see Sect. 4.8): CAU, IfG, UFZ (Table 5.15).

UFZ

Link to the data set at UFZ data investigation portal (Download only for project members): <https://www.ufz.de/record/dmp/archive/7706/>.

The link contains two input decks for OGS-6 in which pressure driven percolation as described in MEX2 is simulated under different configurations of boundary loading. The first case applies the boundary loading of 12 MPa, 21 MPa, and 8 MPa in x-, y-, and z-direction respectively. It is called “case 1” and the corresponding OGS-6 input file is “me2_insitu_case1.prj”. The second case is loaded with 4 MPa, 15 MPa, and 19 MPa in x-, y-, and z-direction respectively and the input file is named “me2_insitu_case2.prj”. The remaining files are vtu files that describe the computing domain and the boundaries as shown in Fig. 4.58.

Table 5.14 MEX 1-4 (BGR)

Data label	GeomInt, MEX 1-4, BGR
URL	www.ufz.de/record/dmp/archive/7471
Subject	Clay stone, hydraulic-mechanical coupling
Type of data	Collection of various data
Data quality	Quality assured data
Status of data	Raw data
Data format	ASCII
Creators	Bundesanstalt für Geowissenschaften und Rohstoffe (BGR)
Source/Origin	Geological-Geotechnical Safety Analyses
Publisher	BGR, Stilleweg 2, 30655 Hannover
Rights holders	BGR, Stilleweg 2, 30655 Hannover
Contributors	Bernhard Vowinckel, Gesa Zieffle, Jobst Maßmann
Time/period of creation	01.12.2018–31.12.2019
Language of the content	English
Update policy	Stored data will not be extended
Access permissions	Limited access

MEX 2-1a (UFZ) will be also provided as an OGS benchmark case at: https://www.opengeosys.org/docs/benchmarks/phase-field/pf_perc/.

CAU Kiel

The required LEM code and the input variables of the percolation test on saltstone samples are uploaded to the IfG (Kiel) NextCloud server. The data is accessible through the following link: <https://nextcloud.ifg.uni-kiel.de/index.php/s/9JZZcpS4S3JIT9S>.

The uploaded protected MATLAB file in a *.p format requires a MATLAB version with a built-in Voronoi Tessellation and Delaunay Triangulation functions. The input variables are prepared in two files for two different stress configurations. Fig. 5.11 shows the crack surfaces under the percolation test as described in Sect. 4.8.

Meta Data Overview (According to Dublin Core)

See (Tables 5.16 and 5.17).

Table 5.15 MEX 2-1a: Data overview

Type	Spec.	Owner	Access	Comment
EXP	LIT	[2]	Restricted	Literature available online
MOD	LEM	CAU	License	Executable MATLAB P-file
			Free	Input files available
MOD	FEM	UFZ	Open source	via OpenGeoSys portal
	VFP		Free	I/O available

Fig. 5.11 The frack surfaces (red) under the percolation test, Saltstone

Table 5.16 MEX 2-1a (UFZ)

Data label	MEX 0-1a (UFZ)
URL	https://www.ufz.de/record/dmp/archive/7706/
Subject	Bending fracture test
Type of data	Data set (structured data in a defined format)
Data quality	Quality assured data by benchmarking
Status of data	Processed data
Data format	OGS files
Creators	Yoshioka, Keita
Source/Origin	Open source
Publisher	Helmholtz Centre for Environmental Research UFZ
Rights holders	Helmholtz Centre for Environmental Research UFZ
Contributors	Yoshioka, Keita; Wang Wenqing
Time/period of creation	2019–2020
Language of content	English
Update policy	To be merged to OGS benchmarks (see below)
Access permissions	Free access

Table 5.17 MEX 2-1a (CAU)

Data label	GeomInt CAU Percolation test, Saltstone
URI	https://nextcloud.ifg.uni-kiel.de/index.php/s/9JZZcpS4S3JIT9S (Numerics)
Subject	Percolation test (Saltstone)
Type of data	Executable MATLAB P-file, input parameters
Dataquality	Quality assured data
Status of data	Unprocessed data
Dataformat	txt, MATLAB executable P-file
Creators	Kiel University, Institute of Geomechanics and Geotechnics, Ludewig-Meyn-Straße 10, 24118, Kiel
Source/Origin	In-house code
Publisher	Kiel University, Institute of Geomechanics and Geotechnics, Ludewig-Meyn-Straße 10, 24118, Kiel
Rights holders	Kiel University, Institute of Geomechanics and Geotechnics, Ludewig-Meyn-Straße 10, 24118, Kiel
Contributors	Kiel University, Institute of Geomechanics and Geotechnics: Amir Shoarian Sattari, Frank Wuttke
Time/period of creation	2018–2020
Language of the content	English
Update policy	Stored data is final
Access permissions	Full access

5.3.7 MEX 2-1b: Pressure Driven Percolation, Opalinus Claystone

Participating institutions of MEX 2-1b (see Sect. 4.9): CAU, UFZ (Table 5.18).

