Module Handbook

For the study program

Master of Science Geosciences

Institute of Geosciences

1. Introduction to the Handbook

This module handbook provides an overview of the MSc Geosciences curriculum at the Institute of Geosciences of the Ruhr University Bochum. It outlines the modular structure of the program and offers guidance for planning and throughout your studies. The central focus is on descriptions of the currently available modules.

1.1. Advice (Beratung)

Advisor **(Fachberater):** Prior to commencing your studies, you are required to arrange an advisory meeting with either a preferred professor or the study counselor at the *Institute of Geosciences*. During this meeting, a comprehensive study plan, including module selection, is collaboratively established based on your interests. This plan is subject to approval by the examination committee and serves as a binding agreement. One adjustment is allowed within the first year, and additional changes are possible in unavoidable circumstances, such as the unavailability of a specific course. Your advisor, typically also your MSc thesis advisor, can be changed during your studies, if desired

The *Institute of Geosciences* is committed to barrier-free learning. In order to offset disadvantages, the Institute offers individualized alternative plans for measurement of all kinds of performance to students with documented needs.

Board of Examination **(Prüfungsausschuss):** Should you have questions or problems that you cannot resolve with your advisor, members of the Board of Examinations or the Chair of the Board of Examinations are to be addressed.

Student council **(Fachschaft):** You can always seek tips, help and advice from your senior cohorts at the student council.

1.2. Plan of studies (Studienplan)

The plan of study is fully flexible and is set up individually for each student through discussions with the advisor (see above) at the beginning of the study program.

2. Module descriptions

<table>
<tr><td colspan="6">Applied geophysics</td></tr>
<tr><td>Module number</td><td>Credits
10 CP</td><td>Workload
300 h</td><td>Term
2. Sem.</td><td>Frequency
SS</td><td>Duration
1 semester</td></tr>
<tr><td colspan="3">Courses
a) Reservoir geophysics (SS)
b) Rock physics (SS)</td><td>Contact hours
a) 3 SWS
b) 3 SWS</td><td>Self-Study
a) 120 h
b) 90 h</td><td>Group size
Acc. to demand, lab experiments in groups of 3 persons</td></tr>
</table>

Prerequisites:

Formal:

Textual: Sound mathematical skills (vector calculus, differential- and integral calculus).

Preparation: -

Learning outcomes

After successful completion of the module students

- appreciate the scale-dependent approach to the physical characterization of rocks (micro- to decimeter-scale) and reservoirs (deci- to kilometer-scale).
- understand the relation between physical properties of rocks and their chemical composition and microstructure.
- learned the use and limits of empirical and theoretical concepts for the description of heterogeneous media.
- know the practical aspects of a suite of methods in exploration geophysics.
- are familiar with the mathematical description of physical processes on rock and reservoir scale.
- understand the origin of the governing partial differential equations and master some approaches to their solution.

Content

a) Reservoir geophysics (large-scale perspective)

- Introduction to reservoirs (hydrocarbon, geothermal)
- Physical properties of reservoir fluids
- Hydraulic transport (Kozeny-Carman relation) and storage (linear poro-elasticity I: isostatic stress states)
- Theory and practice of pumping tests (diffusion equation, scaling)
- Geothermics (add advection to diffusion)
- Aspects of waves in real media (wave equation, linear poro-elasticity II: add deviatoric stresses)

b) Rock physics (small-scale perspective)

- Introduction to rocks and minerals
- Porosity and interface phenomena
- Hydraulic transport in rocks (Darcy's law, permeability models)
- Elasticity (stress, strain, Hooke's law, averaging schemes)
- Failure of rocks (fracture and friction)

+ Lab practical: students independently conduct simple experiments to determine basic physical properties of rocks (density, porosity, permeability) and fluids (density, viscosity)

Teaching methods

Lectures, assignments (deepening of contents through own research, solving of analytic and numerical problems), laboratory experiments

Mode of assessment

Written final exam (3 hours), report on lab experiments
Requirements for the award of credit points Passed module exam (at least 50%)
Module applicability (to other study programs)
Weight of the mark for the final score: 10 CP of 120 CP
Module coordinator and lecturer(s): Prof. Dr. Jörg Renner (coordinator)
Further information: **Literature:** Jaeger, Cook, Zimmerman “Fundamentals of Rock Mechanics”; Gueguen, Palciauskas “Introduction to the physics of rocks“; Schön “Physical properties of rocks“; Mavko, Mukerji, Dvorkin “The rock physics handbook“; AGU reference shelf “Rock physics and phase relations“; Sully “Elements of petroleum geology”; Wang “Theory of linear poro-elasticity”; Fetter “Applied hydrogeology”; Zoback “Reservoir geomechanics”; Carcione “Wave-fields in real media”

Geophysical field practical

Module number	Credits	Workload	Term	Frequency	Duration
	5 CP	10 h	1. Sem.	SS	1 semesters

Courses	Contact hours	Self-Study	Group size
a) Field practical	3 SWS	40h	18 students

Prerequisites

Formal: Completion of physics or geophysics modules in your BSc. degree

- Programming; either:

Introduction to python programming

or

Introduction to programming in Matlab

Learning outcomes

After successful completion of the module, students

- are able to plan and set up a field campaign, choose appropriate methods and instruments, carry out measurements and use available techniques to analyse the data and model uncertainties when given a geophysical survey task.

Content

Students plan and organize a geophysical field campaign to investigate a specific subsurface target using a specifically selected combination of geophysical survey methods, such as seismics, magnetics, geoelectrics, ground penetrating radar or gravimetry. Data are acquired in the field and analysed in the field. Classroom time will be for extra analysis and interpretation. Students also learn how to georeference the data with RTK GNSS measurements with the aim of publishable quality datasets. Programming skills are employed to prepare and organize data and to visualize results for further interpretation.

Teaching methods

- - Safety preparatory meeting
- - Self study of the methods before fieldwork
- - 3 full days of fieldwork in a 4 day trip to the Eifel (in August).
- - 2 full days of data interpretation in the classroom on campus after fieldwork is completed

Mode of assessment

Students need to submit correctly formatted and labelled datasets, present results in evening sessions during the fieldwork, demonstrate progress during classroom sessions, and submit a report

Requirement for the award of credit points

Achieve >= 50% of the total available points in the assessed parts of the module.

Module applicability

Weight of the mark for the final score: 4.17 % of the final score (5 of 120 CP) for MSc students.

Module coordinator and lecturer(s): Prof. Dr. Jonathan Bedford; Prof. Dr. Harrington, Dr. Kasper Fischer + Q-Stelle of TG and EP groups.

Further information

Enrolled students will be contacted early in the semester for practical details regarding dates of safety briefing and fieldwork, and also the payment of travel and accommodation costs. Students who do not respond within the given deadlines will not be able to complete the module. Applied Geophysics, 2nd Ed., Telford, Geldart, Sheriff, Cambridge Univ. Press

Geophysical practical					
Module number	**Credits** 5 CP	**Workload** 150 h	**Term** 1., 2. or 3. Sem	**Frequency** every semester	**Duration** 1 semester
Courses			**Contact hours** 20 days	**Self-Study**	**Group size**

Prerequisites:

Formal: None

Textual: None

Preparation:

Learning outcomes

After successful completion of the module students

- are able to formulate and continuously adapt a work plan for a month.
- appreciate the integration of their work into a team effort.
- have deepened their command of specific tools and their insight into specific geophysical problems.
- are familiar with typical work processes in geophysics-related companies and are able to work through a well-defined geophysics-related operational task in a structured way within a given time.

Content

Students spend 20 days in a company or a working group of the institute, where they are integrated into operational work processes and work on theoretical or practical tasks related to the research activities of the company or working group.

Teaching methods

Team work, project work

Mode of assessment

Report

Requirements for the award of credit points

Assessment of a written report by the advisor

Module applicability (to other study programs)

Weight of the mark for the final score: 5 CP of 120 CP

Module coordinator and lecturer(s): Prof. Dr. Bedford , Prof. Dr. Renner, Prof. Dr. Harrington

Further information

Geophysical Seminar					
Module number	**Credits** 6 CP	**Workload** 180 h	**Term** WS/SS	**Frequency** Every semester	**Duration** 2 semesters
Courses a) Deformation mechanisms and tectonics of subduction zones b) Induced and triggered seismicity seminar			**Contact hours** (a) 2 SWS (b) 2 SWS	**Self-study** (a) 75 h (b) 75 h	**Group size** (a) 30 students (b) 30 students

Prerequisites

The course module is open to all MSc students with a background in the Earth sciences (BSc degree) who are scheduled to complete an MSc. Project in the working groups of Prof. Dr. Harrington, Prof. Dr. Renner, or Prof. Dr. Bedford.

Learning outcomes

After successful completion of the module, students will

- understand the different causes of induced earthquakes, including fluid injection from unconventional energy production, mining, gas/fluid extraction.
- be familiar with the geological settings and controls in which earthquakes are produced.
- understand and describe the statistical properties of induced earthquakes, as well as the current understanding of correlations between injection parameters and event magnitude.
- be familiar with the competing influence of effective vs. poroelastic stress transfer in the role of generating fault failure, as well the current related scientific studies.
- understand the chemical and mechanical differences in the brittle-ductile transition zone, and the relation to seismic vs. aseismic slip generation.
- have a quantitative understanding of the different types of slip events that generate a spectrum of seismic and aseismic signals, including tectonic tremor and LFEs, and slow-slip events.
- understand methods for detecting accelerations in plate motions across observational scales.
- understand the history and developments toward the current state of the art analytical, numerical, and analog models for earthquake cycle deformation.
- understand the role of both seismic, geological, and geodetic data in the assessment of seismic hazard.

Content

Overview of induced earthquakes in the context of fluid flow near faults and fault systems, the influence of lithology and geology on generating induced earthquakes, statistics and source properties of induce earthquakes, earthquakes induced by reservoir impoundment, gas extraction, enhanced geothermal systems, wastewater and hydraulic fracturing injection, physical mechanisms that induce fault slip, the seismogenic and brittle-ductile transition zone in the crust, seismic and geodetic signals from the seismogenic and fault transition zone, slow earthquakes and triggering of earthquakes at shallower depths, slow earthquakes as stress meters, the rock record of fault slip, experimental work on slow earthquakes, tectonic tremor, transition zone evolution after large earthquakes, resolution limits of current geophysical observation networks, selection of modeling approaches for on- and off- fault deformation, rate-and-state friction equations and their application in numerical modeling and observational data from real fault zones.

Teaching methods

Courses (a) and (b) are held in a group discussion format.

Mode of assessment

The course consists of scientific paper discussion in both (a) and (b). The paper discussion in (a) and (b) must be evaluated a passing grade (50%).

Requirements for the award of credit points Passing grades for courses (a) and (b) require the presentation/leading of one reading topic and active participation in 70% of the discussions.
Module applicability
Weight of the mark for the final score 5% of the total grade (6/120 CPs)
Module coordinator and lecturer(s) Prof. Dr. Rebecca Harrington, Dr. Marco Roth, Dr. David Essing, Prof. Dr. Bedford, Prof. Renner
Further information

Physics of the solid Earth

Module number	**Credits**	**Workload**	**Term**	**Frequency**	**Duration**
	10 CP	300 h	1. + 3. Sem.	WS	2 semesters

Courses	**Contact hours**	**Self-Study**	**Group size**
a) Continuum mechanics b) Physics of Earth materials (	a) 3 SWS b) 3 SWS	a) 110 h b) 100 h	acc. to demand

Prerequisites

Formal:

Textual: Sound mathematical skills (vector calculus, differential and integral calculus)

Preparation: -

Learning outcomes

After successful completion of the module students

- know micromechanical/atomistic concepts behind bulk properties (in particular density and viscosity).
- appreciate the basic theoretical concepts of solid-state physics and thermodynamics.
- are familiar with the basic approaches and techniques in continuum mechanics.
- understand the basic concept of numerical solution of differential equation master.
- are capable of coding simple finite-difference schemes.
- grasp the relevance of physical properties of rocks for geodynamic problems, such as subduction and delamination.
- can apply the introduced mathematical tools to problems encountered for the three Earth spheres: atmosphere, hydrosphere, and geosphere.

Content

a) Continuum Mechanics

- Differentiation and integration of scalar and vectorial fields.
- Kinematics (Euler and Lagrange description).
- Conservation laws in differential and integral form (Navier-Stokes equations).
- Applications (specific cases of the Navier-Stokes equations and similarity numbers).

b) Physics of Earth materials

- Geophysical and geochemical Earth models.
- Elastic constitutive equations for minerals at high temperature and pressure.
- Crystal defects (point defects, dislocations, grain boundaries).
- Deformation mechanisms at high temperatures (diffusion and dislocation creep).
- Applications of flow laws to geodynamic problems.

Teaching methods

Lectures, assignments (deepening of contents through own research, solving of analytic and numerical problems including programming of a finite-difference algorithm).

Modes of assessment

Written module exam (3 hours)

Requirement for the award of credit points

Passed module exam (at least 50%)

Module applicability (to other study programs)

Weight of the mark of the final score: 10 CP of 120 CP

Module coordinator and lecturer(s): Prof. Dr. Jörg Renner (Coordinator)

Further information:
Literature: Schubert, Turcotte, Olson "Mantle convection in the Earth and Planets"; Karato "The dynamic structure of the deep Earth"; Anderson "New theory of the Earth"; Poirier "Creep of crystals"; Hirth, Lothe "Theory of dislocations"; Gerya "Numerical geodynamic modeling"; Holzapfel "Nonlinear solid mechanics"; Tritton "Physical fluid dynamics";

Earthquake processes					
Module number	**Credits** 6 CP	**Workload** 180 h	**Term** 2. Sem.	**Frequency** SS	**Duration** 1 semester
Courses Earthquake seismology and the seismic cycle			**Contact hours** 4 SWS	**Self-study** 120 h	**Group size** 30 students

Prerequisites

The course module is open to all MSc students with a background in the Earth sciences (BSc degree). It has a co-requisite of Physics of the Solid Earth II.

Learning outcomes

After successful completion of the module, students will be able to

- understand and explain earthquake source parameters such as seismic moment, magnitude, static stress drop, radiated energy, and spectral corner frequency.
- understand how earthquake source parameters are measured and quantified, such as via fault plane solutions, moment tensors, directivity.
- understand and explain empirical earthquake relations, such as the Gutenberg-Richter magnitude-frequency relation, Omori's Law.
- understand the basics of seismic signal processing and its applications to studies of earthquakes.
- understand and explain the relation between earthquake occurrence and friction on fault surfaces, as well as fracture mechanics models of earthquakes.
- understand and explain the earthquake cycle and the occurrence of intraplate and interpolate earthquakes.
- relate earthquake triggering and induced earthquakes to tectonic and stress loading, and identify possible earthquake triggers.
- understand and describe physical characteristics and underlying mechanisms of the various types of volcanic seismic signals observed at active volcanoes.

Content

Topics included in the course include: Earthquake source studies (focal mechanisms, moment tensors, directivity, seismic moment, source spectra and scaling laws, energy partitioning, stress drop and radiated energy), earthquake statistics, fundamentals of seismic signal processing, fracture mechanics and its relation to rate-state friction, fault friction and the effects of temperature and pressure at depth, earthquake cycle deformation and the spectrum of fault slip, inter- and intraplate earthquakes, fault drilling, volcanic earthquakes, and triggered and induced earthquakes.

All lecture materials are digitally available via the course Moodle, and student projects are strongly encouraged to incorporate digital data processing. Lectures and paper discussion occur in English.

Teaching methods

Lecture period of 1,5 hours/week followed by paper discussion and/or exercises of 1,5 hours/week.

Mode of assessment

Final report weighted 70% for the written component (with a 10-week working period), with the remaining 30% weight being placed on the oral presentation the last week of the lecture period. Paper discussion/exercises will be evaluated based on participation, and must be completed with a passing grade of 60% in order to submit the final report.

Requirements for the award of credit points

Passing grade for the paper discussion entitles the course participant to submit the Module Exam (term project). Term project presentation with a passing grade (written and oral parts will be combined for a total number of points).
Module applicability (in other majors)
Weight of the mark for the final score 5% of the total Grade (6/120 CPs)
Module coordinator and lecturer(s) Prof. Dr. Rebecca Harrington
Further information *Helpful texts (not required):* Stein, S. and M. Wyssession, Introduction to Seismology, Earthquakes, and Earth Structure, Blackwell Publishing, 2003 Scholz, C. H., The Mechanics of Earthquakes and Faulting, 2nd Ed., Cambridge University Press, 2002

Geology and geohazards in an active subduction zone					
Module number	**Credits** 5 CP	**Workload** 150 h	**Term** 2. Sem.	**Frequency** SS	**Duration** 1 semester
Courses Geology and geohazards in an active subduction zone			**Contact hours** 3 SWS	**Self-study** 100 h	**Group size** 16 students (maximum)

Prerequisites

Open to all MSc students who have successfully completed either the "Earthquake Processes" or "Seismotectonics and Seismic Hazard" module. Successful completion of a structural geology and a fundamental geologic mapping course are also prerequisites.

Learning outcomes

After successful completion of the module, students will

- be able to assess and quantify uplift associated with large thrust fault earthquakes (e.g., Mw 8.3 July 365 CE earthquake in the Hellenic subduction zone) and recent uplift based on current location of tectonic units.
- recognize and map tsunami landscapes and associated deposits.
- map fault surface trace orientations, measure kinematic indicators, and quantify associated displacement. Use observations collected in the field to estimate regional stress field orientations through stereographic projections.
- measure fold elements and estimate the stress field through stereographic projections.
- perform earthquake locations using NonLinLoc (open source program) and assess possible associated geo-hazards given the obtained hypocentral coordinates and magnitudes.
- use the seismotectonic setting and earthquake locations to evaluate tsunami hazard and estimate an early warning time window.

Content

This block course will give an introduction to the world of earthquake and tsunami hazards in an active subduction zone, associated geological and seismological observations, and the methods used to study them. It will explore the fundamental mechanics of faulting in an active subduction zone through a combination of fieldwork that examines along arc extension, compression related to the subduction thrust, and kinematic/structural indicators of deformation. It will also explore onshore evidence of subduction thrust movement, including normal faulting in the forearc, archeological evidence of large historical earthquakes, and tsunami deposits. In addition, current deformation as evidenced by earthquakes will be explored through exercises using seismic data and analysis that combines theoretical, observational, and field perspectives. A preparatory 3-hour lecture block will take place prior to a 7-day trip that will consist of 1.5 days of lecture/data analysis, and five days of field work. The course is open to MSc students.

Teaching methods

Course will consist of a combination of lecture format with digital materials, group discussion format, and exercises using open-source software and digital forms of data, and which digitize field observations.

Mode of assessment

Evaluation of the report due after the completion of course.

Requirements for the award of credit points

Passing grade for the course.

Module applicability

Weight of the mark for the final score

4,2% of the total grade (5/120 CPs)

Module coordinator and lecturer(s)
Prof. Dr. Rebecca Harrington, Dr. Gian Maria Bocchini, Dr. Alessandro Verdecchia
Further information

Seismotectonics and seismic hazard

Module number	Credits	Workload	Term	Frequency	Duration
	6 CP	180 h	1. Sem.	WS	1 semester

Courses	Contact hours	Self-study	Group size
Seismotectonics and seismic hazard	4 SWS	120 h	15 students

Prerequisites

Students must have successfully completed a BSc in the earth sciences. The course consists of exercises and lecture; exercises must be completed with a passing grade (60%) to access to the final exam on which the module grade will be based. It has a co-requisite of Physics of the Solid Earth II.

Learning outcomes

After successful completion of the module, students will be able to

- understand the relationship between lithosphere rheology and earthquake distribution.
- understand the relationship between frictional properties and faulting.
- understand the basics of earthquake detection and location.
- understand the relationship among subsequent earthquakes (earthquake and fault interactions).
- understand the primary (faulting) and secondary (liquefaction, landslides, etc.) effects produced by seismic events.
- understand the basics of Tectonic Geodesy.
- understand the basics of Tectonic Geomorphology.
- understand the basics of Paleoseismology.
- understand the basics of probabilistic and deterministic seismic hazard calculations.

Content

A multidisciplinary approach is strongly needed in order to better quantify the seismic potential of any region in the world. Geological data give us a long-term (~1000 years) view of earthquake phenomena, but they are limited to the first meters of the crust. Seismological and geophysical data can generally better describe deformation processes occurring at depth, but usually with a smaller temporal (tens of years) and spatial resolution. This course will provide an introduction to the earthquake problem from both geological and geophysical points of view, with emphasis on the methodologies commonly used to produce the data necessary to understand and quantify the seismic hazard in any active region.

Topics included in the course are: rheology of the lithosphere, frictional properties of faults, the seismic cycle, earthquake location, geological effects of earthquakes, tectonic geodesy, tectonic geomorphology, paleoseismology, earthquake and fault interactions, probabilistic and deterministic seismic hazard.

