Master in Earth sciences - Courses Descriptions

Year 2022 - 2023

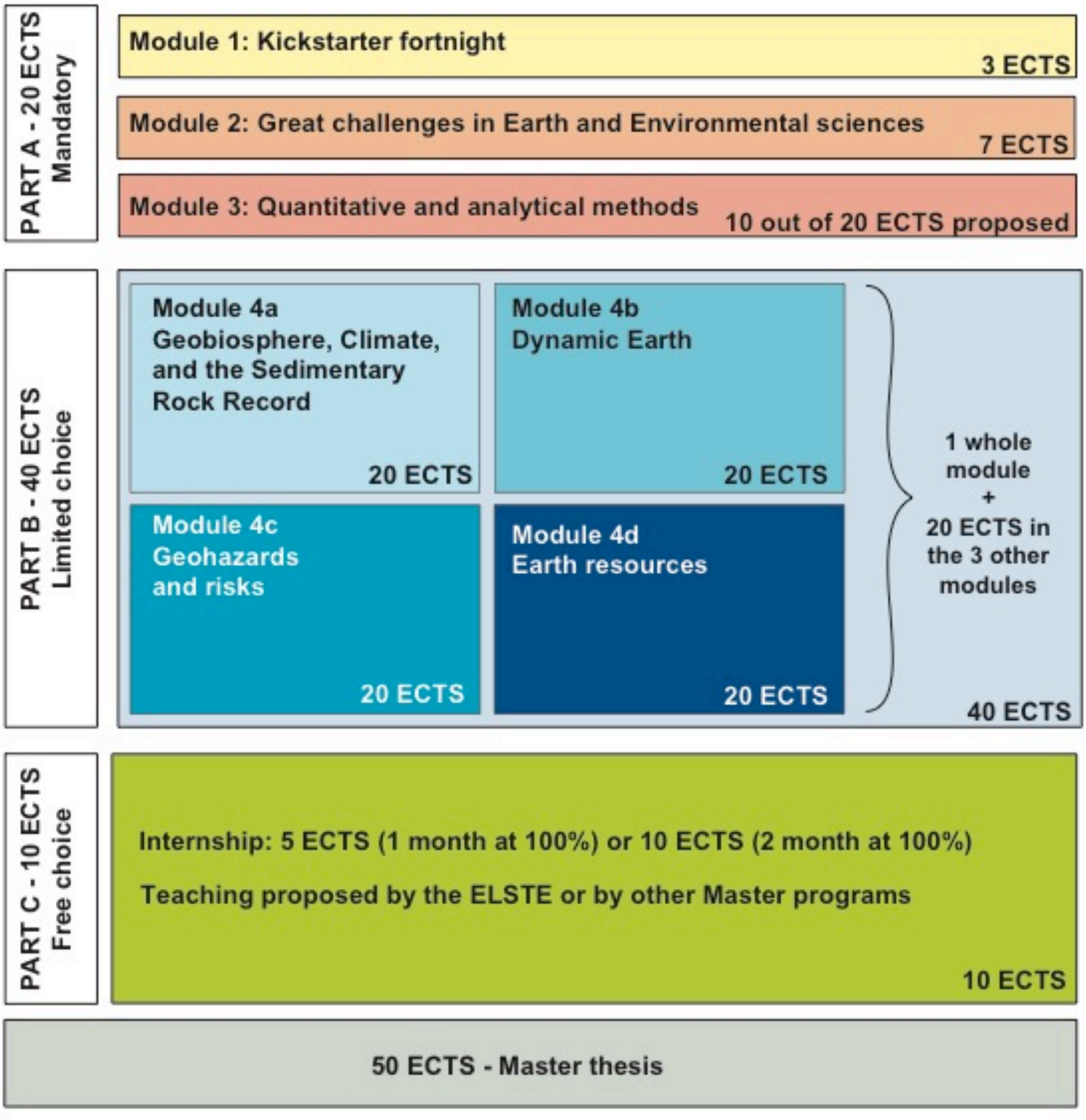
Preamble

The present document has not been validated by the higher instances. It is for information only and it is internal to the ELSTE. The details of the evaluation modalities are indicative and will be given at the beginning of each course by the teacher in charge. One ECTS (European Credit Transfer System) amounts to 25 to 30 hours of effective work. In order to have a coherent program, the number of scheduled hours attributed to each ECTS was decided using following the rule: 18 hours of scheduled course correspond to 2 ECTS; 27 hours correspond to 3 ECTS; 36 hours correspond to 4 ECTS. However, some exceptions have been made for: i) teaching requiring a lot of presence in the labs or in the field; ii) teaching proposed in other Master program.