CAU (LEM)

The experimental results of the pressure driven percolation test on the cubic Opalinus Clay samples are uploaded to the IfG (Kiel) NextCloud server. The data is accessible through the following link: <https://nextcloud.ifg.uni-kiel.de/index.php/s/EMdNkdF4PRKWCqa>.

Table 5.18 MEX 2-1b: Data overview

Type	Spec.	Owner	Access	Comment
EXP		CAU	Free	CAU-Cloud
MOD	LEM	CAU	Open	Executable MATLAB P-file
			Free	Input files available
MOD	FEM	UFZ	Open source	via OpenGeoSys portal
	VPF		Free	Input files available

Fig. 5.12 The recorded results depicting the evolution of the borehole pressure versus flow volume for the 1st stress configuration

The experimental data (*.ASCII) of two different stress configurations (Sect. 2.4.2) are uploaded to the server. The data includes the time ($\Delta T = 1s$), pump volume (mL), given oil pressure (Bar) and actual oil pressure in the system (Bar). Fig. 5.12 illustrates an example of the plotted borehole pressure versus flow volume for the 1st stress configuration discussed in the Sect. 4.9.

The required LEM code and the input variables of the percolation test on Opalinus Clay samples are uploaded to the IfG (Kiel) NextCloud server. The data is accessible through the following link: <https://nextcloud.ifg.uni-kiel.de/index.php/s/tFKKjxnSpgNG25b>.

The uploaded protected MATLAB file in a *.p format requires a MATLAB version with a built-in Voronoi Tessellation and Delaunay Triangulation functions. The input variables are prepared in two files for two different stress configurations. Fig. 5.13 illustrates an example of the evolved frack surfaces for the 2nd stress configuration discussed in the Sect. 4.9).

UFZ (FEM-VPF)

MEX 2-1b (UFZ) will be also provided as an OGS benchmark case.

Meta Data Overview (According to Dublin Core)

See (Tables 5.19 and 5.20).

5.3.8 MEX 2-2: Closure and Healing of Cracks (IfG)

Participating institutions of MEX 2-2 (see Sect. 4.10): IfG, UFZ (Table 5.21).

The measured gas flow is converted into permeabilities, which are stored as time series in an Excel file. For each of the three experiment there are two columns. The

Fig. 5.13 The frack surfaces (red) for the 2nd stress configuration

Table 5.19 MEX 2-1b (CAU)

Data label	GeomInt, MEX 2-1b, CAU, percolation test, Opalinus Clay
URL (Experiments)	https://nextcloud.ifg.uni-kiel.de/index.php/s/EMdNkdF4PRKWCqa
URL (Numerics)	https://nextcloud.ifg.uni-kiel.de/index.php/s/tFKKjxnSpgNG25b
Subject	Percolation test (Opalinus Clay)
Type of data	Experimental data, Executable MATLAB P-file, Input parameters
Data quality	Quality assured data
Status of data	Unprocessed data
Data format	txt, ASCII, MATLAB executable P-file
Creators	Kiel University, Institute of Geomechanics and Geotechnics, Ludwig-Meyn-Straße 10, 24118, Kiel
Source/Origin	In-house code
Publisher	Kiel University, Institute of Geomechanics and Geotechnics, Ludwig-Meyn-Straße 10, 24118, Kiel
Rights holders	Kiel University, Institute of Geomechanics and Geotechnics, Ludwig-Meyn-Straße 10, 24118, Kiel
Contributors	Kiel University, Institute of Geomechanics and Geotechnics: Amir Shoarian Sattari, Frank Wuttke
Time/period of creation	2018–2020
Language of the content	English
Update policy	Stored data is final
Access permissions	Full access

Table 5.20 MEX 2-1b (UFZ)