In addition to theoretical information presented via lecture material, the practical exercises teach fundamental data analysis via MATLAB, and other software distributed during the course.

Teaching methods

Lecture period of 1,5 hours/week with practical exercises of 1,5 hours/week. Exercises are completed primarily in digital format (basic programming in Matlab).

Mode of assessment

Exercises must be completed with a passing grade of 60% in order to access the final exam.

The grade of the module is based on the grade of the final written exam.

Requirement for the award of credit points

Exercises must be completed with a passing grade of 60% in order to access the final exam.

The module grade is based on the final exam grade.
Module applicability
Weight of the mark for the final score 5% of the total grade (6/120 CPs)
Module coordinator and lecturer(s) Prof. Dr. Rebecca Harrington, Dr. Alessandro Verdecchia
Further Information *Helpful texts (not required):* **Structural Geology**, Haakon Fossen, Cambridge University Press, 2013. **The Geology of Earthquakes**, R. S. Yeats, K. Sieh and C. R. Allen, Oxford University Press, 1997. **The Mechanics of Earthquakes and Faulting**, C. H. Scholz, Cambridge University Press, 2012. **Paleoseismology**, J. P. McCalpin, Academic Press, 2nd Ed.

<table>
<tr><td colspan="6">Python programming for Geosciences</td></tr>
<tr><td>Module number</td><td>Credits
10 CP</td><td>Workload
300 h</td><td>Term
1. + 2. Sem.</td><td>Frequency
WS, SS</td><td>Duration
2 semester</td></tr>
<tr><td colspan="3">Courses
a) Introduction to programming in Python
b) Advanced programming in Python</td><td>Contact hours
a) 3 SWS
b) 3 SWS</td><td>Self-Study
105 h
105 h</td><td>Group size
Max. 30</td></tr>
<tr><td colspan="6">Prerequisites
No programming skill or knowledge is required to attend course a). Students should have basic computer literacy, such as knowing how to navigate folders, manage files, and use standard applications on their operating system.
To attend course b) either course a) needs to be passed or a similar course from other faculties needs to be documented when registering for the course.
Preparation: Installing anaconda and reading its documentation on managing module environments.</td></tr>
<tr><td colspan="6">Learning outcomes
After successful completion of the module, students will
•have the programming skills to perform basic signal processing and data analysis on different types of time series signals, such as seismic and geodetic signals, and to visualize results digitally.
•Have the programming skills to scrap publicly available types of geo-data from public repositories and visualize data through maps and other types of plots.</td></tr>
<tr><td colspan="6">Content
a) Installation and setup of programming environment (python) and additional modules and packages. Teaching will give knowledge about data types, mathematical operations and functions, reading various input formats, writing output files, characters and strings, arrays and loops, conditional statements, subroutines and functions, derived data types, polymorphic types and classes, numerical and statistical methods, basic visualization, geographic visualization. Basic time-series analysis applications, application of concepts to geophysical problems.
b) Digital analysis of time-series signals including, setup of analysis software packages (ObsPy), making maps, downloading and analyzing seismic waveforms and GNSS data, earthquake catalog data, picking seismic phases, analyzing earthquake source parameters, and visualizing all results.</td></tr>
<tr><td colspan="6">Teaching methods
Course format consists of lectures and accompanying exercises.</td></tr>
<tr><td colspan="6">Mode of assessment
Evaluation of written programs and oral presentation of assignments.</td></tr>
<tr><td colspan="6">Requirement for the award of credit points
Submission of programming work, oral presentation</td></tr>
<tr><td colspan="6">Module applicability (to other study programs)</td></tr>
<tr><td colspan="6">Weight of the mark for the final score: 8,3 % of final grade (10 CP of 120 CP)</td></tr>
<tr><td colspan="6">Module coordinator and lecturer(s): Dr. David Essing, Dr. Marco Roth</td></tr>
<tr><td colspan="6">Further information
Literature: Python online documentation and tutorials.
Introduction courses http://seismo-live.org (by Lion Krischer) and the http://edx.org web course "Introduction to Computer Science and Programming Using Python"</td></tr>
</table>

Introduction to programming in Matlab

	Credits	Workload	Semester	Frequency	Duration
	6 CP	180 h	2. Sem.	SS	1 Semester

Courses	Contact hours	Self-study	Group size
Introduction to Matlab	4 SWS	120 h	Max. 30

Prerequisites

Learning outcomes

After completing this course, students will be able to perform basic programming in Matlab aimed at problems in the Geosciences, including:

- Inputing and outputting data files of mixed content and of any size, including strings, and numerical data
- Manipulate and analyze data using mathematical operations, loop statements, switch statments, selection statements, and vectorized codes
- Store and manipulate data using structures
- Visualize data by plotting, including 2D and 3D plots with specialized symbols, legends, and labels
- Perform curve fitting and interpolation of data

Content

Modern Earth and environmental scientists deal with complex and often very large quantitative datasets that are typically not useful or understandable in raw form. Thus, quantitative data analysis skills are highly desired and useful in quantitative Earth science subdisciplines. This course provides an introduction to processing, visualizing, and interpreting quantitative Earth and environmental science data using scientific widely used computing techniques. Computational methods and visualization will be performed using the scientific computing language, MATLAB. Previous programming experience is not required. Weekly meetings introduce the necessary theoretical and computational background to complete weekly assignments that demonstrate applications to Earth science data. The weekly assignments will involve writing algorithms that use quantitative methods to process and visualize data relevant to the Earth sciences. Expected topics to be covered may include Earth science applications of: conditional statements, loops, vector and matrix operations, importing data, automated data analysis & visualization (including 3D visualization), differentiation, interpolation, curve fitting, error estimation and propagation, and linear regression and confidence interval estimation.

Teaching methods

Weekly lecture + interactive exercise meetings (90 + 90 minutes)

Mode of assessment

Evaluation is based on the points given for weekly assignments (70% of the grade) and discussion (30% of the grade).

Requirement for the award of credit points

Passing grade on weekly assignments (> 50%) which count 70% of the course grade, weekly discussion 30% of the final grade.

Weight of the mark for the final score

5% of final grade (6 CP of 120 CP)

Module coordinator and lecturer(s)

Prof. Dr. Rebecca Harrington

Further information

Literature: Matlab: A Practical Introduction to Programming and Problem Solving, Edition 4, S. Attaway

Measuring Earth surface motions with InSAR and GNSS					
Module number	**Credits** 6 CP	**Workload** 180 h	**Term** WS	**Frequency** Each WS	**Duration** 1 semester
Courses Measuring Earth surface motions with InSAR and GNSS			**Contact hours** 4 SWS	**Self-study** 120 h	**Group size** 18 students
Prerequisites For students enrolled in MSc programs. For BSc this is a supplementary module (Ergänzungsmodul), prerequisites are successful completion of the BSc modules mathematics and physics.					
Learning outcomes • After completion of the module the student will be able to: • Understand the principles of how GNSS and InSAR are used to measure surface deformation. • Understand and reproduce the static surface deformation induced by earthquake, volcanic, and anthropogenic processes using simple models. • Recognize the quality of solutions and diagnose sources of error in InSAR and GNSS measurements. • Recognize shallow (anthropogenic) and deep (solid-earth) signals in InSAR and GNSS data. • Recover earthquake, volcanic, and anthropogenic surface deformation signals from raw InSAR data using SNAP ESA software.					
Content This course will provide an introduction to the principles of Earth surface displacements derived from Global Navigation Satellite Systems (GNSS) and Interferometric Synthetic Aperture Radar (InSAR) applied to tectonic, volcanic, and anthropogenic signals. Interpretations of the data will be taught with simple models such as elastic surface loading models, fault-slip dislocation models, and Mogi-source models. For GNSS we will cover topics including reference frames, the earthquake cycle, volcanic signals, and seasonality. For InSAR, we will cover topics including SAR technology, amplitude and phase, the challenges in retrieving surface displacements due to tropospheric and topographic effects, and orbital errors.					
Teaching methods 2 hours per week lecture. 2 hours per week practical in the computer lab. Each week, we will introduce new concepts in the 2 hour lectures. This will be followed by a 2 hour practical in which students learn how to explore features of surface deformation data. Notably, students will learn how to use an InSAR processing software, SNAP, to process their own surface deformation maps from raw InSAR SLC data.					
Mode of assessment Weekly quizzes during first 9 weeks: The best 5 results from 9 quizzes will be counted towards 60% of the final grade. 10% of the grade will be assessed from participation. 30% will come from a final and individual poster presentation that takes place at the end of the teaching semester. The preparation of these posters begins in week 9.					
Requirement for the award of credit points Successful completion of weekly quizzes and poster.					
Module applicability The course is open to students from both BSc and MSc programs, however, due to limited number of potential participants, priority is given to students from BSc and MSc programs in Geoscience.					

Weight of the mark for the final score 5 % of the final score (6 of 120 CP) for MSc students. 3,3 % of the final score for BSc students.
Module coordinator and lecturer(s) Prof. Dr. Jonathan Bedford; Dr. Carlos Peña
Further information **Literature** Teunissen, P.J. and Montenbruck, O. eds., 2017. Springer handbook of global navigation satellite systems (Vol. 10, pp. 978-3). Cham, Switzerland: Springer International Publishing. Hanssen, R. (2001), Radar Interferometric: Data and Error analysis, Kluwer academic publishers, ISBN 0-7923-6945-9 Ferretti, A. (2007) InSAR Principles: Guidelines for SAR Interferometric Processing and Interpretation, ISBM 92-9092-233-8 – www.esa.int Segall, P. (2010), Earthquake and Volcano Deformation, Princeton University Press, ISBM 97814008338 56

Optimization methods for geophysics					
Module number	**Credits** 6 CP	**Workload** 180 h	**Term** Summer	**Frequency** each SoSe	**Duration** 1 semester
Courses Optimization methods for geophysics			**Contact hours** 4 SWS	**Self-study** 120 h	**Group size** 18 students

Prerequisites

- For students enrolled in MSc programs who have completed math and physics modules in their Bsc education.
- Completion of Introduction to programming in python or Introduction to programming in Matlab.

Learning outcomes

After completion of the module the student will be able to:

- understand how model parameters are optimized by the geoscientific research community and the various approaches for estimating model uncertainties,
- propose optimization strategies given the specific model parameters, datasets, physics, and constraints of the problem,

and

- implement simple linear and non-linear optimizations on a computer.

Content

First we will explore classical optimization approaches, that have been developed heavily in geophysics over the past decades, and that can nowadays be classed as sub-types of supervised machine learning that are suitable for models with a few thousand parameters. In this course, we will first cover these classical inversion approaches before understanding the approaches that faciliate the optimization of millions (to billions) of parameters in deep learning.
The lecture series will through the following topics:
(1) Introduction to concepts of data vector, model vector, and model assumptions (d, m, and G of traditional geophysical inversion problems). (2) Linear problems and their solution through the matrix solution of normal equations (least squares regression). (3) Non-linear inverse problems and their iterative solutions. (4) How data errors translate into model uncertainties. (5) The concepts of regularization and parameter constraints. (6) Model resolution and data sensitivity (7) Terminology of traditional geophysical inversion in more universal, machine learning optimization language. Distinctions between three types of machine learning (supervised, unsupervised, reinforcement) and how these relate to the framwework of classical linear and non-linear optimization approaches. (8) Introduction to the optimization methods of deep learning and how modern optimization problems scale on modern computing hardware

Teaching methods

Each week, we will introduce new concepts in the 2 hour lecture slot. In the 2 hour practical slot, students carry out an optimization exercise. Starting in week 2, there will be a quiz (20 minutes in duration) at the beginning of each lecture. Starting in week 10, there will be a series of exam preparation programming exercises in which students accumulate their own working optimization scripts that will be useful in the exam and beyond

Mode of assessment

Weekly, 20-minute long quizzes during weeks 2-10: The best 5 results from a total of 9 quizzes will be counted towards 60% of the final grade. 10% of the grade will be assessed from participation. 30% will come from a final independent coding exercise that takes place under exam conditions during the semester exam period.
Therefore, there is a mixed mode of assessment including written quizzes, an examined programming exercise, and general effort of participation.

Requirement for the award of credit points

Credit points can be awarded if the student accumulates >=50% across the various modes of assessment.

Module applicability

Weight of the mark for the final score

5 % of the final score (6 of 120 CP) for MSc students.

Module coordinator and lecturer(s)

Prof. Dr. Jonathan Bedford; Tectonic Geodesy working group Q-Stelle.

Further information

Literature

Menke, W., 2018. Geophysical data analysis: Discrete inverse theory. Academic press.

Gravity and magnetics / Potential fields					
Modul-Nr.	**Credits** 5 CP	**Workload** 150 h	**Term** Summer	**Frequency** each SoSe	**Duration** 1 semester
Courses Gravity and magnetics / Potential fields			Contact hours 3 SWS	**Self-study** 105 h	**Group size** 18 students

Prerequisites

Participants are expected to have prior knowledge of basic geophysics, vector calculus and differential equations, as well as familiarity with fundamental gravity and magnetic concepts at BSc level.
Basic experience with a scientific computing environment (e.g. Matlab or Python) is recommended.
Passed courses: Continuum mechanics of the module Physics of the solid Earth, Introduction to programming in Python of the module Python programming for Geosciences

Learning outcomes

After completion of the module the student will be able to:

- Describe gravitational and magnetic fields and the geoid.
- Compute gravitational and magnetic fields from their potential.
- Formulate and solve basic forward and inverse problems in gravity and magnetics.
- Apply standard corrections to regional gravity and magnetic data and understand key terms used in potential-field applications.
- Interpret gravity and magnetic anomaly maps in terms of subsurface density and magnetization structure (e.g. basins, intrusions, ore bodies).
- Assess resolution limits, non-uniqueness, and the role of prior information in potential-field inversions.
- Construct simple quantitative models from measured data and implement basic processing and modelling workflows in a scientific computing environment.

Content

- Newtonian potential and gravitational field.
- Magnetic potential, magnetization, and the geomagnetic field.
- The geoid and regional gravity fields.
- Spherical harmonic analysis of global gravity and magnetic fields.
- Forward and inverse methods in potential-field geophysics.
- Fourier-domain modelling, upward continuation, analytic signal, and Hilbert transformation.
- Gravity and magnetic anomalies of typical geological structures (e.g. sedimentary basins, faults, intrusions, ore bodies).
- Data acquisition and processing for gravity and magnetic surveys (reference fields, basic corrections, anomaly calculation).
- Numerical exercises on forward modelling, simple inversion, and data processing in a scientific computing environment.

Teaching methods

2 hours per week lecture. 1 hours per week exercises.
The module consists of weekly lectures and accompanying exercises. Each week, new theoretical concepts are introduced in a 90-minute lecture. These concepts are then applied and deepened in a 45-minute exercise session, which may include analytical problem solving, numerical assignments, and computer-based data processing or modelling tasks. In weeks with a stronger numerical focus, the balance between lecture and exercise time may be adjusted accordingly.

Mode of assessment

The module is assessed by a written examination and additional continuous assessment during the teaching period. The written examination contributes 60% to the final module grade. The continuous assessment component (e.g. assignments, quizzes, or programming exercises) contributes 40% to the final module grade. The final module grade is determined from the combined percentage score of the continuous assessment and the written examination.
Requirement for the award of credit points The final grade of the combined percentage score of the continuous assessment and the written examination must reach 50% or more.
Module applicability The module is intended for students enrolled in MSc programmes in the geosciences or related fields.
Weight of the mark for the final score 4,2 % of the final score (5 of 120 CP) for MSc students.
Module coordinator and lecturer(s) Dr. Kasper D. Fischer
Further information **Literature** 50

<table>
<tr><td colspan="6">Applied geothermal energy</td></tr>
<tr><td>Module number</td><td>Credits
8 CP</td><td>Workload
240 h</td><td>Term
1.+ 2. Sem.</td><td>Frequency
a) each WS
b) each SS</td><td>Duration
2 semesters</td></tr>
<tr><td colspan="3">Courses
a) Shallow geothermal energy (WS)
b) Deep geothermal energy (SS)</td><td>Contact hours
(a) 2 SWS
(b) 3 SWS</td><td>Self-study
(a) 65 h
(b) 100 h</td><td>Group size
40 students</td></tr>
</table>

Prerequisites For students in Master programs

Learning outcomes

After completion of the module, the participants will

- be able to dimension simple planning examples for geothermal plants and to determine the necessary parameters.
- understand various sub-areas of geothermal energy (shallow and deep geothermal energy) as well as the different types of geothermal systems (hydrothermal, petrothermal, open and closed systems).
- understand the theoretical background and current calculation methods.
- know the legal principles and guidelines for the construction of geothermal plants and boreholes.
- The deep geothermal energy course deals with physical heat transfer processes at greater depths and the associated processes that are important for the optimal energy yield of such systems.

Content

a) Shallow geothermal energy

Overview of geothermal energy and energy in Germany, functioning of heat pumps, guidelines and legal bases, open and closed systems, dimensioning of geothermal probe systems, insight into seasonal heat reservoirs.

b) Deep geothermal energy

Fundamentals and methods of deep geothermal energy including potentials and uses in Germany and internationally, geophysical exploration and characterization of deep geothermal reservoirs.

Teaching methods

Lectures with accompanying exercises

Mode of assessment

Written examination on the contents of courses a) and b); duration: 120 minutes at the end of the summer semester.

Requirements for the award of credit points

Passed module examination;

Participation in and submission of at least 70 % of the exercises in a) and b).

Module applicability (in other programs)

Weight of the mark for the final score

5 % of the total grade (8 of 120 CP)

Module coordinator and lecturer(s)

Prof. Dr. Renner, Prof. Dr. Reinsch

Other information

Relevant technical literature will be presented at the beginning of each course.

Groundwater hydraulics					
Module number	**Credits** 12 CP	**Workload** 360 h	**Term** 1. Sem	**Frequency** Every WS	**Duration** 1 semester
Courses a) Introduction to groundwater hydraulics (WS) b) Hydraulic groundwater modelling (WS)			**Contact hours** (a) 4 SWS (b) 4 SWS	**Self-study** (a) 120 h (b) 120 h	**Group size** (a) 40 students (b) 40 students

Prerequisites

For students in Master programs

Learning outcomes

At the end of the module, participants will

- be able to describe and evaluate groundwater flow and conservative mass transport in the subsurface.
- know methods of experimental investigation and determination of hydraulic parameters under different boundary conditions and can derive and evaluate these mathematically.
- be familiar with the evaluation and interpretation of groundwater hydraulic parameters and use them to deal with classical hydrogeological problems.
- be able to use numerical modelling approaches to effectively model groundwater flow based on existing hydrogeological information.
- be in the position to estimate and describe the quality and limitations of hydraulic models and use them to predict future situations.

Content

a) Introduction to groundwater hydraulics

- Methods for the collection and evaluation of hydraulic parameters (Darcy-tests, pump tests, Slug&Bail tests).
- Conveyance of knowledge about groundwater flow and the construction of groundwater level plans.
- Execution and evaluation of pumping tests by means of graphical and analytical solutions.
- Practical tasks for lowering the groundwater level through well systems in excavation pits or calculation of well yield.

b) Hydraulic groundwater modelling

- Teaching of knowledge and methods for understanding and evaluation of mass transport processes in groundwater.
- Methods for quantifying the subsurface (geostatistical approaches).
- Knowledge transfer for the modelling of mass transport with regard to the structure of a model, boundary conditions, advantages and disadvantages of models and how modelling programs work.
- Visualization and interpretation of model results.

Teaching methods

Lectures with accompanying calculation exercises.

Software exercises on the PC.

Mode of assessment

Written examination on the contents of the courses, Introduction to groundwater hydraulics‘ and ‚Hydraulic groundwater modelling‘; duration: 120 minutes.

Requirements for the award of credit points

Participation in and submission of at least 70 % of the exercises in b).

Module applicability (in other programs)
Weight of the mark for the final score 10 % of the total grade (12 of 120 CP)
Module coordinator and lecturer(s) Dr. Thomas Heinze
Other information Relevant technical literature will be presented at the beginning of each course.

Hydrochemistry					
Module number	**Credits** 12 CP	**Workload** 360 h	**Term** 1. Sem.	**Frequency** Every WS	**Duration** 1 semester
Courses a) Inorganic hydrochemistry b) Organic hydrochemistry			**Contact hours** (a) 4 SWS (b) 4 SWS	**Self-study** (a) 120 h (b) 120 h	**Group size** (a) 40 students (b) 40 students

Prerequisites

For students in Master programs

Learning outcomes

At the end of the module, participants will

- understand the role of chemical processes in water-rock interactions. The fundamentals of thermodynamics enable them to recognize and evaluate hydrogeochemical equilibrium and imbalance states of different reaction types.
- understand the hydrogeochemical basics, terms and methods.
- be able to classify organic substances and pollutants in the subsurface.
- know the relevant structures and properties, and thus understand their behaviour and mobility of contaminants in the environment.

Content

a) Inorganic hydrochemistry

Fundamentals, concepts and methods of inorganic hydrochemistry including law of mass action, concentration and activity, solubility and saturation, types of hydrochemical reactions, equilibrium and imbalance, sorption, toxicity and regulatory provisions.

b) Organic hydrochemistry

Fundamentals, concepts and methods of organic hydrochemistry including classes of substances, structures and properties of organic substances, phase formation, volatility, degradation, solubility, sources and legal regulations, cases of contamination and approaches of remediation.

Teaching methods

Lectures with accompanying calculation exercises

Mode of assessment

Written module examination on the contents of a) and b); duration: 120 minutes at the end of the winter semester.

Requirements for the award of credit points

Passed module examination

Module applicability (in other programs)

Weight of the mark for the final score

10 % of the total grade (12 of 120 CP)

Module coordinator and lecturer(s)

Prof. Dr. Tobias Licha

Other information

Relevant technical literature will be presented at the beginning of each course.

Hydrogeochemical methods I

Module number	Credits	Workload	Term	Frequency	Duration
	6 CP	180 h	1. Sem.	Every WS	1 semester

Courses	Contact hours	Self-study	Group size
a) Isotope hydrogeochemistry (lecture)	2 SWS	120 h	40 students
b) Isotope hydrogeochemistry (exercise)	2 SWS		

Prerequisites

For students in Master programs

Learning outcomes

After completion of the module, students will be able to grasp the importance of isotope ratios for the study of the origin of water and dissolved constituents in the hydrological cycle. They are familiar with a wide range of relevant isotope systems that are widely used in the fields of hydrogeochemistry and environmental geosciences to answer different questions. The participants can use radiogenic isotopes for dating of water and rock samples, determination of residence times, flow path of water, as tracer and for designation of origin. Stabile isotopes will be used as geothermometer for determination of origin of water, elements, gases and pollutants, redox reactions and process determination. You will get familiar with analytical methods for sampling and determining of isotope data, and be able to process and evaluate them. The lecture is complemented by course-related exercises based on real case studies..

Content

Isotope hydrogeochemistry (lecture)

Basics, terms and methods of isotope hydrogeochemistry including stable, radioactive and radiogenic isotopes, relevant isotope systems and ratios, fractionation processes, their applications and analytical methods, possibilities of interpretation in hydrogeological and hydrogeochemical questions.

Isotope hydrogeochemistry (exercise)

Application of theoretical background in guided exercises on real case studies.

Teaching methods

Lectures with accompanying exercises.

Mode of assessment

Written exam on the contents of the courses duration: 90 minutes. Evaluation of the exercises

Requirement for the award of credit points

Passed written module exam

Participation in, and submission of at least 70% of the exercises

Module applicability (all Master course of the Institute Geosciences)

Weight of the mark for the final score

5 % of the total grade

Module coordinator and lecturer(s)

Dr. Andrea Hachenberg

Further information

Relevant literature will be presented at the beginning of each course.

<table>
<tr><td colspan="6">Hydrogeochemical methods II</td></tr>
<tr><td>Module number</td><td>Credits
9 CP</td><td>Workload
270 h</td><td>Term
3. Sem.</td><td>Frequency
Every WS</td><td>Duration
1 semester</td></tr>
<tr><td colspan="3">Courses
a) Environmental forensics
b) Hydrogeochemical modelling</td><td>Contact hours
(a) 2 SWS
(b) 4 SWS</td><td>Self-study
(a) 60 h
(b) 120 h</td><td>Group size
20 students</td></tr>
<tr><td colspan="6">Prerequisites
Registered in Master programs</td></tr>
<tr><td colspan="6">Learning outcomes
(a) Anthropogenic use of groundwater is often associated with a contamination of the same. It is becoming increasingly relevant to identify the polluters of such contamination. For this purpose, the emerging field of environmental forensics offers some methodological possibilities, which the participants will learn to know and apply. Further, the students will learn about the recent development of reactive tracers for geothermal applications but also for studying subsurface processes. The participants will learn which tracers are useful for which problem by means of examples.
(b) Hydrogeochemical modeling allows the students to gain a deeper understanding of the hydrogeochemical processes discussed and how to represent them in model form. They understand the added value of numerical equilibrium modeling for hydrochemical data, and can describe, evaluate, and predict the effects of different frameworks on solute distribution.</td></tr>
<tr><td colspan="6">Content
a) Environmental forensics
Basics, terms and methods of environmental forensics including polluter pays principle and legal basis, hydrochemical proxies and indicators, possibilities of using reactive tracers, international and national case studies.
b) Hydrogeochemical modelling
Basics, terms and methods of hydrogeochemical modeling including models and databases, simulation of hydrochemical equilibrium reactions, mixing reactions, kinetically controlled reactions, inverse modeling, 1D reactive solute transport and isotopic fractionation, graphical presentation of the results with various programs.</td></tr>
<tr><td colspan="6">Teaching methods
Lectures with accompanying exercises, software exercises (PhreeqC) on the PC</td></tr>
<tr><td colspan="6">Mode of assessment
Written exam on the contents of the courses a) and b); duration 120 minutes. Evaluation of the exercises during the course in b and a final project in b.</td></tr>
<tr><td colspan="6">Requirement for the award of credit points
Passed written module exam; Participation in, and submission of at least 70% of each of the exercises and the final project in b.</td></tr>
<tr><td colspan="6">Module applicability (all Master course of the Institute Geosciences)</td></tr>
<tr><td colspan="6">Weight of the mark for the final score
7.5 % of the total grade</td></tr>
<tr><td colspan="6">Module coordinator and lecturer(s)
Dr. Andrea Hachenberg; Prof. Dr. Tobias Licha</td></tr>
<tr><td colspan="6">Further information
Relevant literature will be presented at the beginning of each course.</td></tr>
</table>

Environmental sciences					
Modul number	**Credits** 6 CP	**Workload** 180 h	**Term** 2. Sem.	**Frequency** Every WS	**Duration** 1 semester
Courses a) Climate change and water resources b) Toxic trace elements in groundwater			**Contact hours** (a) 2 SWS (b) 2 SWS	**Self-study** (a) 50 h (b) 50 h	**Group size** 20 students
Prerequisites For students in Master program					
Learning outcomes Upon completion of the module, students are able to • assess the impact of climate change on water resources • understanding mitigation strategies to minimize climate change impacts • knowing adaption strategies to reduce the consequences of climate change • assess the impact of toxic trace elements to humans, animals and plants • knowing the sources of toxic trace elements and removal strategies • understanding the detailed processes of adsorption, coprecipitation and ion exchange of different trace elements on/with different minerals					
Content **(a) Climate Change and Water Resources** Fundamentals and concepts of climate change and methods to study its influence on water management: collection, presentation and interpretation of climate data, climate models; global, regional and local impact on quality and quantity of usable water resources; mitigation strategies to minimize climate change impacts; methods of adaptation to the consequences of climate change. **(b) Toxic Trace Elements in Groundwater** Discussion of the toxicity of different elements like lead, mercury, cadmium, chromium, copper, zinc, antimony and arsenic in drinking water to humans, animals and plants. Cycles of different toxic elements including their anthropogenic sources. Removal strategies of toxic trace elements from (drinking) water by adsorption, coprecipitation and ion exchange of different trace elements on/with different minerals.					
Teaching methods Lectures with accompanying calculation exercises and a presentation in b					
Mode of assessment Written exam on the contents of the courses a) and b); duration 120 minutes at the end of WiSe. Grade of your presentation and exercises in b during the course					
Requirement for the award of credit points Participation of the two courses, submit the exercises and giving a presentation in b and passing the module examination.					
Module applicability					
Weight of the mark for the final score 5 % der Gesamtnote (6 von 120 CP)					
Further information Relevant technical literature will be presented at the beginning of each course					
Module coordinator and lecturer(s): Dr. Andrea Hachenberg					

Field courses in applied geology					
Module number	**Credits** 6 CP	**Workload** 210 h	**Term** WS/SS	**Frequency** annual	**Duration** 1 semester
Courses Field courses in applied geology in various hydrogeological settings (Europe, South America, etc.)			**Contact hours** 14 days	**Self-study** 98 h	**Group size** Depending on the location of the courses: between 12 and 20 students
Prerequisites For students in the Masters program Geosciences with the focus in Applied Geology, Sedimentology, Mineralogy, and Crystallography.					
Learning outcomes The learning aims are dependent on the topics of the field course. The field courses combine aspects of Applied Geology (Hydrogeology, Engineering Geology, Geothermal Energy, Economic Geology) with general geological knowledge like Structural Geology, Sedimentology, Geophysics etc. Generally, the aim is to give the students the possibility to combine knowledge from classes and laboratory exercises with field observation in order to construct a sound geological model, that can be applied to practical purposes like mining, engineering of geothermal applications. After the successful attendance of the module the students are able to understand the complexity of geological settings.					
Content Depends on the field area.					
Teaching methods Seminar before the field trip, discussions in the field, planning and independent work in the field.					
Mode of assessment The module is graded on the basis of the evaluation of the lecture and the report from the pre-seminar and the submitted sketches and reports. Mandatory participation in the fieldwork. The pro-seminar consists of a lecture on selected topics (10-15 minutes) and submission of an abstract of the talk (1-2 pages). Presentation of 4-5 sketches of the field settings (done in the field and refined in the evenings in the field camp). The original copy as well the refined copy are to be submitted.					
Requirement for the award of credit points Active participation in the field work, discussion and seminars. Inability to participate in more than 33% of the field days may be excused only on very well-founded medical grounds; otherwise such absence will lead to a failing grade in the module.					
Module applicability The module is open to students specializing in Sedimentology, Crystallography or Petrology as well. In exceptional cases, after discussion with the instructor, students specializing in other subfields of geosciences may also participate.					
Weight of the mark for the final score 5,8 % of the overall grade.					
Module coordinator and lecturer(s) Prof. Dr. J. Schreuer (coordinator), in cooperation with other lecturers of the Institute Geosciences.					
Further information					

Please contact the instructor if you have questions.
Literature Relevant technical literature will be presented at the beginning of each course

Hydrogeological field methods

Modul number	Credits	Workload	Term	Frequency	Duration
	6 CP	180 h	2. Sem.	Every SS	1 semester

Courses	Contact hours	Self-study	Group size
a) Hydrogeological field exercises b) Analysis of measurement results (Seminar)	(a) 4 days (b) 2 SWS	(a) 40 h (b) 50 h	20 students

Prerequisites

Passing of the examination of "Introduction to Groundwater Hydraulics" plus basic knowledge in computer-based analysis using GIS, EXCEL, Python or Matlab to be proven by passing the course "Hydraulic groundwater modeling" or a respective course from the Geosciences curriculum.

Learning outcomes

Upon completion of the module, students are able to

- Perform, evaluate, and interpret hydrogeological field tests independently.
- Present their methods and results adequately in a written report.
- Transfer their knowledge from the lecture hall to real-world problems.

Content

(a) Hydrogeological field exercises

Performance of hydrogeologic field methods such as infiltration and pumping tests, discharge measurements, groundwater leveling, monitoring of water quantity and water properties, and water sampling. Conducting tracer tests with sampling & observation to characterize a flow system. Documentation and reporting of methods applied.

(b) Analysis of measurement results (seminar)

Computer-based analysis of measurement results from the field exercises using GIS, EXCEL, MATLAB, and specialized software for the respective tasks: Time series analysis of monitoring data, analysis of pumping tests using curve matching to obtain aquifer properties & characterize aquifer; Curve matching of tracer passage curves to obtain transport properties; (Inverse) modeling of infiltration experiments to obtain infiltration capacity of the soil; GIS based catchment analysis and calculations of groundwater recharge.

Teaching methods

Lectures with accompanying calculation exercises and field exercises.

Mode of assessment

Grading of written reports and experiment analysis

Requirement for the award of credit points

Active participation in all field work, discussion, and seminars. Absence from field work will lead to failing the module. Submission of a report covering the description of the field experiments, their results and an in-depth analysis according to the techniques covered in the course.

Module applicability

Weight of the mark for the final score

5 % der Gesamtnote (6 von 120 CP)

Module coordinator and lecturer(s)

Dr. Thomas Heinze

Further information

Relevant technical literature will be presented at the beginning of each course

Siedlungswasserwirtschaft					
Modul number	**Credits** 5 CP	**Workload** 150 h	**Term** 2. Sem.	**Frequency** Every SS	**Duration** 1 semester
Courses a) Siedlungswasserwirtschaft			**Contact hours** 3 SWS	**Self-study** 105 h	**Group size** 40 students

Prerequisites

Für Studierende in Master-Programmen

Learning outcomes

Studierende sind nach Beendigung des Moduls in der Lage,

- Methoden, Zusammenhänge und Einflüsse im Bereich der Siedlungswasserwirtschaft zu beschreiben und zu bewerten.
- kennen die grundlegenden hydrologischen Prozesse in natürlichen und anthropogenen Systemen und Ansätze zu deren Untersuchung.
- kennen die komplexen Interaktionen des Menschen mit der Hydrosphäre.

Content

Grundlagen, Begriffe und Methoden der Siedlungswasserwirtschaft: natürliche hydrologische Systeme und deren Erkundung, anthropogene Nutzung von Wasserressourcen: Wassergewinnung, Wasseraufbereitung, Wasserspeicherung, Wasserförderung und –verteilung, Betriebswasser, Abwasser und Klärschlamm, Regenwasserbewirtschaftung, Flächenversiegelung.

Teaching methods

Vorlesungen mit begleitenden Übungen

Mode of assessment

Schriftliche Klausur über die Inhalte der Lehrveranstaltungen, Dauer 90 Minuten am Ende des SS.

Requirement for the award of credit points

bestandene Modulprüfung

Teilnahme an, und Abgabe von jeweils mindestens 70 % der Übungen

Module applicability

Weight of the mark for the final score

4,17 % der Gesamtnote (5 von 120 CP)

Module coordinator and lecturer(s)

Prof. Dr. Tobias Licha (Lehrtransfer von Fakultät Bauingenieurwesen)

Further information

Relevante Fachliteratur wird am Beginn der jeweiligen Veranstaltungen vorgestellt.

<table>
<tr><td colspan="6">Grundlagen des Geoingenieurwesens</td></tr>
<tr><td>Module number</td><td>Credits
6 CP</td><td>Workload
150-180 h</td><td>Semester
1. Sem.</td><td>Frequency
Every WS</td><td>Dauer
1 semester</td></tr>
<tr><td colspan="3">Courses
a) Grundlagen der Ingenieurgeologie
b) Darstellen und Analysieren geotechnischer Informationen</td><td>Contact hours
(a) 2 SWS
(b) 2 SWS</td><td>Self-study
(a) 60 h
(b) 60 h</td><td>Group size</td></tr>
<tr><td colspan="6">Prerequisites</td></tr>
</table>

Learning outcomes

Die Ingenieurgeologie ist eine interdisziplinäre Wissenschaft, welche den Baugrund erkundet und aus den Erkenntnissen ein geotechnisches Modell für bautechnische Zwecke erstellt. Die Erkundung des Baugrundes sollte hierbei immer unter Berücksichtigung der lokalen Geologie und deren Genese sowie der geodynamischen Prozesse erfolgen, um die Unsicherheiten des Models zu minimieren. Im Rahmen des Kurses werden die grundlegenden Verfahrenschritte der Erkundung und die normative Basis erläutert. Darüber hinaus wird phänomenologisch-deskriptiv ein Gefühl für das Verhalten von Festgestein, Fels und Lockergestein unter den typischen bautechnischen und geologisch-bedingten Belastungssituationen vermittelt. Aus dem Verständnis des rheologischen Verhaltens werden Parameter abgeleitet, welche den Baugrund charakterisieren.

Die Darstellung von ingenieurgeologischen und geotechnischen Informationen bildet die Grundlage einer jeden Ergebnispräsentation; umgekehrt muss der/die Ingenieurgeolog:in in der Lage sein graphisch dargestellte technische und geotechnische Informationen zu erfassen und zu analysieren.

Nach erfolgreichem Abschluss des Moduls (a) sind die Teilnehmerinnen und Teilnehmer mit der ingenieurgeologischen Fachterminologie zur fachgerechten Beschreibung und Benennung von Lockergestein, Festgestein und Fels vertraut, (b) verstehen sie die Zusammenhänge zwischen geologischen Verhältnissen, physikalischen, hydraulischen und mechanischen Eigenschaften von Boden und Fels, (c) kennen die Teilnehmerinnen und Teilnehmer die wichtigsten Parameter zur Beschreibung der Eigenschaften von Locker- und Festgesteinen und (d) sind sie mit den Grundlagen der Normung und Richtlinien vertraut. Darüber hinaus sind die Teilnehmerinnen und Teilnehmer mit den grundlegenden Methoden der Darstellung und Analyse geotechnischer Informationen vertraut. Dies umfasst das Erfassen markscheiderischer und technischer Darstellungen, das zeichnerische Darstellen von Aufschlüssen und Aufschlussdaten, das geometrisch-technisch-zeichnerische Darstellen von Ergebnissen, die Darstellung und Analyse von Festigkeits- und Gefügedaten, sowie das Verfassen von Berichten.

Content

- Definition der Ingenieurgeologie; normativer Rahmen des Bauwesens inkl. EC 7; Ablauf einer Baugrunderkundung; Einordnung der Ingenieurgeologie in UN SDGs; Einführung des Homogenbereichskonzeptes; Definition Gestein, Fels, Lockergestein, Boden inkl. Boden und Fels als Mehrphasenmodell; Übersicht über Aufschlussverfahren; Benennen und Beschreiben von Locker- und Festgesteinen sowie Trennflächen und Fels; Einführung in Stoffmodelle für Trennflächen, Gestein und Boden; Hydrogeologie im Geoingenieurwesen; Spannungen im Untergrund aus Auflast und resultierende Spannungen und Setzungen unter Bauwerken; Klassifizieren und Bewerten von Boden und Fels für bautechnische Zwecke; Einführung in grundlegende Belastungsszenarien und Bemessungsansätze.
- Konstruktion geologischer Schnitte; zeichnerische Darstellung geologischer Informationen in Form von Verwitterungsprofilen, Aufschlusszeichnungen und Abwicklungen; Bohrprofile; Operationen in der stereographischen Projektion; Spannungsdarstellung und -analyse mittels Mohr'schem Spannungskreis; Lesen und Analysieren technischer Darstellungen; Graphen und Tabellen; Risswerke; geotechnisches Berichtswesen.

Teaching methods

Vorlesung mit integrierten Übungen Vorlesung, Übung
Mode of assessment Modulklausur
Requirement for the award of credit points Übungsaufgaben (Testate), benotete Übungsaufgaben, Modulprüfung Grundlagen des Geoingenieurwesens
Module applicability ---
Weight of the mark for the final score 5 % der Gesamtnote (6 von 120 CP)
Module coordinator and lecturer(s) Prof. Dr. Tobias Backers
Further information Relevante Fachliteratur wird am Beginn der jeweiligen Veranstaltungen vorgestellt.

<table>
<tr><td colspan="6">Rock mass stress fields</td></tr>
<tr><td>Module number</td><td>Credits
5 CP</td><td>Workload
150-180 h</td><td>Term
1. Sem.</td><td>Frequency
Every WS</td><td>Duration
1 semester</td></tr>
<tr><td colspan="3">Courses
a) Stress field and rock mass behaviour
b) Stress field modelling and simulation</td><td>Contact hours
(a) 2 SWS
(b) 1 SWS</td><td>Self-study
(a) 55 h
(b) 50 h</td><td>Group size</td></tr>
</table>

Prerequisites

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Learning outcomes

Stresses in the Earth's crust are the driving 'force' of many processes and a definitive quantity of assessing the stability of geologic structures such as interfaces or faults. In addition, knowledge of the stresses at work is of extraordinary importance in the design of structures in the near-surface and deep subsurface. The English language course develops the mechanical principles for the representation of the stress field in the Earth's crust and discusses the sources of stress. Methods for estimating and measuring stresses are introduced.

This includes modeling of the primary field (green and brown field) and the derivation of secondary stresses by civil engineering structural engineering measures.

The simulation of the alteration of the in-situ stresses is in many rock and mining projects and mining projects to estimate the secondary stresses and the load on the geological structures and geological structures as well as civil engineering works. In addition to the lecture “Stress Field and Rock Mass behaviour”, exemplary models are created autodidactically using standard software of rock are created autodidactically and the resulting stresses and their distribution are simulated.

The rule is to work in teams; depending on the industry, these teams are composed internationally, depending on the industry. The English-language course takes this into account.

The students are familiar with rock and rock mass behavior and the sources of stress in the Earth's crust. They know how to estimate and measure rock mass stress. In addition, the enrolled students are familiar with the determination of stress alterations and redistributions by anthropogenic sources.

The students are familiar with the numerical simulation of stress alterations due to geological or constructional features using a commercial software package.