Data label	GeomInt, MEX 2-1b, UFZ, percolation test, Opalinus Clay)
URL	https://www.opengeosys.org/docs/benchmarks/
Subject	Bending fracture test
Type of data	Data set (structured data in a defined format)
Data quality	Quality assured data by benchmarking
Status of data	Processed data
Data format	OGS files
Creators	Yoshioka, Keita
Source/Origin	Open source
Publisher	Helmholtz Centre for Environmental Research UFZ
Rights holders	Helmholtz Centre for Environmental Research UFZ
Contributors	Yoshioka, Keita
Time/period of creation	2019–2020
Language of content	English
Update policy	To be merged to OGS benchmarks (see below)
Access permissions	Free access

Table 5.21 MEX 2-2: Data overview

Type	Spec.	Owner	Access	Comment
EXP	LAB	IfG	Limited	Available on demand
MOD	DEM	IfG	License	Commercial code
			Restricted	I/O: Available on demand
MOD	FEM	UFZ	Open source	via OpenGeoSys portal
	VPF		Free	I/O Available

first contains the time in hours since the start of the experiment, the second contains the permeability (Fig. 5.14).

Meta Data Overview (According to Dublin Core)

See (Table 5.22).

Table 5.22 MEX 2-2 (IfG)

Data label	GeomInt, MEX 2-2, IfG, pressure driven percolation (healing)
URL	http://www.ufz.de/record/dmp/archive/7588
Subject	Rissschließung Steinsalz
Type of data	Dataset (structured data in a defined format)
Data quality	
Status of data	
Data format	
Creators	IfG GmbH
Source/Origin	IfG GmbH
Publisher	IfG GmbH, Friederikenstraße 60, 04279 Leipzig
Rights holders	IfG GmbH, Friederikenstraße 60, 04279 Leipzig
Contributors	Mathias Nest,
Time/period of creation	2019
Language of the content	German
Update policy	
Access permissions	Limited access

Fig. 5.14 Graphical representation of data

5.3.9 MEX 2-3: Effect of Compressibility on Pressure Driven Percolation

Participating institutions of MEX 2-3 (see Sect. 4.11): CAU, IfG, UFZ (Table 5.23).

CAU Kiel

The required LEM code and the input variables for simulating the effect of compressibility are uploaded to the IfG (Kiel) NextCloud server. The data is accessible through the following link: <https://nextcloud.ifg.uni-kiel.de/index.php/s/6Mfg3P4PyKNN6By>.

The uploaded protected MATLAB file in a *.p format requires a MATLAB version with a built-in Voronoi Tessellation and Delaunay Triangulation functions. The input variables are prepared in two different files for the simulation of the pressure drop in gas and brine reservoirs. Fig. 5.15 shows the differences between the pressure drop in gas and brine reservoirs.

Meta Data Overview (According to Dublin Core)
See (Table 5.24).

Table 5.23 MEX 2-3: Data overview

Type	Spec.	Owner	Access	Comment
EXP	LIT	[2]	Restricted	Literature available online
MOD	LEM	CAU	License	Executable MATLAB P-file
			Free	Input files available
MOD	DEM	IfG	License	Commercial software
			Free	I/O available
MOD	FEM	UFZ	Open source	via OpenGeoSys portal
	VFP		Free	I/O available

Fig. 5.15 The comparison between the pressure drop in gas and brine reservoirs

Table 5.24 MEX 2-3: Meta Data according to Dublin Core

Data label	GeomInt, MEX 2-3, CAU, effect of compressibility, salt
URL (Numerics)	https://nextcloud.ifg.uni-kiel.de/index.php/s/6Mfg3P4PyKNN6By
Subject	Effect of compressibility (Saltstone)
Type of data	Executable MATLAB P-file, Input parameters
Data quality	Quality assured data
Status of data	Unprocessed data
Data format	txt, MATLAB executable P-file
Creators	Kiel University, Institute of Geomechanics and Geotechnics, Ludwig-Meyn-Straße 10, 24118, Kiel
Source/Origin	In-house code
Publisher	Kiel University, Institute of Geomechanics and Geotechnics, Ludwig-Meyn-Straße 10, 24118, Kiel
Rights holders	Kiel University, Institute of Geomechanics and Geotechnics, Ludwig-Meyn-Straße 10, 24118, Kiel
Contributors	Kiel University, Institute of Geomechanics and Geotechnics: Amir Shoarian Sattari, Frank Wuttke
Time/period of creation	2019–2020
Language of the content	English
Update policy	Stored data is final
Access permissions	Full access

5.3.10 MEX 2-4: Large Wellbore Test (Springen)

Participating institutions of MEX 2-4 (see Sect. 4.12): IfG (Table 5.25).

Meta Data Overview (According to Dublin Core)

See (Table 5.26).