Content

Definition of stress, rock deformation, rock failure, rock mass definition, sources of stress in the earth crust, methods of stress measurement and stress modelling, determination of stress alterations and stress redistribution.

Teaching methods

Lectures with exercises, self-educational homework

Mode of assessment

Oral exam at the end of the term

Requirement for the award of credit points

successful submission (i.e. 50%) of 90% of the weekly homework

Module applicability

Weight of the mark for the final score

5 % der Gesamtnote (5 von 120 CP)

Module coordinator and lecturer(s)
Prof. Dr. Tobias Backers, Daniel Bücken
Further information
Relevant literature will be presented at the beginning of each session.

Grundbau und Bodenmechanik					
Module number	**Credits** 9 CP	**Workload** 150-180 h	**Semester** 1.+ 2. Sem.	**Frequency** Annually	**Duration** 2 semesters
Courses a) Grundbau b) Bodenmechanik c) Geotechnische Herausforderungen des Anthropozäns			**Contact hours** (a) 3 SWS (b) 3 SWS (c) 0,5 SWS	**Self-study** (a) 50 h (b) 90 h (c) 25 h	**Group size**

Prerequisites

Modul Grundlagen des Geoingenieurwesens

Learning outcomes

Die Inhalte von a) und b) sind den Beschreibungen des VLV zu entnehmen.

c) Das jüngste Antropozän zeichnet sich durch u.a. massive Veränderungen der Geländemorphologie durch den Menschen, den Wandel des Klimas und damit verbundene extreme Wetterereignisse, die Notwendigkeit der Endlagerung radioaktiver Abfälle oder die Notwendigkeit der massiven Erneuerung der Energieversorgung aus. Dies bedingt auch geotechnische Lösungen. Im Rahmen des Kurses erstellen die Kursteilnehmerinnen und -teilnehmer zu einem Thema ein Diskussionspapier, in dem Sie die Herausforderungen, die sich auch geologisch-geotechnischer Sicht ergeben, definieren und versuchen realistisch/kreative Lösungsansätze unter Berücksichtigung der vorhandenen Literatur zu dem Thema zu skizzieren. In einem Impulsvortrag stellen Sie das Thema und Ihre Thesen vor und stellen den Bezug zu den UN SDGs her. Die Diskussionsergebnisse und Hinweise zum Impulsvortrag reflektieren Sie in Ihrem Diskussionspapier.

Nach erfolgreichem Abschluss des Kurses sind die Teilnehmenden mit den grundlegenden Methoden der Beschreibung von Böden vertraut, wissen um das grundlegende Verhalten von Böden und dessen mathematisch idealisierte Beschreibung, besitzen die Fähigkeit, diese Konzepte auf die Bemessung von Grundbauwerken anzuwenden und haben das Verständnis Berechnungsergebnisse kritisch zu hinterfragen.

Die Teilnehmerinnen und Teilnehmer sind mit den UN SDGs vertraut und üben die Auseinandersetzung mit einem gesellschaftlich relevanten, technischen Thema, welches geotechnische Lösungen verlangt. Durch den Impulsvortrag stärken die Teilnehmenden Ihre Präsenations- und Diskussionskompetenz

Content

Beschreibung und Klassifizierung von Böden, Bodeneigenschaften und -kenngrößen, Baugrunderkundung, Wirkungen von Grundwasser im Boden, Spannungsausbreitung im Baugrund, Setzungs- und Konsolidierungsberechnungen im Boden, Scherfestigkeit, Erddruck auf Wände und Stützmauern, Standsicherheit von Böschungen, Flachgründungen, Stützkonstruktionen, Grundwasserhaltungen, Baugruben, Pfahlgründungen, Baugrundverbesserung; Erstellung eines Diskussionspapiers; Impulsvortrag; Diskussion

Teaching methods

Vorlesung, Übung, Seminar

Mode of assessment

Klausur, Diskussionspapier

Requirement for the award of credit points

Bestandene Klausur, benotetes Diskussionspapier

Module applicability

Weight of the mark for the final score 5 % der Gesamtnote (6 von 120 CP)
Module coordinator and lecturer(s) Prof. Dr. Tobias Backers, Prof. Dr.-Ing. Torsten Wichtmann
Further information Relevante Fachliteratur wird am Beginn der jeweiligen Veranstaltungen vorgestellt.

Rock mass mechanics and rock engineering (Felsmechanik und Felsbau)					
Module number	**Credits** 5 CP	**Workload** 150-180 h	**Term** 2. Sem.	**Frequency** Every SS	**Duration** 1 semester
Courses a) Rock Mass Mechanics (Felsmechanik) b) Rock Engineering (Felsbau)			**Contact hours** (a) 2 SWS (b) 2 SWS	**Self-study** (a) 45 h (b) 45 h	**Group size**

Prerequisites

Module 'Rock Mass Stress Fields' recommended for specialisation ‚Geoingenieurwesen', mandatory for specialisation in ‚Geological Engineering for Subsurface Energy Systems'

Learning outcomes

Als Teilgebiet der Geomechanik beschäftigt sich die Felsmechanik mit der Beschreibung der rheologischen Eigenschaften und assoziierten Stoffmodelle von Gestein und Trennflächen; durch die Integration kann das Deformationsverhalten von Fels (= Gestein + Trennflächen) durch eine Änderung der thermischen, hydraulischen oder mechanischen Randbedingungen abgeschätzt werden. Das Verständnis des mechanisch-hydraulisch-thermischen Verhaltens des Fels (vielfach auch als Gebirge bezeichnet) bildet die Grundlage für die bautechnische oder werkstoffliche Nutzung des Fels oder Gesteins.

Der Felsbau beschäftigt sich mit den bautechnischen Maßnahmen im Fels; die Nachbardisziplin Erd-/Grundbau beschreibt die Methoden in Lockermaterialien. Die bautechnischen Maßnahmen umfassen das Lösen, das Sichern und die Gewinnung von Gestein, die Gründung im Fels und die Erstellung von Hohlräumen. Aufbauend auf den felsmechanischen Grundlagen werden die Prinzipien des Felsbaus besprochen.

Die Simulation der Interaktion von Bauwerk und Baugrund hat zum Ziel, die Belastungen aus dem Bauwerk und die Reaktion des Baugrunds bei komplexen felsbaulichen Projekten umfassend beurteilen zu können. In Ergänzung zu den Vorlesungen Felsmechanik und Felsbau werden unter Verwendung einer Standardsoftware des Felsbaus beispielhafte Modelle autodidaktisch erstellt und die resultierenden Belastungen des Baugrunds simuliert und beurteilt.

Die Teilnehmerinnen und Teilnehmer sind mit den Grundlagen der Rheologie der Gesteine, dem mechanischen Verhalten von Gestein und Trennflächen, Gebirgsklassifikationen und mechanischen Eigenschaften des Gebirges vertraut und kennen die typischen Kennwerte nach Bedeutung und Größe. Darüber hinaus sind die geomechanischen Grundlagen und Zusammenhänge vertieft. Die Teilnehmerinnen und Teilnehmer sind mit den Grundlagen der Erstellung und Sicherung von Felsbauwerken vertraut. Die Teilnehmerinnen und Teilnehmer sind mit der Anwendung einer Standartsoftware des Felsbaus vertraut und können für einfache felsbauliche Fragestellungen numerische Modelle erstellen und die Auswirkung der Bauwerkserstellung auf den Baugrund beurteilen.

Content

Deformation und Versagen von Gestein; Einführung in die Versuchstechnik; Deformation und Versagen von Trennflächen; Gebirgsklassifikationen; Deformation und Versagen von Fels; Charakteristika von Tunneln, Stollen und Felskavernen; Prinzipien des Hohlraumbaus; Gründungen auf Fels und Böschungen aus Fels; Aufgabenstellungen und Messgrößen bei der geotechnisch/geomechanischen Überwachung; felsmechanische numerische Simulation.

Teaching methods

Vorlesung, Übungen,

Mode of assessment

Modulklausur

Requirement for the award of credit points Übungsaufgaben
Module applicability
Weight of the mark for the final score 5 % der Gesamtnote (6 von 120 CP)
Module coordinator and lecturer(s) Dr. Mandy Duda
Further information Relevante Fachliteratur wird am Beginn der jeweiligen Veranstaltungen vorgestellt. Brady B, Brown E. 2006. Rock Mechanics for underground mining. Springer Science

Engineering geological digital mapping strategies					
Module number	**Credits** 5 CP	**Workload** 150 h	**Semester** 1. Sem.	**Frequency** Every WS	**Duration** 1 semesters
Courses a) UAV License b) Digitally supported engineering geological mapping			**Contact hours** (a) 1 SWS (b) 1 SWS	**Self-study** (a) 25 h (b) 105 h	**Group size**

Prerequisites

UAV License A1/A3 is required for Digitally supported engineering geological mapping.

Learning outcomes

New technological developments proceed constantly in engineering geology and digital skills are becoming increasingly important in both research and industry. The module aims to introduce students to independent, research-oriented work at an early stage, familiarize them with new technological developments in engineering geology, enhance their digital competencies, contribute to a more inclusive geosciences program and thus reduce barriers, and increase flexibility in the study process.

In the course UAV License A1/A3, a drone driving license is acquired through self-study. The course Digitally supported engineering geological mapping aims to map a location and to acquire engineering geology data using photogrammetry from drone footage. Close cooperation with the geological services of the federal states as well as with the Geoparks Germany is an integral part of the module. The mapping takes place at a time and location chosen by the students, thereby also allowing consideration of individual needs (social, familial, financial, health-related).

To a great extent, the module allows students to work independently, which enables flexible implementation.

Learning objectives:

- enhancing expertise on digitally supported fieldwork and the research questions built on it
- increasing teaching and communication skills through the creation of educational materials that can be used in teaching
- conveying media and methodological competencies, creating core competencies and competitive advantages
- improving self-management and communication skills
- enhancing social skills by raising awareness of gender equality and diversity issues, as well as better utilizing competence resources through self-organized work in small groups

Content

Digital field mapping, discontinuity characterization, media and methodological competence, scientific work, growing consciousness of equality and diversity issues

Teaching methods

Online lectures, Field excursion

Mode of assessment

LBA assessment, Report

Requirement for the award of credit points

Active participation in field work, UAV License A1/A3

Module applicability

Weight of the mark for the final score

4 % der Gesamtnote (5 von 120 CP)

Module coordinator and lecturer(s)

Dr. Mandy Duda
Further information: The fee for the UAV License A1/A3 (25 €) must be covered by the students.

Digital mapping research project

Module number	Credits	Workload	Semester	Frequency	Duration
	5 CP	150 h	2. Sem.	Every SS	1 semesters

Courses	Contact hours	Self-study	Group size
a) Digital mapping research project	(a) 1 SWS	(a) 105h	
b) Engineering geology colloquium	(b) 1 SWS	(b) 25 h	

Prerequisites

Module Engineering Geological Digital Mapping Strategies.

Learning outcomes

The module aims to introduce students to independent, research-oriented work at an early stage, familiarize them with new technological developments in engineering geology, enhance their digital competencies, contribute to a more inclusive geosciences program and thus reduce barriers, and increase flexibility in the study process.

Based on the data collected within Digitally supported engineering geological mapping a research question is developed and addressed. Research-based learning is implemented by allowing students to focus on a self-chosen research topic related to digital methods in engineering geology fieldwork. Students are free to choose their research question, methodology, and the timing of their project within the module's topic. Students are expected to present their findings in a way that allows them to be published in a scientific journal and shared with a broader public audience. The results are presented as an oral talk with discussion to an open audience during the Engineering Geology Colloquium.

To a great extent, the module allows students to work independently, which enables flexible implementation.

Learning objectives:

- enhancing expertise on digitally supported fieldwork and the research questions built on it
- increasing teaching and communication skills through the creation of educational materials that can be used in teaching
- conveying media and methodological competencies, creating core competencies and competitive advantages
- improving self-management and communication skills
- enhancing social skills by raising awareness of gender equality and diversity issues, as well as better utilizing competence resources through self-organized work in small groups

Content

Digital field mapping, discontinuity characterization, media and methodological competence, scientific work, growing consciousness of equality and diversity issues

Teaching methods

Lectures, Seminar

Mode of assessment

Report (80%), Talk (20%)

Requirement for the award of credit points

Active participation in engineering geology colloquium

Module applicability

Weight of the mark for the final score

4 % der Gesamtnote (5 von 120 CP)

Module coordinator and lecturer(s)

Dr. Mandy Duda
Further information:

Rock mass characterisation (Baugrundcharakterisierung Fels)					
Module number	**Credits** 5 CP	**Workload** 125-150 h	**Semester** 2.+3. Sem.	**Frequency** Annually	**Dauer** 2 semesters
Courses a) Rock Mass Mapping b) Rock Mass lab			**Contact hours** (a) 5 days (b) 2 SWS	**Self-study** (a) 40 h (b) 50 h	**Group size** (a) 12 students (b) 18 students

Prerequisites

Modul Grundlagen der Ingenieurgeologie, Modul Baugrunderkundung und Dokumentation; Modul Felsmechanik und Felsbau.

Learning outcomes

Im Rahmen der Baugrundmodellerstellung sind das Gestein und Trennflächen durch gesteins- bzw. felsmechanische Laborversuche zu charakterisieren. Der Kurs vermittelt die grundsätzlichen Arbeitsmethoden der gesteins- bzw. felsmechanischen Laborarbeit. Darüber hinaus werden eine Reihe von Standardversuchen vorgestellt, durchgeführt, ausgewertet und die Kennwerte eingeordnet.

Für felsbauliche Projekte ist die Darstellung und Erhebung von felsmechanischen Kennwerten (hier insbesondere Gesteinseigenschaften, Trennflächengefüge und -charakteristika) von besonderer Bedeutung. Im Rahmen der Geländeübung wird die Aufnahme von Gesteins- und Gefügecharakteristika im Gelände erlernt. Einen besonderen Stellenwert nimmt hier die zeichnerische Darstellung des Aufschlusses und die graphische Dokumentation von Messdaten ein. Die erhobenen und ausgewerteten Daten werden graphisch als integrierte DIN A3 Darstellung zusammengefasst und durch einen zweiseitigen Kurzbericht eingeordnet.

Die Teilnehmerinnen und Teilnehmer erlernen die methodischen Grundlagen der Bestimmung von Gesteins- und Trennflächenparameter. Darüber hinaus sind sie mit der prinzipiellen Durchführung und Auswertung wesentlicher Laborversuche vertraut. Weiterhin wird das dazugehörige normative Berichtswesen geübt.

Die Teilnehmerinnen und Teilnehmer erlernen die Methoden der ingenieurgeologischen Felskartierung. Hierzu gehören die Ansprache der Gesteine im Aufschluss, das Einmessen von Flächen, die Beschreibung der Trennflächen und deren Charakteristika. Die Methodik der Auswertung und Darstellung der im Gelände aufgenommenen Messwerte wird geübt. Die Anwendung einer Gebirgsklassifikation wird gefestigt.

Inhalt

Grundlagen der Erhebung gesteins- und felsmechanischer Kennwerte; Durchführung und Auswertung von Standardversuchen; ingenieurgeologisch-felsmechanische Aufnahme und Beschreibung des Trennflächengefüges; Gesteinsansprache; zeichnerische Darstellung eines Aufschlusses; Scanlinemethodik; Bestimmung von Gesteins- und Trennflächenfestigkeiten im Feld; regionalgeologische Aspekte des Harz und nördlichen Vorharzes.

Teaching methods

Laborpraktikum, Geländeübung

Mode of assessment

Berichte

Requirement for the award of credit points

Berichte

Module applicability

Weight of the mark for the final score

4 % der Gesamtnote (5 von 120 CP)
Module coordinator and lecturer(s) Prof. Dr. Tobias Backers
Further information Relevante Fachliteratur wird am Beginn der jeweiligen Veranstaltungen vorgestellt.

Baugrundcharakterisierung Boden					
Module number	**Credits** 5 CP	**Workload** 125-150 h	**Semester** 2.+3. Sem.	**Frequency** Annually	**Duration** 2 semesters
Courses a) Bodenmechanisches und -hydraulisches Laborpraktikum b) Lockergesteinskartierung und hydrogeologisches Feldpraktikum			**Contact hours** (a) 2 SWS (b) 5 days	**Self-study** (a) 40 h (b) 50 h	**Group size** (a) 12 students (b) 18 students

Prerequisites

Modul Grundlagen der Ingenieurgeologie, Modul Baugrunderkundung und Dokumentation

Learning outcomes

Im Rahmen der Baugrundmodellerstellung ist das Lockergestein durch bodenmechanische Laborversuche zu charakterisieren. Der Kurs vermittelt die grundsätzlichen Arbeitsmethoden der bodenmechanischen Laborarbeit. Darüber hinaus werden eine Reihe von Standardversuchen vorgestellt, durchgeführt, ausgewertet und die Kennwerte eingeordnet.

Der Baugrunderkundung und -modellierung kommt in bautechnischen Projekten eine grundlegende Bedeutung zu. Es sind die wesentlichen Kennwerte zu bestimmen und ein Untergrundmodell zu erstellen. Im Rahmen der Geländeübung werden eine Reihe von Erkundungsbohrungen geteuft, der erbohrte Lockergesteinsbaugrund angesprochen und ein Untergrundmodell (Profilschnitt) erstellt. Darüber hinaus wird die Grundwassersituation dokumentiert und Proben für eine weitergehende Charakterisierung des Baugrunds genommen.

Die Teilnehmerinnen und Teilnehmer erlernen die methodischen Grundlagen der Bestimmung von bodenmechanischen Parametern. Darüber hinaus sind sie mit der prinzipiellen Durchführung und Auswertung wesentlicher Laborversuche vertraut. Weiterhin wird das dazugehörige normative Berichtswesen geübt.

Die Teilnehmerinnen und Teilnehmer erlernen die Baugrunderkundeung mittels leichtem und mittelschwerem Bohrgerät (u.a. Bohrstock, Schlitzsonde, Carl Hamm Argos), sind mit den Bohrwerkzeugen vertraut und kennen die Vor- und Nachteile bei der Probengewinnung, können Lockergestein normgerecht ansprechen und Proben nehmen. Darüber hinaus sind die Teilnehmerinnen und Teilnehmer mit der Darstellung der Ergebnisse als Profilschnitt mithilfe einer Standardsoftware vertraut.

Inhalt

Grundlagen der Erhebung bodenmechanischer Kennwerte; Durchführung und Auswertung von Standardversuchen; Durchführung einer Baugrunderkundung in Lockergestein; Kenntnis der verfahrenstechnischen Schritte einer Erkundungsbohrung; Lockergesteinsansprache; Probennahme; Profilerstellung mittels Standardsoftware.

Teaching methods

Laborpraktikum, Geländeübung

Mode of assessment

Berichte

Requirement for the award of credit points

Berichte

Module applicability
Weight of the mark for the final score 4 % der Gesamtnote (5 von 120 CP)
Module coordinator and lecturer(s) Prof. Dr. Tobias Backers, Linus Eickhoff
Further information Relevante Fachliteratur wird am Beginn der jeweiligen Veranstaltungen vorgestellt.

Geomechanik					
Module number	**Credits**	**Workload**	**Semester**	**Frequency**	**Duration**
	10 CP	250-300 h	3. Sem.	Every WS	1 semester
Courses			**Contact hours**	**Self-study**	**Group size**
a) Geomechanik und Geotechnik komplexer Systeme b) geomechanische numerische Simulation c) Geotechnisches Projekt			(a) 2 SWS (b) 1 SWS (c) 1 SWS	(a) 75 h (b) 55 h (c) 130 h	

Prerequisites

Modul Grundlagen der Ingenieurgeologie, Modul Baugrunderkundung und Dokumentation; Modul Felsmechanik und Felsbau

Learning outcomes

Geomechanik ist eine integrative Disziplin, welche das mechanische Verhalten des geologischen Untergrundes bei Änderungen von Spannungen, Verschiebungen, Porendruck, der Temperatur oder weiterer Randbedingungen quantifizierend beschreibt. Unter Geotechnik versteht man Methoden der bautechnischen Nutzbarmachung des Untergrundes, d.h. des Baugrundes. Für eine umfassende und nachhaltige Herangehensweise ist es dabei notwendig Kenntnisse der Geologie, Bodenmechanik, Felsmechanik, Gesteinsphysik und verschiedener bau- und verfahrenstechnischer Disziplinen integrativ anzuwenden.

Im Rahmen des Kurses werden anhand von Anwendungsfeldern die einzelnen erlernten Kompetenzen des Curriculums zusammengeführt, um ein Verständnis für die notwendigen Maßnahmen zur Beschreibung des Untergrundes und das geoingenieurmäßige Herangehen an die Themenfelder zu generieren. Hierbei wird der Fokus auf die Diskussion geologisch oder bautechnisch komplexer Systeme gelegt.

Die Bearbeitung von Projekten in der späteren Berufspraxis setzt im Allgemeinen die Zusammenarbeit in Teams voraus; dies bedingt sich häufig aus der Komplexität der Aufgaben. Im Rahmen des geotechnischen Projektes wird in Kleingruppen eine Fragestellung bearbeitet, welche sich an reale Daten und Fragestellungen anlehnt. Hierbei werden die Kursteilnehmer im Format eines Planspiels eine Firma gründen, sich um den Auftrag zur Bearbeitung einer Fragestellung bewerben und hierbei grundlegende Kenntnisse im Bereich der Unternehmensformen und Preisgestaltung autodidaktisch erlernen. Nach Erteilung des Auftrages erarbeiten die ‚Firmen' eine Lösung unter Anwendung und auch Intensivierung des im Rahmen des Curriculums des Geoingenieurwesens erlernten Kompetenzen. Die individuellen Stärken und Kompetenzen der ‚Firmenangehörigen' werden sich hierbei ergänzen, zu optimierten Lösungen führen und den anderen Teilnehmenden neue Aspekte aufzeigen.

Zwischenergebnisse werden dem ‚Auftraggeber' vorgestellt; hier erhalten die Kursteilnehmer Feedback und profilieren ihre Präsentations- und Diskussionsfähigkeiten. Am Ende des Kurses steht eine Gesamtpräsentation der erarbeiteten Lösung und die Übergabe des Berichtes an den ‚Auftraggeber'.

Die Teilnehmerinnen und Teilnehmer sind in der Lage die Komplexität von geologischen, bzw geotechnischen Systemen zu erfassen und zu analysieren. Dabei wird die Kompetenz zur Identifikation der einzelnen geomechanischen Fragestellungen in komplexen Problemen profiliert, um die kritischen systemisch relevanten Randbedingungen zu isolieren. Darüber hinaus sind die Teilnehmerinnen und Teilnehmer mit den typischen Charakteristika von typischen Projekten vertraut.

Die Teilnehmerinnen und Teilnehmer intensivieren ihre Präsentations- und Diskussionskompetenz. Durch die Gruppenarbeit wird die Teamfähigkeit gestärkt. Die intensive Beschäftigung mit einer komplexen Fragestellung wird ein tiefergehendes Verständnis der

geologischen und bautechnischen Zusammenhänge generiert und dies trainiert die Berücksichtigung ingenieurgeologischer Aspekte zur Problemlösung
Content Erkundungsanforderungen, Fragestellungen, Verfahrenstechnik und Bautechnik im u.a. Bereich des Tunnelbaus, der Erstellung von Tiefbohrungen, Entwicklung von tieferngeothermischen Reservoiren oder des Talsperrenbaus; Erarbeitung eines geotechnischen Berichtes; Teamarbeit; Anwendung der erlernten Grundlagen des Studiums des Geoingenieurwesens.
Teaching methods Vorlesung mit integrierten Übungen, Projekt
Mode of assessment Modulprüfung, Bericht
Requirement for the award of credit points Bericht, Präsentationen
Module applicability
Weight of the mark for the final score 8 % der Gesamtnote (10 von 120 CP)
Module coordinator and lecturer(s) Prof. Dr. Tobias Backers
Further information Relevante Fachliteratur wird am Beginn der jeweiligen Veranstaltungen vorgestellt.

Geological Engineering for Subsurface Energy Systems					
Module number	**Credits** 10 CP	**Workload** 250-300 h	**Semester** 3. Sem.	**Frequency** Every WS	**Duration** 1 semester
Courses a) Reservoir Geomechanics b) Simulation of Geological Systems Behaviour c) Subsurface Energy Utilisation Project			**Contact hours** (a) 2 SWS (b) 1 SWS (c) 1 SWS	**Self-study** (a) 75 h (b) 55 h (c) 130 h	**Group size**
Prerequisites Module Rock Mass Stress Fields, Module Rock Mass Mechanics and Rock Engineering, Module Rock Mass Characterisation					
Learning outcomes Society is facing multiple challenges due to climate change and increasing energy demand. Sustainable solutions are needed. One area of engineering with a high potential to face the above mentioned societal challenges is geological engineering of the subsurface for sustainable energy extraction and storage. It will cover the basics of reservoir engineering for subsurface energy systems and give an introduction to numerical simulation of typical reservoir engineering questions. A project thesis will complement the teaching and foster team-work, self-guided canvassing of information and handling of incomplete geological engineering data sets.					
Content Reservoir Engineering					
Teaching methods Lectures, exercises, numerics lab, project					
Mode of assessment Module exam, report					
Requirement for the award of credit points Passing grades on report, presentations, exercises					
Module applicability					
Weight of the mark for the final score 8 % of the final grade (10 von 120 CP)					
Module coordinator and lecturer(s) Prof. Dr. Tobias Backers					
Further information to be announced					

Kristallchemie

Module number	Credits	Workload	Term	Frequency	Duration
	10 CP	300 h	2. + 3. Sem.	SS/WS	2 semesters

Courses	Contact hours	Self-study	Group size
a) Kristallchemie (Vorlesung und Übung)	(a) 2 SWS	(a) 70 h	15 students
b) Realstrukturbau und Phasenumwandlungen (Vorlesung und Übung)	(b) 2 SWS	(b) 70 h	
c) Edelsteinkunde (Vorlesung)	(c) 2 SWS	(c) 70h	

Prerequisites

Formal: Für Studierende in natur- und ingenieurwissenschaftlichen Masterprogrammen.

Textual: Kenntnisse über Aufbau und Symmetrieeigenschaften von Kristallen sowie Kenntnisse in der allgemeinen und anorganischen Chemie werden vorausgesetzt.

Preparation: –

Learning outcomes

Nach dem erfolgreichen Abschluss des Moduls

- kennen Studierende die grundlegenden Prinzipien, die zur Ausbildung einer spezifischen Kristallstruktur führen.
- kennen Studierende strukturelle Grundtypen sowie wichtige Strukturfamilien und deren Eigenschaften.
- können die Studierenden strukturelle Instabilitäten erkennen und daraus resultierende Phasenumwandlungen klassifizieren.
- sind die Studierenden in der Lage, die Auswirkungen von Phasenumwandlungen auf physikalische Eigenschaften von Kristallen und deren mögliche Anwendungen abzuschätzen.
- kennen Studierende die wichtigsten Kristallarten, die als Edelsteine gehandelt werden, können diese identifizieren und grundlegend gemmologisch bewerten.

Content

- Atombau, Quantenzahlen.
- Chemische Bindungen, Hybridisierung, Paulingsche Regeln.
- Gitterenergie, Packungsmuster in Kristallen, Bindungsvalenzen, Strukturformeln.
- Kristallfeldtheorie, Magnetismus.
- Beschreibung und Darstellung von Kristallstrukturen.
- Strukturelle Grundtypen, Spinelle, Perowskite, Silikate.
- Komplexe Kristallstrukturen (Zeolithe, Schichtsilikate), Kristallchemie von H_2O.
- Klassifikation von Gitterdefekten.
- Fremdatome, thermische Punktdefekte, Diffusion.
- Versetzungen, Plastizität.
- Flächendefekte, Stapelfehler, Zwillinge, Formgedächtniseffekte.
- Klassifikationen von Phasenumwandlungen.
- Grundzüge der Landau-Theorie, kritische Phänomene.
- Atomistische Ursachen struktureller Instabilitäten, Auswirkung auf physikalische Eigenschaften.
- Natürliche und synthetische Edelsteine (Entstehung, Vorkommen bzw. Züchtung).
- Kriterien zur Identifizierung und Bewertung von Edelsteinen.
- Optische Eigenschaften von Edelsteinen (Farbe, Brechungsindex, Dispersion).

Teaching methods

Vorlesung und schriftliche Übungsaufgaben.

Mode of assessment	
Schriftliche Modulabschlussprüfung (Modulklausur) von 2 h.	
Requirement for the award of credit points	
Bestandene Modulklausur, Bearbeitung aller schriftlichen Übungsaufgaben.	
Module applicability	
Weight of the mark for the final score	
8,3 % der Gesamtnote (10 von 120 CP).	
Module coordinator and lecturer(s)	
Prof. Dr. Jürgen Schreuer; Dr. Marie Münchhalfen	
Further information	
Literatur: A.R. West: Grundlagen der Festkörperchemie, VCH Brown, LeMay, Bursten: Chemie, Studieren kompakt, Pearson R.C. Evans: Einführung In die Kristallchemie, deGruyter J. Bohm: Realstruktur von Kristallen, E. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart 1995, ISBN 3-510-65160-X. T. Häger: Edelsteinkunde. Bestimmung, Eigenschaften und Behandlung. Springer Spektrum, ISBN 978-3-662-61305-4.	

Kristallisation					
Modul number	**Credits** 10 CP	**Workload** 300 h	**Term** 2. + 3. Sem.	**Frequency** SS/WS	**Duration** 2 semesters
Courses a) Mineralization in geothermal systems b) Synthetische Kristalle			**Contact hours** (a) 4 SWS (b) 2 SWS	**Self-study** (a) 150 h (b) 60 h	**Group size** 12 students

Prerequisites

Formal: Für Studierende in natur- und ingenieurwissenschaftlichen Masterprogrammen.

Textual: Kenntnisse über Aufbau und Symmetrieeigenschaften von Kristallen werden vorausgesetzt, Kenntnisse über Röntgenbeugung sind wünschenswert.

Preparation: –

Learning outcomes

Nach dem erfolgreichen Abschluss des Moduls

- kennen Studierende die grundlegenden Parameter und Prozesse, welche die Nukleation und das Wachstum von Keimkristallen in unterschiedlichen Milieus bestimmen.
- sind Studierende in der Lage, Phasendiagramme zu lesen und unter Einbeziehung thermoanalytischer Daten mögliche Kristallisationsszenarien daraus abzuleiten.
- kennen Studierende typische Verfahren zur Synthese bzw. Züchtung aus Lösung, Schmelze und Gasphase, und können diese im Hinblick auf das spezifische Züchtungsziel bewerten.
- sind Studierende in der Lage, einfache Synthese-/Züchtungsaufgaben selbstständig durchzuführen und die Produkte strukturell und thermoanalytisch zu charakterisieren.

Content

- Stoffsysteme, Zustandsgrößen, thermodynamische Potentiale, chemische Potentiale, Phasenumwandlungen.
- Phasenregel, Phasendiagramme, Ein- und Zweistoffsysteme.
- Verteilungskoeffizienten, Segregationseffekte, Stofftransport durch Diffusion und Konvektion, Viskosität, konstitutionelle Unterkühlung.
- Konventionelle Nukleationsprozesse, homogene und heterogene Keimbildung, kritischer Keimradius, Ostwald-Miers-Bereich, Ostwaldsche Stufenregel.
- Wachstumsprozesse, Anlagerungsenergien, Grenzflächenenergien, Flächenkeime, Wachstumsgeschwindigkeiten, Einfluss von Versetzungen, Morphologie von Kristallen.
- Nichtkonventionelle Nukleation und Wachstumsprozesse.
- Lösungseigenschaften von Fluiden unter Bedingungen der Erdkruste
- Experimentelle und technische Verfahren zur Einkristallzüchtung aus Gasphasen, Lösungen und Schmelzen.
- Verfahren zur Charakterisierung von Kristallisationsprodukten (u.a. Differentialthermoanalyse, Röntgenbeugung).

Teaching methods

Vorlesung, praktische Laborübungen unter Verwendung diverser Züchtungs- und Messgeräte.

Mode of assessment

Schriftliche Modulabschlussprüfung (Modulklausur) von 2 h.

Requirement for the award of credit points

Bestandene Modulklausur, Durchführung aller Laborübungen, erfolgreicher Bericht zu Laborübungen mit Auswertung der gewonnenen Beobachtungen/Messdaten.

Module applicability

Weight of the mark for the final score

8,3 % der Gesamtnote (10 von 120 CP).
Module coordinator and lecturer(s) Prof. Dr. Jürgen Schreuer; Dr. Marie Münchhalfen
Further information Literature: K.-Th. Wilke und J. Bohm: Kristallzüchtung, Leipzig 1993, ISBN 978-3326000923.

Kristallphysik					
Modul number	**Credits** 10 CP	**Workload** 300 h	**Term** 1. + 2. Sem.	**Frequency** WS/SS	**Duration** 2 semesters
Courses a) Kristallphysik b) Physikalische Charakterisierung			**Contact hours** (a) 3 SWS (b) 4 SWS	**Self-study** (a) 50 h (b) 145 h	**Group size** 12 students

Prerequisites

Formal: Für Studierende in natur- und ingenieurwissenschaftlichen Masterprogrammen.

Textual: Kenntnisse über Aufbau und Symmetrieeigenschaften von Kristallen werden vorausgesetzt.

Preparation: –

Learning outcomes

Nach dem erfolgreichen Abschluss des Moduls

- kennen Studierende die grundlegenden Konzepte der tensoriellen Kristallphysik und verstehen die Zusammenhänge zwischen der atomaren Struktur von Kristallen und deren thermischen, mechanischen und elektrischen Eigenschaften.
- sind Studierende befähigt, Strategien zur vollständigen Bestimmung tensorieller Eigenschaften von anisotropen Medien zu entwickeln.
- kennen Studierende geeignete Messverfahren zur Untersuchung thermischer und elektromechanischer Eigenschaften und können entsprechende Messapparaturen nutzen sowie die dafür notwendigen Präparate herstellen.,
- sind Studierende in der Lage, Messergebnisse kritisch zu hinterfragen, mögliche Fehlerquellen zu diagnostizieren und deren Auswirkungen auf die Resultate zu quantifizieren.

Content

- Kristallographische und kristallphysikalische Bezugssysteme.
- Zustandsgrößen, thermodynamische Potentiale, Basiseigenschaften.
- Nichttensorielle und tensorielle Eigenschaften, Transformationsverhalten.
- Einfluss von Symmetrie, Neumannsches Prinzip, Curiesches Prinzip.
- Herstellung von Präparaten für Messzwecke (Orientieren, Sägen, Schleifen).
- Longitudinal- und Transversaleffekte, Bezugsflächen, Extremwerte von Eigenschaften.
- Tensoren 0. Stufe: Dichte und Wärmekapazität, Verfahren zur Bestimmung der Dichte bzw. Wärmekapazität.
- Tensoren 1. Stufe: Symmetriereduktion, pyroelektrischer Effekt, Messstrategien, Tensorfläche.
- Tensoren 2. Stufe: Symmetriereduktion, Bezugsflächen, symmetrische und antisymmetrische Tensoren, Hauptachsentransformation, Dielektrizitätstensor, Ferroelektrizität, Deformationstensor, thermische Ausdehnung einschließlich der gängigen Messmethoden.
- Tensoren 3. Stufe: Tensorfläche, Messstrategien, piezoelektrischer Effekt, Elektrostriktion, Verfahren zur Messung von druckinduzierten Ladungen bzw. feldinduzierten Deformationen.
- Tensoren 4. Stufe: Symmetriereduktion, Elastizitätstensoren, Voigt-Notation, Elastostatik, Elastodynamik, Wellenausbreitung in Kristallen, diverse Messmethoden (insbesondere Ultraschallresonanzspektroskopie).
- Nichttensorielle Eigenschaften.
- Kritische Analyse von Messdaten und deren Aufbereitung für Berichte bzw. Publikationen.

Teaching methods

Vorlesung, praktische Laborübungen an typischen Messgeräten.

Mode of assessment

Schriftliche Modulabschlussprüfung (Modulklausur) von 2 h.
Requirement for the award of credit points Bestandene Modulklausur, Durchführung aller Laborübungen, erfolgreicher Bericht zu Laborübungen mit Auswertung der gewonnenen Messdaten.
Module applicability
Weight of the mark for the final score 8,3 % der Gesamtnote (10 von 120 CP).
Module coordinator and lecturer(s) Prof. Dr. Jürgen Schreuer
Further information Literatur: S. Haussühl: Physical properties of crystals. Wiley-VCH, Weinheim 2007, ISBN 978-3527405435. R.E. Newnham: Properties of materials: Anisotropy, symmetry, structure, Oxford University Press, New York 2005, ISBN 978-0198520764.

Festkörperspektroskopie					
Module number	**Credits** 10 CP	**Workload** 300 h	**Term** 2.+3. Sem.	**Frequency** a)+c) SS b)+d) WS	**Duration** 2 Semester

Courses	**Kontaktzeit**	**Selbststudium**	**Gruppengröße**
a) Festkörperspektroskopie I: NMR Spek.	2 SWS	12 h	12 Studierende
b) Festkörperspektroskopie II: Allg. Spek.	2 SWS	12 h	
c) Laborübungen zu FK I	2 SWS	80 h	
d) Laborübungen zu FK II	2 SWS	80 h	

Prerequisites

Formal: Für Studierende in natur- und ingenieurwissenschaftlichen Masterprogrammen.

Textual: Mathematische Kenntnisse zur Analysis, Statistik und Vektoralgebra, sowie physikalische Kenntnisse der Elektrodynamik und Mechanik, und Kenntnisse zur allgemeinen Chemie und Kristallographie müssen in einem mit > 50% bewerteten Eingangstest (Dauer 1h) nachgewiesen werden.

Preparation: Analysis (Integral- u. Differentialrechnung), Statistik, Vektoralgebra, Mechanik, Elektrodynamik, Atomaufbau, Periodensystem der Elemente, Chem. Bindungen, Punkt- u. Raumgruppen, Kristallsysteme, Röntgenbeugung, reziprok. Gitter, Symmetrieelemente

Learning outcomes

Nach dem erfolgreichen Abschluss des Moduls

- kennen Studierende die grundlegenden Konzepte der Spektroskopie und Quantenmechanik und kennen die wichtigsten spektroskopischen Methoden,
- sind Studierende befähigt, Strategien zur Aufklärung lokaler atomarer Umgebungen zu verfolgen und die korrekte spektroskopische Methode anzuwenden,
- kennen Studierende geeignete spektroskopische Messverfahren zur Untersuchung von anorganischen Festkörpern, natürlichen und synthetischen Mineralen,
- sind Studierende in der Lage, spektroskopische Messergebnisse kritisch zu hinterfragen, mögliche Fehlerquellen zu diagnostizieren und deren Auswirkungen auf die Resultate zu quantifizieren.

Content

Festkörperspektroskopie I: Festkörper NMR Spektroskopie

- Was ist NMR-Spektroskopie?
- Die Zeemanwechselwirkung
- Geschichtliche Entwicklung der Technik
- Continous Wave- und Impulstechnik
- Spin-Gitter-Relaxation und Dynamik
- Magnetische dipolare Wechselwirkungen
- Pulsverfahren (Spin-Echo)
- Spin-Spin Relaxation
- Die Chemische Verschiebung
- Magic-Angle Spinning (MAS)
- Korrelation von Kernnachbarschaften durch heteronukleare dipolare Wechselwir-kung: Cross-Polarisation (CPMAS), Rotational Echo Double Resonance (REDOR)
- Wirkungsweise der Quadrupolwechselwirkung
- Wechselwirkungen 1. und 2. Ordnung, Anisotropie und Quadrupolshift
- Magic Angle Spinning bei Quadrupolwechselwirkungen 2. Ordnung

- Räumliche und Puls-Ausmittelungsmethoden: Double Rotation (DOR), Dynamic Angle Spinning (DAS), Multiquanten Magic Angle Spinning (MQMAS)

Festkörperspektroskopie II: Allgemeine Spektroskopie

- Wozu braucht man Quantenmechanik: Physikalische Phänomene, die sich nicht klassisch erklären lassen
- Plancks Quantelung von Energiezuständen, Welle-Teilchen Dualismus
- Wellenfunktion, Hamiltonoperator, Eigenwerte, -funktionen und Schrödinger-Gleichung, Heisenbergsche Unschärferelation
- Quantenmechanik einfacher eindimensionaler Systeme
- Die elektromagnetische Welle – Aufbau und Polarisation
- Wellenlängenbereiche und Anwendung in der Spektroskopie
- Intensität und Breite von Spektrallinien
- Absorption / Emissionsspektren – Einstein-Koeffizienten
- Energieniveaus und Übergangswahrscheinlichkeiten
- Rotations- und Schwingungsspektroskopie: Starrer und nicht-starrer Rotator, harmonischer und anharmonischer Oszillator
- Auswahlregeln Infrarotspektren, Aufbau moderner Infrarotspektrometer
- Raman-Spektroskopie: Rayleighstreuung, Stokes- und Anti-Stokes Linien
- Schwingungstypen und Gruppentheorie, Irreduzible Darstellungen, Charaktertafeln, Charaktere, Ordnung, Symmetriespezies, Bestimmung der Schwingungstypen mit Hilfe von Charaktertafeln, Bestimmung von erlaubten und verbotenen Übergängen
- Ramanspektren und Aufbau moderner Ramanspektrometer
- IR- und -Schwingungsspektren von Mineralen
- Elektronenspektroskopie: Ein- und Mehrelektronenatome, Elektronenübergänge, Auswahlregeln, Russell-Saunders Kopplung
- Atomabsorptions- und emissionsspektroskopie, Röntgenspektroskopie (XPS, EXAFS)
- Die Schwingungsstruktur der Elektronenübergänge: Feinstruktur und Franck-Condon-Prinzip
- Fluoreszenz und Phosphoreszenz, Funktion von LASERn
- UV-VIS Spektroskopie: Aufbau eines UV-VIS Spektrometers, Kristallfeldtheorie, Molekularorbitaltheorie, d-d Übergänge und Charge-Transfer Übergänge, Termsymbole, Jahn-Teller Verzerrung, Tanabe-Sugano Diagramme
- EPR Spektroskopie: Der Elektronen-Zeeman-Term
- Elektronenspinwechselwirkungen: Die Nullfeld-Aufspaltung (ZFS)
- Elektronen-Kernspinwechselwirkungen: Die Hyperfeinstruktur (HFS)
- Aufbau eines EPR cw-Spektrometers: Einkristallspektren und Rotationsdiagramme
- Der Mößbauereffekt: Rückstoßfreie Kernresonanzabsorption
- Das Mößbauerspektrometer: Ausnutzung des Dopplereffektes
- Isomerieverschiebung, Quadrupol- und magnetische Hyperfeinaufspaltung
- Typischer Mößbauerkern in den Geowissenschaften: 57Fe
- Mößbauerspektren von Mineralen: Bestimmung des Fe2+ / Fe3+ -Verhältnisses

Teaching methods

Vorlesung, praktische Laborübungen an typischen Spektrometern (NMR, IR, UV-VIS).