The data set contains a measured pressure curve over time (50 days) during an injection test in a large wellbore (Springen URL). The injection regime was conducted in 5 bar increasing pressure steps followed by shut-in periods for observing the related pressure diffusion. Corresponding pumping rates were between 1–5.5 liters

Table 5.25 MEX 2-4: Data overview

Type	Spec.	Owner	Access	Comment
EXP	URL	IfG	Restricted	Available on demand
MOD	DEM	IfG	License	Commercial software
			Restricted	I/O available on demand

Table 5.26 MEX 2-4 (IfG)

Data label	GeomInt, MEX 2-4, IfG, large wellbore test, URL Springen
URL	In-house data storage
Subject	Integrity, tidiness of salt rocks for different fluids (gases and brines)
Type of data	Dataset (structured data in a defined format)
Data quality	Quality assured data
Status of data	
Data format	ASCII
Creators	IfG GmbH
Source/Origin	IfG GmbH
Publisher	IfG GmbH, Friederikenstraße 60, 04279 Leipzig
Rights holders	IfG GmbH, Friederikenstraße 60, 04279 Leipzig
Contributors	Mathias Nest
Time/period of creation	2018–2019
Language of the content	German
Update policy	Ongoing updates
Access permissions	Limited access

Fig. 5.16 Measured pressure curve data: $p(t)$

per second. Peak pressures of more than 60 bars were required to create in-situ discontinuities by overcoming the tensile/adhesive rock strength of salt. Additionally, acoustic emission (AE) data were recorded (Fig. 5.16).

5.3.11 MEX 3-1: CNL Direct Shear Test Data (TUBAF)

Participating institutions of MEX 3-1 (see Sect. 4.13): TUBAF (Table 5.27).
Link to the data set at UFZ data portal (DMP): www.ufz.de/record/dmp/archive/7925/.
The CNL data set contains four text files. One text file with the rock properties of the used granite (see Table 2.1). Two files with the scan data of the two surfaces. One point cloud can be seen in Fig. 5.17. The last file contains the laboratory data. In Fig. 5.18 the results for the four shear stress levels can be seen.

Meta Data Overview (According to Dublin Core) See (Table 5.28).

Table 5.27 MEX 3-1: Data overview

Type	Spec.	Owner	Access	Comment
EXP	LAB	TUBAF	Limited	Available, UFZ-DMP
MOD	FFS	TUBAF	Open source	Available via GitHub
			Free	I/O available

Fig. 5.17 Point cloud representing the surface of a granite sample from Saxony. The size is 65 mm by 170 mm and the cloud contains approx. 98000 points

Fig. 5.18 CNL test results

Table 5.28 MEX 3-1 (TUBAF)

Data label	GeomInt TUBAF Data Set CNL
URL	http://www.ufz.de/record/dmp/archive/7925
Subject	Crystalline rock, direct shear test
Type of data	collection of various data
Data quality	quality assured data
Status of data	processed data
Data format	txt, jpg, png
Creators	TU Freiberg, Institut fr Geotechnik, Gustav-Zeuner-Str. 1, 09599 Freiberg
Source/Origin	Rock mechanical laboratory
Publisher	TU Freiberg, Institut fr Geotechnik, Gustav-Zeuner-Str. 1, 09599 Freiberg
Rights holders	TU Freiberg, Institut fr Geotechnik, Gustav-Zeuner-Str. 1, 09599 Freiberg
Contributors	TU Freiberg, Institut fr Geotechnik, Thomas Frühwirt and Daniel Pötschke
Time/period of creation	2018–2019
Language of the content	English
Update policy	Stored data will not be extended
Access permissions	Limited access

Table 5.29 MEX 3-2: Data overview

Type	Spec.	Owner	Access	Comment
EXP	LAB	TUBAF	Limited	Available, UFZ-DMP
MOD	FFS	TUBAF	Open source	Available via GitHub
			Free	I/O available

5.3.12 MEX 3-2: CNS Test

Participating institutions of MEX 3-2 (see Sect. 4.14): TUBAF (Table 5.29).

Link to the data set at UFZ data management portal (DMP): <https://www.ufz.de/record/dmp/archive/7924/>.

The data set of the CNS test contains a file with the rock properties of the used basalt (see Table 2.1), two files with the scan data of the two surfaces. One point cloud can be seen in Fig. 5.19. The results of the laboratory tests are available as ASCII files and the shear curves and the dilatation are visualized in Fig. 5.20. Additionally three photos of the basalt surface before, after the first and after the fourth shear test are included.