Mode of assessment

Mündliche Modulabschlußprüfung von 30 min.

Requirements for the award of credit points

Bestandene mündliche Modulabschlußprüfung, verpflichtender Besuch der Vorlesungen, Durchführung aller Laborübungen, erfolgreiche Berichte zu Laborübungen mit Auswertung der gewonnenen Messdaten

Module applicability (to other study programs)

Weight of the mark for the final 8,3 % der Gesamtnote (10 von 120 CP)	
Module coordinator and lecturer Michael Fechtelkord	

Further information

Literature:

Festkörperspektroskopie I

Abragam A. (1961) The Principles of.Nuclear Magnetism. Clarendon Press (Oxford)

Braun, S., Kalinowski, H., Berger S. (1996) 100 and more basic NMR experiments: a practical course. VCH (Weinheim [u.a.]) ISBN 3-527-29091-5 (brosch.)

Chandrakumar N., Subramanian S. (1987) Modern Techniques in High-Resolution FT-NMR. Springer-Verlag (Heidelberg)

Ernst R. R., Bodenhausen G., Wokaun A.(1987) Principles of Nuclear Magnetic Resonance in one and two Dimensions. Clarendon Press (Oxford)

Engelhardt G., Michel D. (1988) High Resolution Solid-State NMR of Silicates and Zeolites. John Wiley & Sons (Chisester, New York, Brisbaine)

Friebolin, H. (1992) Ein- und zweidimensionale NMR-Spektroskopie: eine Einführung. 2. Aufl., VCH (Weinheim [u.a.]) ISBN 3-527-28507-5

Fukushima E., Roeder B. W. (1981) Experimental Pulse NMR - A Nuts and Bolts Approach. Addison-Wesley (London)

Günther, H. (1992) NMR-Spektroskopie: Grundlagen, Konzepte und Anwendungen der Protonen- und Kohlenstoff-13 Kernresonanz-Spektroskopie in der Chemie. 3. Aufl., Thieme(Stuttgart [u.a.]) ISBN 3-13-487503-9

Kalinowski, H., Berger S. (1984) 13C-NMR-Spektroskopie. Thieme (Stuttgart [u.a.]) ISBN 3-13-632801-9

Mehring M. (1983) Principles of High Resolution NMR in Solids. Springer-Verlag (Heidelberg)

Slichter C. P. (1990) Principles of Magnetic Resonance. 3. Aufl., Springer-Verlag (Heidelberg)

Rose M. E. (1961) Elementary Theory of Angular Momentum. John Wiley & Sons (New York)

Festkörperspektroskopie II

Amthauer, G., Grodzicki, M., Lottermoser, W., Redhammer, G. (2004) Mössbauer spectroscopy: Basic Principles. In: Beran, A., Libowitzky, E. (eds.) (2004) Spectroscopic Methods in Mineralogy. EMU Notes in Mineralogy, Volume 6, Eötvös University Press, Budapest, 345-368.

Atkins, P.W. (1988) Physikalische Chemie. 1. Auflage, VCH Verlagsgesellschaft, Weinheim.

Libowitzky, E., Beran, A. (2004) IR spectroscopic characterisation of hydrous species in minerals. In: Beran, A., Libowitzky, E. (eds.) (2004) Spectroscopic Methods in Mineralogy. EMU Notes in Mineralogy, Volume 6, Eötvös University Press, Budapest, 227-280.

Beran, A., Libowitzky, E. (eds.) (2004) Spectroscopic Methods in Mineralogy. EMU Notes in Mineralogy, Volume 6, Eötvös University Press, Budapest.

Galoisy, L., (2004) X-ray absorption spectroscopy in geosciences: Information from the EXAFS region. In: Beran, A., Libowitzky, E. (eds.) (2004) Spectroscopic Methods in Mineralogy. EMU Notes in Mineralogy, Volume 6, Eötvös University Press, Budapest, 553-588.

Gerthsen, C. (2006) Physik. 23. Auflage, Springer-Verlag, Berlin, Heidelberg, New York.

Hesse, M., Meier, H., Zeeh, M. (1987) Spektroskopische Methoden in der organischen Chemie. 3. Auflage, Georg Thieme Verlag, Stuttgart, New York.

Huheey, J.E., Keiter, E.A., Keiter, R.L. (2003) Anorganische Chemie. 3. Auflage, Walter de Gruyter, Berlin, New York.

McCammon, C.A. (2004) Mössbauer spectroscopy: Applications. In: Beran, A., Libowitzky, E. (eds.) (2004) Spectroscopic Methods in Mineralogy. EMU Notes in Mineralogy, Volume 6, Eötvös University Press, Budapest, 369-398.

Müller, V.F. (2000) Quantenmechanik. Oldenbourg Verlag, München, Wien.

Riedel, E., Janiak, C. (2007) Anorganische Chemie. 7. Auflage, Walter de Gruyter, Berlin, New York.

Schwabl, F. (1993) Quantenmechanik. 4. Auflage, Springer-Verlag, Berlin, Heidelberg, New York.

Wedler, G. (1985) Lehrbuch der Physikalischen Chemie. 2. Auflage, VCH Verlagsgesellschaft, Weinheim.

Crystal structure analysis					
Modul number	**Credits** 10 CP	**Workload** 300 h	**Term** 2. + 3. Sem.	**Frequency** SS/WS	**Duration** 2 semesters
Courses a) Crystal structure analysis (Lectures) b) Single crystal X-ray diffraction: (Practical) c) Powder X-ray diffraction: (Practical)			**Contact hours** (a) 2 SWS (b) 3 SWS (c) 3 SWS	**Self-study** (a) 60 h (b) 60 h (c) 60 h	**Group size** 12 students

Prerequisites

Formal: Master students from natural science and engineering curriculum.

Textual: Basic knowledge on crystal symmetry, crystal chemistry and crystal physics.

Preparation: –

Learning outcomes

After completion of the module the students

- know the principles of X-ray diffraction and structure solution methods.
- know typical techniques and procedures of structural analysis and can apply the necessary correction factors.
- are able to select a suitable procedure for a given problem and have a basics of the necessary computer programs.
- are able to independently carry out a crystal structure analysis from single crystal and powder data on the basis of a given data set, obtain correct crystal structure solution, evaluate errors, and assess the quality of the result.

Content

- reciprocal space, reciprocal lattice, Braggs and Laue laws, Ewald's sphere.
- Bremsstrahlung and characteristic X-rays, X-ray absorption.
- Interaction of X-rays with materials, atomic scattering factor.
- Structure factor, phase factor.
- Correction factors: polarisation, Lorentz, absorptions, scale, temperature, absorption, multiplicity factors.
- Fourier transformation, Differential Fourier synthesis.
- Crystal structure solution: heavy atom technique, direct method, direct space approach, Patterson function, anomalous scattering.
- Crystal structure refinement, restraints und constraints, quality of fitting.
- Representation of crystal structures.
- Rietveld technique.
- Texture and crystal size, real structure characterisation, radial and pair distribution function.
- Qualitative and quantitative phase analysis. Crystal structure date banks.

Teaching methods

Lectures, problems solving, practical laboratory work with X-ray diffractometers and computer software.

Mode of assessment:

Written exam – 2 h

Requirement for the award of credit points

Successful written exam, participation in all laboratory trainings, successful homework.
Module applicability
Weight of the mark for the final score 8,3 % (10 von 120 CP).
Module coordinator and lecturer(s) Dr. Kirill Yusenko
Further information **Literature:** **Int. Tables for Crystallography. Vol. A:** Space-group symmetry **Int. Tables for Crystallography. Vol. C:** Mathematical, physical and chemical tables **Int. Tables for Crystallography. Vol. H**: Powder diffraction **Pecharsky**, **Zavaliy**: Fundamentals of Powder Diffraction and Structural Characterization of Materials

Electron beam microanalysis					
Module number	**Credits** 6 CP	**Workload** 180 h	**Term** 2. Sem.	**Frequency** Every SS	**Duration** 1 semester
Courses a) Lecture: Electron beam microanalysis b) Practical exercises on electron beam microanalysis (SEM, CL, EMPA)			**Contact hours** (a) 2 SWS (b) 2 SWS	**Self-study** (a) 60 h (b) 60 h	**Group size** 9 students
Prerequisites					
Learning outcomes After completion of this module the students • understand the applicability of electron beam microanalytical methods. • know different kinds of methods (SEM, EMPA, TEM, CL, Auger electron). • are able to evaluate the strengths and limitations and perform an analysis of errors. • gained practical experience of diverse electron beam analytical tools.					
Content **a) Lecture: Electron beam microanalysis** Overview of the use of electron beam methods for the analysis of solid materials. Electron – matter interaction (elastic scattering, inelastic scattering, production of X-rays, Auger electrons, and Cathodoluminescence). Construction principles and working of different instruments (TEM, SEM, EMPA, STEM, CL microscopes). Functionality of different parts of the instruments such as pumps, electron optic, generation of electron beams). Analytical methods and interpretation of analytical results (EELS, EBSD, electron optical images, EDX, WDX, diffraction images). **b) Practical exercises on electron beam microanalysis (SEM, CL, EMPA)** Familiarization with the equipment and their parts. Coating a sample with C or Au. Inserting and extracting a sample holder from the sample chamber under vacuum. Adjusting the electron beam. Navigation on the sample. Use of different detectors (SE, BSE, CL, EBSD) for imaging. Experiments on the effects of accelerating voltage and sample current. Qualitative analysis and identification of minerals with the help of the energy dispersive detectors. Collecting wavelength dispersive spectra in the electron microprobe. Comparison of results from EDX and WDS. Production of element distribution maps. Generation of crystallographic orientation images (SEM). Conceiving a quantitative analytical program. Determination of peak and background positions, choice of spectrometers, standard materials, counting times and beam parameters (EMPA). Evaluation of the analyses through the calculation of mineral formulae and estimate of errors.					
Teaching methods Lectures and practicals.					
Mode of assessment Written examination on the lecture part. Passing this exam is a pre-requisite for participation in the practical exercises. A written report about the practical work (description and examination of an unknown rock sample, along with description of the underlying theoretical aspects) will be graded..					
Requirements for the award of credit points Active participation in the practical demonstrated through a detailed record of experiments in the lab book and a written report.					
Module applicability					
Weight of the mark for the final score					

5,0 % of the overall grade (6 CP from 120)
Module coordinator and lecturer(s) Dr. René Hoffmann and Dr. Niels Jöns
Literature Potts et al.: Microprobe techniques in the Earth sciences; Springer Loretto (1984): Electron beam analysis of materials. 2nd ed., Springer-Verlag. Hughes & Hase (2010): Measurements and their uncertainties. 1st ed., Oxford University Press Goldstein et al. (2018): Scanning electron microscopy and X-ray microanalysis. 4th ed., Plenum Press. Reed (2005): Electron microprobe analysis and scanning electron microscopy in Geology, 2nd ed., Cambridge University Press.

Igneous petrology					
Module number	**Credits** 10 CP	**Workload** 300 h	**Term** 1. Sem.	**Frequency** Every WS	**Duration** 1 semester
Courses a) Petrology of igneous rocks b) Thin section exercises with igneous rocks c) Numerical exercises with data from igneous rocks			**Contact hours** (a) 2 SWS (b) 2 SWS (c) 2 SWS	**Self-study** (a) 70 hours (b) 60 hours (c) 80 hours	**Group size** 15 students

Prerequisites

Pre-requisites are the passed modules "Baumaterial der Erde" (BSc) or "Basics in Petrology" (MSc).

Learning outcomes

The students

- gain an advanced understanding of igneous petrology.
- master detailed microscopic and macroscopic descriptions and documentation of igneous rocks
- are able to use textural and thermodynamic criteria to work out the genetic history of the rocks
- know how to place the results in a geodynamic context of thermal evolution of the crust and the mantle

Content

a) Petrology of igneous rocks

- Thermal structure of the Earth and formation of melts.
- Classification of igneous rocks.
- Geochemical characteristics of igneous rocks.
- Trace element and isotopic characteristics of igneous rocks.
- Physical properties of silicate melts.
- Phase equilibria and phase diagrams.
- Melting in the mantle.
- Igneous processes in selected tectonic settings: Mid ocean ridges, subduction zones.
- Crustal melting and genesis of granitic rocks.
- Volcanic processes and basics of volcanology and volcanic hazards.

b) Thin section exercises with igneous rocks

- Igneous minerals in thin sections.
- General information on documenting thin section reports.
- Case studies of a range of volcanic and plutonic rocks to read the rock record to infer the processes that led to their formation.
- An emphasis is on relating the observations to phase diagrams and on inferring multistage processes from the rock record.

c) Numerical exercises with data from igneous rocks

- Calculation of CIPW Norm.
- Trace element modelling.
- Calculation of magma mixing, fractionation, assimilation and other igneous processes.
- Use of thermodynamic software such as MELTS to calculate equilibrium assemblages and compositions as well as to model the evolution of magmatic systems.

Teaching methods

Lectures and practicals (microscopy and calculations).

Mode of assessment
A final written examination including questions on microscopy of thin sections.
Requirements for the award of credit points
Passing grade in written examination.
Module applicability
Weight of the mark for the final score
8 % of the overall grade (10 CP from 120)
Module coordinator and lecturer(s) and lecturers
Dr. Thilo Bissbort, Prof. Raúl Fonseca
Literature
A.R. Philpotts, J.J. Ague (2009): Principles of igneous and metamorphic petrology. Cambridge University Press. ISBN 978-0-521-88006-0 J.D. Winter (2014): Principles of igneous and metamorphic petrology. Pearson Education. ISBN 978-1-292-02153-9 R. Gill (2010) Igneous rocks and processes – a practical guide. Wiley Blackwell. ISBN 978-0-6320-6377-2. M. Wilson (1997) Igneous petrogenesis – A global tectonic approach. Chapman & Hall. ISBN 0 412 53310 3. L.A. Raymond (1995) The study of igneous, sedimentary and metamoprphic rocks. Wm. C. Brown Communications Inc. ISBN 0-697-00190-3. McBirney, A. (2006) Igneous Petrology. Jones & Bartlett Publ. ISBN 10: 0763734489.

Basics in petrology					
Module number	**Credits** 6 CP	**Workload** 180 h	**Term** 1. Sem.	**Frequency** Every WS	**Duration** 1 semester
Courses a) Mineralogy b) Optical mineralogy			**Contact hours** (a) 2 SWS (b) 3 SWS	**Self-study** (a) 60 hours (b) 70 hours	**Group size** 20 students

Prerequisites

Mandatory course for all students pursuing the research direction "Petrology and Geochemistry", unless you have completed the BSc. module "Baumaterial der Erde".

Learning outcomes

The students:

- gain a basic understanding of the main groups of minerals, and key concepts of crystal structure, crystal chemistry, and optical mineralogy.
- will learn how to use the petrographic microscope to identify minerals based on their optical properties.
- are expected to transfer this knowledge to more advanced courses in both the Petrology and Geochemistry and Tectonics and Resources research directiongain an advanced understanding of igneous petrology.

Content

a) Mineralogy

- Minerals and crystal structure
- Crystal chemistry, chemical bonding and crystal field theory
- Thermodynamics and mineral stability
- The phase rule and phase diagrams
- Silicate groups (neso-, soro-, cyclo-, chain-, sheet-, and framework-silicates)
- Non-silicates (oxides, sulfides, sulfates and phosphates)

b) Optical Mineralogy

- Optical properties of minerals
- Mineral identification based on their optical properties

Teaching methods

Lectures (Mineralogy) and practicals (optical mineralogy)

Mode of assessment

a) a final written examination of max. 90 minutes,

b) practical exam (max. 90 minutes) using the polarization microscope as well as written question on theoretical aspects of thin section microscopy

Requirements for the award of credit points

Passing grade in both exams for course a) and b)

Module applicability

Weight of the mark for the final score

5 % of the final grade (6 CP from 120)

Module coordinator and lecturer(s) and lecturers

Prof Dr. Raúl Fonseca

Literature

- Deer, W. A., Howie, R. A., & Zussman, J. (2013). An introduction to the rock-forming minerals. Mineralogical Society of Great Britain and Ireland.
- · Ness, W. D. (1991). Introduction to optical mineralogy. Oxford University Press 4th Edition
- · Putnis, A. (1992). An introduction to mineral sciences. Cambridge University Press.

Metamorphic petrology

Module number	Credits	Workload	Term	Frequency	Duration
	12 CP	360 h	2. Sem.	Every SS	1 semester
Courses a) Petrology of metamorphic rocks b) Thin section exercises with metamorphic rocks c) Numerical exercises with data from metamorphic rocks d) THERMOCALC course			**Contact hours** (a) 2 SWS (b) 2 SWS (c) 2 SWS (d) 1 SWS	**Self-study** (a) 70 h (b) 60 h (c) 80 h (d) 60 h	**Group size** 15 students

Prerequisites:

Learning outcomes

- The students
- gain an advanced understanding of metamorphic petrology.
- master detailed microscopic and macroscopic descriptions and documentation of metamorphic rocks.
- are able to use textural and thermodynamic criteria to work out the genetic history of the rocks.
- know how to place the results in a geodynamic context.

Content

a) Petrology of metamorphic rocks

- Introduction to the basic questions in petrological research; how metamorphic rocks can be used to answer geodynamic questions. Crystal chemical basis (coordination polyhedra, exchange vectors). Representation of minerals in chemographic diagrams. Gibbs phase rule. Topology of phase diagrams and thermodynamic basis.
- Types of metamorphism: Regional – limited (cataclastic, mylonitic, contact); Regional – extended (burial, orogenic). P-T-t evolution due to crustal thickening and extension. Subduction, magmatic underplating.
- Metamorphic zones and facies series. Barrow type, Abukuma type, Subduction type.
- Types of metamorphic equilibria: Solid-gas equilibria (dehydration reactions, decarbonation reactions, redox reactions). Solid-solid reactions (Influence of solid solution on location of phase boundaries, divariant thermometers, divariant barometers). Trace element thermometers.
- Zoning in minerals (diffusion controlled growth, retrograde Fe-Mg exchange).
- Mass transport in metamorphism (fluid flow, metasomatism).
- Observations of metamorphic evolution of model systems (ultramafics, metabasics, calc-silicates, metapelites).
- Basics of geochronology of metamorphic rocks.

b) Thin section exercises with metamorphic rocks

- Identification of the most important metamorphic minerals in thin sections.
- General information on documenting thin section reports.
- Case studies of metapelites and metabasites (hand specimen description, petrographic description, texture analysis, discussion of possible protoliths, P-T evolution, phase relations, topology of phase diagrams).

c) Numerical exercises with data from metamorphic rocks

- Calculation of mineral formulae from chemical analyses.
- Representation of mineral compositions and phase relations.
- Schreinemaker's Analysis.
- Application of Clausius-Clapeyron equation to construct phase boundaries in P-T space. Generation of compatibility diagrams.

• P-T sections, T-X sections, P-X sections and P-T pseudosections with the help of thermodynamic software. Interpretation of the results using examples from real metamorphic rocks. Geothermobarometric calculations. Derivation of P-T conditions of formation of rocks on the basis of P-T grids. **d) THERMOCALC course** Advanced pseudosection modelling course for more complex model systems involving solid solutions, based on case studies in metabasic rocks.
Teaching methods Lectures and practicals (microscopy and calculations).
Mode of assessment Written final examination. Each individual makes microscopic observations on a sample and writes down observations and interpretations. Furthermore, general questions about metamorphic petrology have to be answered along with some numerical calculations
Requirements for the award of credit points Report with passing grade.
Module applicability
Weight of the mark for the final score 10 % of the overall grade (12 CP from 120)
Module coordinator and lecturer(s) Niels Jöns, Ralf Dohmen, Annika Dziggel
Literature F.S. Spear (1995); Metamorphic phase equilibria and pressure-temperature-time paths. Mineralogical Society of America Monograph. Washington DC. ISBN 0-939950-34-0 A.R. Philpotts, J.J. Ague (2021): Principles of igneous and metamorphic petrology (3rd Ed.). Cambridge University Press. ISBN 9781108492881 J.D. Winter (2014): Principles of igneous and metamorphic petrology. Pearson Education. ISBN 978-1-292-02153-9 D. Turcotte, G. Schubert (2014): Geodynamics. Cambridge University Press. ISBN 978-1107-00653-9

Thermodynamics for earth scientists

Module number	Credits	Workload	Term	Frequency	Duration
	6 CP	180 h	2. Sem.	SS	1 semester

Courses	Contact hours	Self-study	Group size
Thermodynamics for earth scientists	4 SWS	120 h	

Prerequisites

Learning outcomes

Students understand

- the basic principles of thermodynamics.
- solution thermodynamics and know thermodynamic modelling.

Content

Principles of elementary thermodynamics

- Nature of thermodynamics; Definition of systems (open, closed, isolated), processes (reversible, irreversible etc.), time scales - to the extent it does or does not play a role.
- Work, energy and functions of state
- Heat, energy conservation and first law (i.e. What is possible?).
- Heat capacity, enthalpy.
- Irreversibility and entropy - second law and very brief mention of third law (i.e. What really happens?).
- Combined first and second law and Master equation of thermodynamics - energy balance.
- Mathematical digression - Exact and inexact differentials, Legendre transformation, Chain rule.
- Accessory Functions - G, H and A. Maxwell's Laws.
- P-V-T equation of state for solids, fluids and gases - What properties they should have and what they look like for some geomaterials.
- Chemical equilibrium - I. Stoichiometric substances (Concept of G minimum, log K and Clausius-Clapeyron equation and P-T slopes).

Solution phase thermodynamics

- Chemical potential, activity, fugacity. Raoult and Henry's law. Possibility of various standard states (i.e. nothing unique about it), e.g. 1bar, T vs. P,T.
- Ideal and excess properties, activity – composition relations, dilute solutions and trace elements.
- Free-energy composition relations i.e. G-X diagrams and stability of solutions.
- Combine chemical equilibrium relations and mixtures to calculate - (i) Shift of equilibrium boundaries on solution formation (ii) Phase rule and Duhem's theorem, with various applications.
- Temperature (and pressure) dependence of reactions (Delta H) and melt phase diagrams (eutectic, binary solid solution loop).

Types of courses

Lectures and practicals

Types of examinations

A written final examination

Prerequisites for earning the credit points

Passing grade in the final examination

Module applicability

Percentage of the grade for the overall examination

5 % (6 CP of 120 CP)

Head of the module

Dr. Ralf Dohmen
Literature Thermodynamics of natural systems – Theory and Applications in Geochemistry and Environmental Sciences; G.M. Anderson (Cambridge University Press, 2017) Thermodynamics in Earth and Planetary Sciences; J. Ganguly (Springer Verlag, 2019) Thermodynamics of the Earth and Planets; Alberto Patino-Douce (Cambridge University Press, 2011) Physical Chemistry; G.K. Vemulapalli (Prentice Hall International, 1993) Applied Mineralogical Thermodynamics; N.D. Chatterjee (Springer Verlag, 1991) Mixtures and Mineral Reactions; J. Ganguly and S.K. Saxena (Springer Verlag, 1987) The Principles of Chemical Equilibrium; K. Denbigh (Cambridge University Press, 1984)

High-temperature geochemistry					
Module Number	**Credits** 6 CP	**Workload** 180 h	**Term** SS	**Frequency** Annually	**Duration** 1 semester
Courses a) High-temperature geochemistry – application of radiogenic and stable isotopes to high-temperature geological systems and ore deposits (SS) b) Practical – Application of mass spectrometry to radiogenic and stable isotope systems. Data reduction and treatment. (SS)			**Contact hours** (a) 2 SWS (b) 2 SWS	**Self-study** 60 h case studies and exercises 60 h of exercises and protocols	**Group size** No limitations in either course.

Pre-requisites

Students in the MSc. program of Geosciences and related MSc. programs. Prior attendance of Sedimentary Geochemistry (MSc.) is strongly encouraged, Einführung in die Geochemie (Introduction to Geochemistry - 5. Semester BSc.) is mandatory.

Learning outcomes

After successful completion of the module the students will:

- understand how isotope systems can be used to answer fundamental questions related to high-temperature geological systems.
- know analytical techniques related to the acquisition of trace element and isotope data from magmatic, metamorphic and ore mineral samples.
- be able to understand how to interpret these data to identify high-temperature processes occurring at various scales (e.g. from Earth's crust and mantle to solar system planetary differentiation).

Content

The lecture will provide an overview of the application of radioactive and stable isotopes to high-temperature geological systems, including igneous and metamorphic samples, as well as magmatic and hydrothermal ore deposits. In the first half of the Module, students will learn to apply data from classic radioactive decay systems (i.e. Rb-Sr, U-Pb, Sm-Nd, Lu-Hf isotopes) to different rock types produced as a result of high-temperature processes (metamorphism, melting and crystallization). Students will be introduced to other radioactive systems (both extant and extinct) that have seen increasing application in Earth Sciences, like Hf-W, Pd-Ag, Re-Os, Pt-Os etc.. All these systems can be used to identify specific processes, which range in scale from crystallization of silicate and sulfide minerals from magmas, to core formation in planetary bodies.

The second half of the Module will deal with non-traditional stable isotope systems and how they can be used to complement data from radioactive decay systems in a variety of applications. These systems will include an overview of B, Ti, V, Fe and Li isotopes to characterize processes and variables ranging from fluid-rock interaction, crustal recycling, redox conditions, mantle source compositions and many others.

The lecture will be complemented by a practical (Übung) where geochemical data from natural and experimental samples will be discussed and evaluated. Moreover, case studies involving different high-temperature geological settings will be discussed.

Mode of assessment

Written final exam (90 minutes) and numerical exercises during the semester.

Requirement for the award of credit points Students must attend at least 70% of the practical exercises. Failure to meet this participation threshold will result in exclusion from the final exam. The final exam grade will determine the overall module grade. The exam will assess both: 1) Theoretical understanding of the concepts covered during the semester, and 2)Practical skills in solving numerical exercises related to geochemical data.
Module applicability This module is aimed at students who wish to pursue research or work in the fields of Petrology, Geochemistry, Tectonics and Ore Geology. This module is complementary to the WS MSc. Module "Sedimentary Geochemistry". As such, and for a greater overview of techniques and applications in Isotope Geochemistry, students are strongly encouraged to participate in both modules.
Weight of the mark for the final score 5% of final grade (6 CP of 120 CP)
Module coordinator and lecturer(s) Prof. Raúl Fonseca
Further information Will be communicated at the beginning of each class. Students may contact the lecturer for more detailed information on course contents prior to the start of the semester.

Field course in tectonics and resources					
Modul-Nr.	**Credits** 10 CP	**Workload** 300 h	**Term** 2. + 3. Sem.	**Frequency** Annually	**Duration** 10 days
Courses a) Pre-field course seminar b) Field course			**Contact hours** (a) 1 SWS (b) ~10 days	**Self-study** (a) 140 h (b) 70 h	**Group size:** 14 students
Prerequisites					
Learning outcomes Upon successful completion of this module, the students • know how to document and interpret structural and petrological data. • are able to integrate field observations with theoretical knowledge in tectonics and/or economic geology.					
Content The content and exact duration of the field course depend on the field area, which is variable each year (Elba, Scotland, etc.). The field course is preceded by a seminar. The aim of this field course is to train the students' field skills in tectonics and economic geology, and to combine theoretical knowledge with field observations. The field course may include small mapping projects and visits to open pit and underground mines.					
Teaching methods Field trip, seminar.					
Mode of assessment Report.					
Requirements for the award of credit points Active participation in the field trip and seminar, passed practical exam. Passing grade for the report.					
Module applicability					
Weight of the mark for the final score 8,3 % (10/120 CP)					
Module coordinator and lecturer(s) Prof. Annika Dziggel (Ph.D), Dr. Mathias Hueck					
Other information Relevant literature will be presented at the beginning of each course.					

<table>
<tr><td colspan="6">Economic geology II</td></tr>
<tr><td>Modul-Nr.</td><td>Credits
10 CP</td><td>Workload
300 h</td><td>Term
1. + 2. Sem.</td><td>Frequency
WS, SS</td><td>Duration
2 semesters</td></tr>
<tr><td colspan="3">Courses
a) Metallic mineral deposits
b) Non-metallic mineral deposits
c) Research project on ore deposits</td><td>Contact hours
(a) 2 SWS
(b) 1 SWS
(c) 3 SWS</td><td>Self-study
(a) 70 h
(b) 30 h
(c) 110 h</td><td>Group size:
20 students</td></tr>
<tr><td colspan="6">Prerequisites: Attendance is mandatory in the Research project on ore deposits</td></tr>
<tr><td colspan="6">Learning outcomes
Upon successful completion of this module, the students
• have an in-depth understanding on the processes of formation of metallic and non-metallic mineral deposits and their different geodynamic settings.
• are able to identify and document the mineralogical and textural characteristics of a wide range of deposit types.
• know how to evaluate the conditions and processes of element enrichment using a variety of analytical techniques as well as whole rock and mineral-chemical data.</td></tr>
<tr><td colspan="6">Content
(a) Metallic mineral deposits
Introduction to ore forming processes, genetic concepts and classifications. Conceptual difference between mineral resources and ore reserves; economic aspects. Magmatic(-hydrothermal) ore forming systems: ortho-magmatic deposits, deposits related to granites, Cu-porphyries, ore deposits in mid-ocean ridges and ophiolites. Hydrothermal ore-forming systems related to metamorphic processes; ore deposits in supergene and sedimentary settings.
(b) Non-metallic mineral deposits
Introduction into the use and properties of industrial minerals, earths and rocks, salt and gemstones (diamond only).
(c) Research project on ore deposits
This course encompasses the guided independent study of well-characterized hydrothermal ore deposits using hand specimens, thin- and polished sections and a range of whole rock and mineral-chemical data. This course introduces students to research-oriented learning and is aimed at preparing the students for their Master projects. Attendance is mandatory</td></tr>
<tr><td colspan="6">Teaching methods
Lectures, practicals, project work in small teams</td></tr>
<tr><td colspan="6">Mode of assessment
Written examination on the contents of courses a) and b); extended abstract and oral presentation in c).</td></tr>
<tr><td colspan="6">Requirements for the award of credit points
Passing grade for the written examination and extended abstract/oral presentation.</td></tr>
<tr><td colspan="6">Module applicability</td></tr>
<tr><td colspan="6">Weight of the mark for the final score
8,3 % (10/120 CP)</td></tr>
<tr><td colspan="6">Module coordinator and lecturer(s)
Prof. Annika Dziggel (Ph.D), Dr. Mathias Hueck</td></tr>
<tr><td colspan="6">Other information
Relevant literature will be presented at the beginning of each course.</td></tr>
</table>

Geochemical analyses by laser ablation-ICP-mass spectrometry

Module-No.	Credits	Workload	Term	Frequency	Duration
	5 CP	150 h	3. Sem.	Annually	1 semester
Courses a) Methods of LA-ICPMS (lecture) b) Practical course in LA-ICPMS (block course of 4 days)			**Contact hours** (a) 2 SWS (b) 2 SWS	**Self-study** (a) 30 h (b) 60 h	**Group size:** No limitations in course a) Max. 5 students in course b)

Prerequisites

The module is open to students with a BSc in Earth Sciences. Successful completion of one of the modules "High-temperature Geochemistry" or "Mantle Petrology" is recommended but not mandatory.

Regular attendance and a passing grade of "Methods of LA-ICPMS" (course a) are required to attend the "Practical course in LA-ICPMS" (course b).

Learning outcomes

Upon successful completion of this module, the students

- have an in-depth understanding of the principles of laser ablation and inductively coupled plasma-mass spectrometry methods (SF-, TQ-, MC-ICPMS).
- are able to choose the best-suited method for a given geoscientific research question.
- can critically evaluate the results, and identify possible sources of analytical problems.

Content

a) Lecture in methods of LA-ICPMS:

1) Laser ablation: principles of laser radiation, analytical approaches (profile, spot, mapping), interaction of the laser beam with solid matter, combination of LA-ICPMS + LIBS, split-line method.

2) Mass spectrometry: principles of (Inductively Coupled Plasma-) Mass Spectrometry, advantages and drawbacks of different mass spectrometer designs (e.g., SF, TQ, MC; reaction cell, high- vs. low-resolution), data evaluation (incl. analytical uncertainty, counting statistics).

b) Practical course in LA-ICPMS: The students learn the basics about handling and tuning of a modern laser ablation system connected to a state-of-the-art triple-quadrupole-ICP-mass spectrometer. Analyses select from a large variety of solid materials like glasses, alloys (e.g. coins), mineral phases (e.g., zircons, olivines, garnets, ...), or samples from different ore deposits (e.g., hydrothermal settings). Age determinations of selected zircons (U-Pb ages) and/or garnets (Lu-Hf ages) are included, and calculation and evaluation of the age will be part of the practical course.

This course is especially welcoming students who are interested in master projects that evolve around in-situ analyses of solid samples (e.g., glasses, minerals, alloys, ...).

Teaching methods

Weekly lectures, practical course as a 4-day block course in the winter semester break.

Mode of assessment

Written examination of course a), report including theoretical aspects of laser systems and mass spectrometers, the analytical procedure, and presentation and evaluation of the results of course b).

Requirements for the award of credit points

Regular attendance during the lecture, 50 or more % points in the written examination, active performance and daily attendance in the practical course, and 50 or more % points for the written report (weighing 50% examination and 50% practical course).
Module applicability
Weight of the mark for the final score 4 % (5/120 CP)
Module coordinator and lecturer(s) Dr. Stephan Schuth
Other information Literature: Gill, R. (2002): Modern Analytical Geochemistry. Pearson. Nelms, S.M. (2005): ICP Mass Spectrometry Handbook. Blackwell Publishing. Sigrist, M.W. (2018): Laser: Theorie, Typen und Anwendungen. Springer Spektrum. Skoog, D.A. & Leary, J.J. (1996): Instrumentelle Analytik. Springer. Sylvester, P. (2008): Laser ablation ICP-MS in the Earth Sciences – Current practices and outstanding issues. Mineralogical Association of Canada. Thomas, R. (2013): Practical Guide to ICP-MS. CRC Press.

Economic geology I

Module number	**Credits**	**Workload**	**Term**	**Frequency**	**Duration**
	10 CP	300 h	1. + 2. Sem.	Annually	2 semesters

Courses	**Contact hours**	**Self-Study**	**Group size**
(a) Petroleum geology I (WS) (b) Petroleum geology II (SS) (c) Field trip (SS)	(a) 2 SWS (b) 2 SWS (c) 1 day	(a) 75 h (b) 120 h (c) 35 h	12-20 students

Prerequisites

Students enrolled in a Geosciences Master-Program

Learning outcomes

The module consists of a winter-term lecture (a), a summer-term lecture (b) and a summer term field trip (c).

(a) Petroleum geology I

The assessment center exercise aims at communicative interaction and gaining/deepening „soft-skills“ (team work, resilience to challenging time vs. content preparations, concept selection, short presentation, facing a managerial board, staying in control of a meeting, addressing challenging questions constructively and authentically).

Students gain academic level knowledge and applied competences to gather, interpret and rank such reservoirs:

- in their context of primary depositional environment, its fundamental controls on global, regional and local scale.
- using systemically relevant geogenic alteration factors with positive and/or negative consequences on the reservoir properties and their economic relevance.
- executing analysis, interpretation and assessment of pore fluids with respect to their geo-heritage and economic value.

(b) Petroleum geology II

The students gain/learn:

- systemic competencies of applying the competences of (a) in a different regional geo-context.
- global and regional geological knowledge, analogous occurrences of subsurface architectures versus unique settings and their characteristics.
- risks and opportunities derived from analogous versus unique settings, specifically with respect to economic exploration, development and production of the subsurface reservoir.
- risk minimization in previously unknown regional settings through the use of analogues in the competency context of analysis – recollection – application – assessment.

Module part (b) is supplemented by an offering of a ½ day assessment center exercise. Participation is voluntary.

(c) Field trip

Conducted in the border region of the Netherlands, Lower Saxony and North Rhine-Westphalia. The field trip aims at acquiring the practical skills to combine prior knowledge gained in other field trips, prior regional geological knowledge and the economical geological skills of the lectures. As a result, a new/adjusted/different/professionally relevant assessment of the area is achieved and learning for later work life is performed.

- The students learn the practical relevance of the theoretical systemic knowledge acquired in (a) and (b).
- The students learn to integrate prior knowledge of fieldwork within the context of subsurface reservoir interpretation.
- The students gather, describe, assess and interpret the outcrops based on rock samples taken.

- The students integrate for each outcrop the new insights with those from previous outcrops.
- They form, then deepen or revise hypothesis and build a regional to subregional interpretation framework.
- They achieve a systemic and economic assessment of existing subsurface reservoirs in the region and their past, current and future utilization.

Digitalization: The relevance and importance of geological modeling of sedimentary basins, subsurface porous network flow modeling and economic assessments are introduced with respect to exemplary software packages. Digital interpretation methods, based on prior manual preparation of data and geological thinking, are taught. The importance of AI and ML (artificial intelligence/machine learning) methods for the consistent processing of large geological data sets, specifically in the context of subsurface reservoirs are discussed. Example data sets and scenarios are used in both economic and geotechnical exercises. Software is not developed in this course.

Content

One lecture date is used for a practical in-field exercise within the vicinity of the University. Interactively the acquired competences are applied, practiced and thereby deepened.

(a) Petroleum geology I

Presentation, questioning and feedback methods in English language

- The petroleum system and its controls.
- Sediments and facies.
- Reservoir petrology, petrophysics.
- Pore fluids.
- Reservoir fluid properties through time.
- Modelling.
- Assessment center (optional).

(b) Petroleum geology II

Building on (a) and taught for deepening regional geological knowledge with respect to regions with economically relevant subsurface reservoirs. Based on published data, gathering, interpreting and assessing subsurface data forms the core of the student learning. The repetitive evaluation of different regions in the context of the subsurface systemic concept learned in petroleum geology I enables the acquisition of skills to consistently apply prior knowledge and build portfolios differentiating between analogous and unique geological systems.

- Repetition: Petroleum system concept and controls.
- Economic and regional geology.

(c) Field trip

- Petroleum System Emsland.
- Bad Bentheim: sediments, stratigraphy, geological overview.
- Outcrops.
- Production units, history, economic importance.
- Composing an integrated geo-economic concept on the petroleum systems of the Emsland, integrated interpretation.

Teaching methods

Lecture, integrated exercises and field trip

Mode of assessment

One final written exam on (a) and (b) lectures combined, report on the field trip

Requirement for the award of credit points

Written exam: Sufficient level result ("Ausreichend"), successful participation in the field trip

Module applicability

not applicable
Weight of the mark for the final score 8,3 % of final M.Sc. score (10 of 120 CP)
Module coordinator and lecturer(s) Dr. Olaf Podlaha
Further information **Literature** Textbook recommendations (English) for Lecture Petroleum geology I (self-studies, see timetable) Detailed/Extensive material for each lecture (copies of all slides, exercise material) Pending presenting students sign-off, material presented by students is shared Detailed documentation for the field trip

Sedimentary geochemistry					
Module number	**Credits** 10 CP	**Workload** 300 h	**Term** 1. + 3. Sem.	**Frequency** Annually	**Duration** 2 semester
Courses			**Contact hours**	**Self-study**	**Group size**
a) Isotope geochemistry _ Principles and applications (WS; 1. Sem.)			(a) 4 SWS	(a) 120 h exercises	a) no limitations
b) Laboratory course isotope geochemistry (WS, two-week block course, 3. Sem.)			(b) 4 SWS	(b)	b) 1 group à max. 6 students

Prerequisites

Students in the MSc programme Geosciences and related MSc programmes

Attendance is highly recommended for a) and mandatory for b)

Learning outcomes

After successful completion of the module the students

- understand the principles of isotope geology including basics of decay systems and geochronology as well as stable isotope geochemistry.
- know analytical techniques related to traditional and non-traditional stable isotope methods in sedimentary geology.
- will be enabled to assess the application of isotope analytics in sedimentary (diagenetic/ depositional/ alteration) processes, hydrology, (paleo)environmental and paleo(climate) research.