Meta Data Overview (According to Dublin Core)

See (Table 5.30).

Fig. 5.19 Point cloud representing the surface of a basalt sample from Thuringia. The size is 196 mm by 149 mm and the cloud contains approx. 252000 points

Fig. 5.20 CNS test results

5.3.13 *MEX 3-3: Inverse Analysis of Reiche Zeche Data and Harmonic Testing of a Single Fracture*

Participating institutions of MEX 3-3 (see Sect. 4.15): UoS, UFZ (Table 5.31).

Link to the data set stored at the Gitlab server located at the Institute of Applied Mechanics, University of Stuttgart:

<https://galilei.isr.uni-stuttgart.de/gitlab/schmidt/geomint> (Fig. 5.21).

The uploaded data set contains two compiled executables for simulations to fit experimental data for the Reiche Zeche fracture characterization tests and to reproduce the non-linear flow response throughout harmonic testing of a single fracture

Table 5.30 MEX 3-2 (TUBAF)

Data label	GeomInt, MEX 3-2, TUBAF, Data Set CNS
URI	http://www.ufz.de/record/dmp/archive/7924
Subject	Crystalline rock, direct shear test
Type of data	collection of various data
Dataquality	quality assured data
Status of data	processed data
Dataformat	txt, jpg, png
Creators	TU Freiberg, Institut fr Geotechnik, Gustav-Zeuner-Str. 1, 09599 Freiberg
Source/Origin	Rock mechanical laboratory
Publisher	TU Freiberg, Institut fr Geotechnik, Gustav-Zeuner-Str. 1, 09599 Freiberg
Rights holders	TU Freiberg, Institut fr Geotechnik, Gustav-Zeuner-Str. 1, 09599 Freiberg
Contributors	TU Freiberg, Institut fr Geotechnik, Thomas Frühwirt and Daniel Pötschke
Time/period of creation	2018–2019
Language of the content	English
Update policy	Stored data will not be extended
Access permissions	Limited access

Table 5.31 MEX 3-3: Data overview

Type	Spec.	Owner	Access	Comment
EXP	LAB	UoS	Free	UoS Cloud / GitLab
MOD	HDF	UoS	Open source	Executable available
			Free	I/O available
MOD	FEM	UFZ	Open source	via OpenGeoSys portal
	VFP		Free	I/O available

on the laboratory scale like described in Sect. 4.15. The folder includes executables, input files and the used discretization in terms of meshing files, required to perform the simulations. README.txt files provide further information how to start the simulations.

Meta Data Overview (According to Dublin Core)

See (Table 5.32).

Fig. 5.21 Visualisation of data obtained from the pre-compiled executable used for inverse analysis computations of pumping tests performed at Reiche Zeche at a depth of 40.6 m

Table 5.32 MEX 3-3: Reiche Zeche Data

Data label	GeomInt, MEX 3-3, UoS, Data Set Reiche Zeche
URL	https://galilei.isr.uni-stuttgart.de/gitlab/schmidt/geomint
Subject	Non-linear hydro-mechanics / fracture flow
Type of data	Executable, mesh input, parameter input
Data quality	Quality assured data
Status of data	Unprocessed data
Data format	txt, msh, linux executable
Creators	University of Stuttgart, Institute of Applied Mechanics—Continuum Mechanics, Pfaffenwaldring 7, 70569 Stuttgart
Source/Origin	In-house code
Publisher	University of Stuttgart, Institute of Applied Mechanics—Continuum Mechanics, Pfaffenwaldring 7, 70569 Stuttgart
Rights holders	University of Stuttgart, Institute of Applied Mechanics—Continuum Mechanics, Pfaffenwaldring 7, 70569 Stuttgart
Contributors	University of Stuttgart, Institute of Applied Mechanics—Continuum Mechanics, Patrick Schmidt and Holger Steeb
Time/period of creation	2018–2019
Language of the content	English
Update policy	Stored data is final
Access permissions	Full access

References

1. A. Tarokh, C.-S. Kao, A. Fakhimi, and J.F. Labuz. Spalling and brittleness in surface instability failure of rock. *Geotechnique*, 66(2):161–166, 2016. cited By 5.
2. W.P. Kamlot. *Habilitationsschrift: Gebirgsmechanische Bewertung der geologischen Barrierefunktion des Hauptanhydrits in einem Salzbergwerk*. des Instituts für Geotechnik der Technischen Universität Bergakademie Freiberg, 2009.

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