Content

The lecture provides a basic overview on radiogenic isotope geology (radioactive dating methods) and stable isotope geology (traditional and non-traditional isotope systems) and their application in geological research. Complementary to the lecture the practical laboratory course aims at imparting the knowledge and know-how of selected (available) isotope techniques and methodologies in mass spectrometry.

(a) Isotope Geochemistry - Principles and Applications

Introduction to principles of isotopes, natural radioactivity and radioactive dating methods. Common radioactive dating methods (Rb-Sr, Sm-Nd, U-Th-Pb, Pb-Pb) are outlined and application examples are provided. In addition, U-series age determination methods (secular equilibrium and disequilibrium) and their application to sedimentary geology are introduced. The relevance of cosmogenic isotopes for research in applied geology, sedimentary systems and archaeology is taught and examples are given. The emphasis lies on the stable (traditional and so called non-traditional) isotope systems in sedimentary (carbonate) geology and hydrogeology. The isotope systems of H, N, C, O, S, Mg, Ca and Fe are outlined in detail. and complemented by the rather novel proxies of clumped isotopes and triple oxygen isotopes. Their common use in (palaeo)environment and (palaeo)climate research, sedimentology, speleology, palaeontology and hydrogeology are discussed. The lecture is supported by exercises in the respective topics.

(b) Laboratory course Isotope Geochemistry

With regard to the actual research topics and instrumental equipment selected isotope analyses are performed. In general, students work supervised on a complete procedure from hand specimen to result. From a polished hand specimen of a carbonate rock genetically different material is sampled by micro-drilling. Elemental composition is determined by ICP-OES and subsequently aliquots of the material are prepared for C/O and Sr isotope analysis and following measured. Aim is the evaluation of the state of preservation of fossil carbonate material, the degree of diagenetic overprint and an assessment of the geological age based on Sr isotope stratigraphy. In addition, the carbon isotope composition of dissolved inorganic carbon (DIC) from water samples are analysed in order to determine the origin (biogenic/abiogenic) of the water sources. Finally, the carbon isotope signature of CO_2 of respiratory air is measured, which provides

information on the diet of the respective person The lab course concludes with the final interpretation of the results and the evaluation of the geological significance of the data.
Teaching methods Lecture, exercises and practical laboratory work
Mode of assessment a) Exercises and written exam (90 min) b) Laboratory work report
Requirement for the award of credit points 50 % or more in exercises to be admitted to the exam; 50% or more in written exam and laboratory work report, active performance in the laboratory course; Final grade weighing: a) 10% for exercises and 50% for exam and b) 40% for laboratory work
Module applicability Please note that both courses of the module are in principle open for students from other disciplines. Due to the limitation of the number of students in the laboratory course, students who are planning an MSc thesis with focus on isotope geochemistry will be given preference. Exceptions are possible depending on the demand for the course. Prerequisite for participation in the laboratory course (b) is the active attendance of the lecture (a).
Weight of the mark for the final score 8.3% of the final score (10 of 120 CP)
Module coordinator and lecturer(s) Dr. S. Riechelmann
Further information Will be communicated at the beginning of each class

<table>
<tr><td colspan="6">Structural geology</td></tr>
<tr><td>Module number</td><td>Credits
10 CP</td><td>Workload
300 h</td><td>Term
1. + 2. Sem.</td><td>Frequency
Annually</td><td>Duration
2 semesters</td></tr>
<tr><td colspan="3">Courses
a) Lectures, seminars, exercises in structural geology
b) Special methods in structural geology
c) Structural geology field camp</td><td>Contact hours
(a) 2 SWS
(b) 2 SWS
(c) 2 SWS</td><td>Self-study
(a) 70 h
(b) 70 h
(c) 70 h</td><td>Group size
20 students</td></tr>
</table>

Prerequisites

Attendance is compulsory in all courses of this module.

For students enrolled in the MSc curriculum.

Learning outcomes

The purpose of the module is to make the students familiar with advanced concepts in structural geology and tectonics. The theoretical and practical teaching and training offered in the module is highly relevant for industry, in particular for exploitation of mineral and water resources. After achievement of the module the student

- is acquainted with different applications of structural geology,
- knows the mechanisms of tectonic fracture and fluid transfer,
- to elaborate a coherent geological model from field data..

Content

The module is organised in three courses, progressing from general aspects in structural geology to specific aspects on tectonic fractures. Finally, a field camp consolidates the knowledge acquired in the classroom.

a) Lectures, seminars, exercises in structural geology

The aim of the lecture is to consolidate and deepen fundamental aspects in structural geology. During the two first sessions basic notions are recalled by the instructor. The following sessions consist of oral presentations by the students. The topics to be presented are selected by the participants according to a list of scientific papers proposed by the instructor. In addition, the writing of an essay following the oral presentation is required.

b) Special methods in structural geology

This lecture addresses various aspects of tectonic fractures. Firstly, the different types of fractures are introduced in detail with emphasis to their identification and correct interpretation in nature. In the following, fundamentals of fracture mechanics are presented in relation to specific characteristics of natural fractures. The discussion is then expanded to include the impact of fractures on fluid and heat transfer, in particular, and their relevance for operation of geo-energy systems.

c) Structural geology field camp (8 days)

The exercise involves the structural/geological mapping in fine detail of selected areas using traditional techniques and tools (i.e. compass, hammer, lens...). As such the field camp aims to strengthen field work experience and sharpen geologist skills. In the course of the writing of the report, the student will learn how to analyse field data and how to extract from them a coherent geological synthesis.

Teaching methods

Lectures, exercises and training in the field

Mode of assessment

a) oral presentation (% mark, 4 CP)

b) Special methods in structural geology: written exam (% mark, 3 CP) c) Structural geology field camp: active participation + report (% mark, 3 CP)
Requirement for the award of credit points Weighted average of the three marks obtained in a), b) and c) equal or higher than 50% (weighting proportional to number of CPs)
Module applicability
Weight of the mark for the final score 8,3 % of the final score (10 of 120 CP)
Module coordinator and lecturer(s) Prof. Dr. Christophe Pascal
Further information **Literature** Davis and Reynolds, 1996. Structural Geology of Rocks and Regions, John Wiley & Sons. Twiss and Moores, 1992 (2007). Structural Geology, Freeman.

<table>
<tr><td colspan="6">Geomorphology and geohazards</td></tr>
<tr><td>Module number</td><td>Credits
10 CP</td><td>Workload
300 h</td><td>Term
2. + 3. Sem.</td><td>Frequency
Annually</td><td>Duration
2 semesters</td></tr>
<tr><td colspan="3">Courses
a) Earth surface processes and environmental change (SS)
b) Geohazards: types, causes and strategies (WS)
c) Field course on geomorphology and geohazards (ab WS 26/27)</td><td>Contact hours
(a) 2 SWS
(b) 2 SWS
(c) 2 days + 2 block course</td><td>Self-study
(a) 60 h
(b) 90 h
(c) 60 h</td><td>Group size
(c) 20 students</td></tr>
<tr><td colspan="6">Prerequisites
The courses are open to all M.Sc. students with a successfully completed B.Sc. in Earth Sciences. The module is also available to B.Sc. students in Geosciences as part of their complementary course work.

Passed exam of a) is pre-requisite for participation in the field course c)</td></tr>
<tr><td colspan="6">Learning outcomes
After successful completion of the module, students will

• Understand how earth surface processes shape landscapes
• Understand the difference between qualitative and quantitative geomorphology
• Gain knowledge on modern concepts in research of earth surface processes
• Learn which techniques are used to study environmental change
• Be able to classify and define different types of geohazards
• Gain insights into the causes of geohazards
• Understand the impacts of geohazards on societies and ecosystems
• Learn field strategies for analyzing geomorphic processes and geohazards</td></tr>
<tr><td colspan="6">Content
a) Earth surface processes and environmental change
This seminar introduces and explores Earth surface processes such as weathering, erosion, sediment transport, and landform development to gain insights into landscape dynamics and how environmental changes over the past few million years have shaped today’s landscapes. The course critically examines the influences of climate change, tectonic activity, and human impact on the environment. Modern concepts and cutting-edge techniques for reconstructing past environmental changes will be introduced through a series of interactive lectures. These lectures are complemented by paper discussions that allow to apply theoretical knowledge to real-world scenarios.
b) Geohazards: types, causes and strategies
Geohazards are the result of geomorphological, geological and/or geophysical processes that pose risks to the environment and society. The seminar introduces different types of geohazards (e.g., landslides, floods, volcanic eruptions, tsunamis), along with their processes, dynamics, and timescales. Extreme events will be discussed from around the world, whilst the seminar also emphasizes examples of geohazards from Germany. The seminar will also cover risk assessments and mitigation strategies. Students will be lead through the different themes through interactive lectures, student oral presentations and group discussions.
c) Field course on geomorphology and geohazards</td></tr>
</table>

This 2-days field course will focus on regional examples of geomorphic processes and associated geohazards. Students will engage in hands-on learning through site visits, discussions, and practical exercises to understand the region's geological history, landform development, and associated risks for the society (e.g., mass wasting, floods). In addition, students will be introduced to field sampling strategies. At the end of the term, students will recap their findings from the field exercises and present them in the form of a poster during a block course. This will consist of one day immediately after the field class to review the findings, followed by one day at the end of the semester to allow enough time for poster preparation.

Teaching methods

a) The course combines lectures with paper discussions.

b) The course combines lectures with student oral presentations. Topics for the presentations will be provided at the beginning of the course.

c) Field exercises include for example mapping, field measurements, documentation of sediment profiles, and sampling. After the field course, findings will be presented as poster and group discussions.

Mode of assessment

a) Discussions will be evaluated based on participation (passing grade 50 %). A final exam is weighted 100 %.

b) Discussions will be evaluated based on participation (passing grade 50 %). The course will be evaluated based on participation in discussions, an oral presentation (50%) and a final report (max. 1500 words) (50%).

c) The field course is evaluated based on participation in field discussions and exercises, as well as on a poster presentation (100%).

The final grade is evaluated based on a) 40%, b) 40%, and c) 20%

Requirement for the award of credit points

Participation in at least 70% of the lectures/exercises. Passed written exams. Passed practical exam in c.)

Module applicability

Weight of the mark for the final score

8 % of the final score (10 of 120 CP)

Module coordinator and lecturer(s)

Prof. Dr. Melanie Kranz

Further information

Literature

Quaternary geochronology					
Module number	**Credits** 5 CP	**Workload** 120 h	**Term** 2. Sem.	**Frequency** SS	**Duration** 1 semesters
Courses a) Quaternary geochronology b) Quaternary geochronology (exercises)			**Contact hours** 2 SWS	**Self-study** 120	**Group size**
Prerequisites The courses are open to all M.Sc. students with a successfully completed B.Sc. in Earth Sciences.					
Learning outcomes After successful completion of the module, students will • Gain knowledge on various dating techniques that are relevant to understand landscape evolution during the recent geological past • Understand processes to chronologically constrain rocks and sediments • Learn how to use chronological data to reconstruct environmental change • Learn how to evaluate real research data • Develop scientific writing skills					
Content The study of environmental change is highly dependent on a robust chronology. The seminar gives an overview of all common physical and chemical dating methods that are relevant for constraining the timing and rates of landscape evolution during the Quaternary period. This includes geochronological and low-temperature thermochronological methods (e.g., fission track, (U-Th)/He, cosmogenic nuclides, luminescence, radiocarbon) applied to sedimentary sequences and bedrock. The seminar will also explore practical applications of these methods in research, as well as their advantages and disadvantages. In lecture format, the fundamentals of the geo- and thermochronological methods will be introduced, followed by exercises in which students analyze research data for selected dating methods.					
Teaching methods The course combines lectures with scientific paper discussions and technique-specific exercises focusing on real-world data.					
Mode of assessment Discussions and exercises will be evaluated based on participation and discussions, the submission of two exercises and a final exam. The final grade is evaluated based on 40% (exercises) and 60% (exam).					
Requirement for the award of credit points Passed written exam.					
Module applicability					
Weight of the mark for the final score 4 % of the final score (5 of 120 CP)					
Module coordinator and lecturer(s) Prof. Dr. Melanie Kranz, Dr. Mathias Hueck					
Further information **Literature**					

<table>
<tr><td colspan="6">Computational analysis in tectonic geomorphology</td></tr>
<tr><td>Module number</td><td>Credits
5 CP</td><td>Workload
150 h</td><td>Term
2. Sem.</td><td>Frequency
SS</td><td>Duration
1 semesters</td></tr>
<tr><td colspan="3">Courses
Computational analysis in tectonic geomorphology (SS)</td><td>Contact hours
2 SWS</td><td>Self-study
150</td><td>Group size</td></tr>
<tr><td colspan="6">Prerequisites
Formal: Attendance is mandatory.
Content: The course is open to all M.Sc. students with a successfully completed B.Sc. in Earth Sciences.
Preparation: Prior participation in the course Introduction to MATLAB is strongly recommended.</td></tr>
</table>

Learning outcomes

After successful completion of the module, students will

- Understand the theoretical and analytical foundations of fluvial landscape evolution and tectonic geomorphology
- Learn how to generate and interpret chi maps, identify and classify knickpoints, and calculate normalized steepness indices (Ksn) using digital elevation models (DEM)
- Conduct river profile and stream network analyses for tectonic interpretation
- Explore techniques for terrain classification and evaluate landscape response to tectonic forcing
- Learn to formulate and test hypotheses using digital elevation data and develop basic landscape evolution models
- Develop skills in scientific programming, reproducible analysis, and writing up geoscientific results as reports

Content

This course aims to introduce students to tectonic geomorphology using MATLAB-based (e.g., TopoToolbox) and GIS software (e.g., QGIS), built for topographic and stream network analysis. The course integrates the theoretical and practical basis behind digital terrain analysis techniques relevant for investigating active tectonics, fluvial systems, and landscape evolution. Basic MATLAB skills will be briefly refreshed during the course.

Students will learn how to process and visualize digital elevation models (DEMs), construct chi maps, detect knickpoints, analyze river profiles, compute normalized channel steepness (Ksn), and classify terrain based on tectono-geomorphic signals. Furthermore, the course will offer an introduction to simple landscape evolution modeling, enabling students to link surface processes with tectonic drivers.

Each topic will include a short theoretical lecture followed by a practical exercise (computer-based). Students will work on real-world datasets and interpret geomorphic patterns in tectonically active landscapes.

Teaching methods

The course combines lectures, hands-on tutorials, guided exercises, and critical discussions of selected case studies.

Mode of assessment

Active participation in discussions and exercises during the block course and one final assignment weighed 100%.

Requirement for the award of credit points

Submission and passing of final written assignment.

Module applicability
Weight of the mark for the final score 4 % of the final score (5 of 120 CP)
Module coordinator and lecturer(s) Dr. Erick Prince
Further information **Literature**

Geologie des Pleisto-, Holo- und Anthropozäns

Module number	Credits	Workload	Semester	Frequency	Duration
	5 CP	125-150 h	1. Sem.	Every WS	1 semester

Courses	Contact hours	Self-study	Group size
a) Quartärgeologie b) Quartärgeologie und geogene Risiken	(a) 2 SWS (b) 2 days	(a) 50 h (b) 20 h	

Prerequisites

Learning outcomes

Das Quartär hat in weiten Bereichen der nördlichen Hemisphäre deutliche Spuren hinterlassen. Die Sedimente des Quartärs sind vielfach nicht oder wenig verfestigt und haben dadurch besondere geotechnologische Eigenschaften, welche auch die zivilisatorische Nutzung beeinflussen. Ausgehend von einer Analyse des Klimas und der dadurch gegebenen Bedingungen werden die Liefergebiete, die Ablagerungsräume, die maßgeblichen Sedimente, deren Eigenschaften nebst deren Veränderlichkeit und die sich ausbildende Morphologie vermittelt. Im Rahmen des Kurses werden die speziellen Bedingungen, Prozesse und Ablagerungsräume des Pleistozäns und Holozäns besprochen; initial werden die alpidische Orogene und die tertiären Ablagerungsräume umrissen, um die Ausgangssituation für das Quartär Deutschlands zu definieren.

Das Erkennen dieser Sedimente ist für die Entwicklung von Untergrundmodellen unabdingbar. Ebenso gehen von den pleistozänen Sedimenten und den glazial geprägten Landschaften geogene Risiken aus. Im Rahmen der Geländeübung werden beispielhaft quartäre Formungen und deren Sedimente beschrieben und die Ansprache der Sedimente geübt. In dem Zusammenhang werden die Eigenschaften der Sedimente besprochen und die daraus sich ergebenden geogenen (sowohl natürlich aber auch anthropogen induzierten) Risiken abgeleitet.

Nach erfolgreichem Abschluss des Kurses kennen und erkennen die Teilnehmerinnen und Teilnehmer die wichtigsten quartären Ablagerungsräume und deren Sedimente, kennen sie die grundlegenden Eigenschaften der quartären Sedimente und verstehen die Teilnehmerinnen und Teilnehmer die grundlegenden Mechanismen der Gletscher. Die Teilnehmerinnen und Teilnehmer können exemplarisch pleistozäne Formungen erkennen und die Sedimente ansprechen. Darüber hinaus kennen sie die wichtigsten von den quartären Formungen ausgehenden Georisiken und sind mit den wesentlichen Prozessen vertraut.

Content

Klimaentwicklung seit der Kreide; Bildung der Alpen; Tertiär in Deutschland als quartäre Basis; Gletscherbildung und -mechanik; glaziale Erosion und Transport; Ablagerungen und Ablagerungsformen; Eigenschaften der Sedimente; Die Kaltzeiten in Nord- und Süddeutschland; Glaziale Sedimentkörper, Sedimentansprache, Einflussfaktoren geologischer Prozesse; geogene Herausforderungen; Georisiko Mensch.

Teaching methods

Vorlesung mit integrierten Übungen

Geländeübung

Mode of assessment

Modulprüfung

Requirement for the award of credit points

Ausreichende Bewertung der Klausur, des Kurzprotokolls und einer Hausarbeit

Module applicability

Das Modul ist nur nach Rücksprache mit den Dozenten für Studierende anderer Studiengänge zugänglich

Weight of the mark for the final score 4 % der Gesamtnote (5 von 120 CP)
Module coordinator and lecturer(s) Prof. Dr. Melanie Kranz
Further information **Literature** Relevante Fachliteratur wird am Beginn der jeweiligen Veranstaltungen vorgestellt.

<table>
<tr><td colspan="6">Mineralization in geothermal systems</td></tr>
<tr><td>Modul number</td><td>Credits
7 CP</td><td>Workload
210 h</td><td>Term
1. or 3. Sem.</td><td>Frequency</td><td>Duration
1 Semester</td></tr>
<tr><td colspan="3">Courses
a) Mineralization in geothermal systems (lecture)
b) Mineralization in geothermal systems (laboratory course)</td><td>Contact hours
1 SWS
3 SWS</td><td>Self-study
30 h
60 h</td><td>Group size
12 Students</td></tr>
<tr><td colspan="6">Prerequisites
Formal: Only for students in the bi-national Master’s program „Applied Geothermics“
Textual: Basic knowledge about thermodynamics, and structure and chemical behavior of minerals.
Preparation: –</td></tr>
<tr><td colspan="6">Learning outcomes
After the successful completion of the module
• students know the basic parameters and processes that determine the nucleation and growth of seed crystals in different environments,
• students are able to read basic phase diagrams and, taking thermoanalytical data into account, derive possible crystallization scenarios,
• students are able to carry out simple synthesis/growth tasks independently and to characterize the products structurally and thermoanalytically.</td></tr>
<tr><td colspan="6">Content
Material systems, state variables, thermodynamic potentials, chemical potentials, phase transformations.
Phase rule, phase diagrams, one- and two-component systems. Partitioning coefficients, segregation effects, mass transport by diffusion and convection, viscosity, constitutional supercooling.
Conventional nucleation processes, homogeneous and heterogeneous nucleation, critical nucleus radius, Ostwald-Miers range, Ostwald's step rule.
Growth processes, accumulation energies, interfacial energies, growth rates, influence of dislocations, morphology of crystals.
Non-conventional nucleation and growth processes.
Solution properties of fluids under conditions of the earth's crust.
Methods for characterizing crystallization products (including differential thermal analysis, X-ray diffraction).</td></tr>
<tr><td colspan="6">Teaching methods
Lecture and laboratory exercises.</td></tr>
<tr><td colspan="6">Mode of assessment
Written exam of 2 h.</td></tr>
</table>

Requirement for the award of credit points
Passed module exam, processing of all laboratory exercises, successful report on laboratory exercises with evaluation of the observations/experimental data obtained.
Module applicability
Weight of the mark for the final score
5,8 % der Gesamtnote (7 von 120 CP).
Module coordinator and lecturer(s)
Prof. Dr. Jürgen Schreuer
Further information
Literature: K.-Th. Wilke und J. Bohm: Kristallzüchtung, Leipzig 1993, ISBN 978-3326000923.