The following abbreviations are used in the document: C: Course – PW: Practical work – E: Exercises – CE: Course/Exercises – F: Fieldwork – d: days – h: hours – N.N.: Teacher not yet named.

In the event of any discrepancy between this document and the official "Study Plan", only the latter shall prevail.

Structure of the Master in Earth sciences



Module M1: Kickstarter fortnight

No template needed as it is an introductory and equalizer course.

Module M2: Great challenges in Earth and Environmental sciences – Mandatory for all

Great challenges in Earth and Environmental Sciences - M2 Les grands défis en sciences de la Terre et de l'environnement
Coordinators: Johanna Marin Carbonne and Luca Caricchi **Number of ECTS:** 7 ECTS **Teaching mode:** 42h C + PW with personal work **Semester:** Spring **Evaluation mode:** Practical (final proposal + two presentations)
Aims of the course - Become familiarized with the Great challenges in Earth and Environmental Sciences relevant to society - Learn how to critically read and summarize scientific literature - Learn how to write a scientific proposal focused on research questions relevant to the topic of the course
Course description - 4 seminars on topics relevant to the Great Challenges - 1 course on literature references and research of publications + soft skills on presentations - Reading and summarizing scientific literature - Presentations by students using their choice of support (video, song, theatre, talk...) - Compilation and analysis of data in groups - Writing and presenting a proposal The formation and evolution of our planet occurred within a restricted range of biogeochemical conditions that finally led to the blooming of life. Now, life and by inference our society face enormous challenges linked to environmental pressure and the necessity to transition to a sustainable future. Earth scientists strive to pose the scientific bases to understand how life evolved on our planet and will play a central role in tackling the Great challenges of modern society. To actively impact on science and the development of a sustainable society, Earth science students need to learn how to integrate multidimensional data and critically assess the wealth of available information. Experts on selected topics will give presentations to introduce fundamental scientific questions, which remain unresolved (natural hazards, climate change, energy transition, deep life, planetary sciences, environmental stresses…). Selected, recently published literature will be critically assessed and presented by the students. During practical sessions, students will learn to compile and integrate data with the aim of writing a proposal on the research required to address one of these Great challenges.
Sequence of the course Teachers to be decided: Introduction to the course + course on literature references + soft skills on presentations (3h) Four seminars on a topics (3h each) Reading group (3h) Student presentations (6h) Compilation and data integration (9h) Writing a proposal (9h) Student presentations (9h)
Comments: Invited seminar by relevant experts will be organized, topics will change regularly.

Module M3: Quantitative and analytical methods – Mandatory for all

Data sciences – Mandatory for all - M3
Traitement quantitatif des données

Coordinators: Thomas Sheldrake and James Irving
Number of ECTS: 4 ECTS
Teaching mode: 36h C + PW, 3h per week
Semester: Autumn and Spring
Evaluation mode: Practical (exercises and project)

Aims of the course
- Introduce students to computational methods for data analysis using programming languages such as R and Matlab
- Provide experience with a variety of techniques commonly used to characterize and assess geochemical and geophysical data
- Develop techniques to interpret and assess causality in geological systems
- Understand how subsurface model parameters can be estimated via inverse methods

Descriptions of the course
Introduction to the quantitative analysis of geochemical, geophysical, and other data. Topics to be discussed include classification and image analysis, uncertainty quantification, regression, and parameter estimation / inversion. Students will learn how to deal with data-bias and non-uniqueness associated with limited and/or imperfect data sets, as well as how to analyze large data sets.

Sequence of the course
T. Sheldrake (Weeks 1-6) – Statistical inference (18h C + TP).
- Data types and programming languages: Characterizing and describing data
- Time series analysis: Stationarity, seasonality, trend smoothing, change points
- Regression: goodness of fit parameters, prediction and estimation
- Multidimensional analysis: clustering, multidimensional scaling
- Image analysis: Segmentation, boundary detection, vectors and rasters

J. Irving (Weeks 7-12) – Parameter estimation and inversion (18h C + TP).
- Model parameter estimation for overdetermined systems
- Ill-posed problems and the need for prior information
- Linear inverse problems with examples from geophysics
- Introduction to non-linear inversion
- The Fourier transform and its application to data analysis and filtering

Comments: Pre-requisites: Students should be familiar with programming languages and have taken the programming course in the Kickstarter fortnight if needed.

Simulating geological processes on computers and in the laboratory - M3
Simulation de processus géologiques

Coordinators: Yury Podladchikov
Number of ECTS: 3 ECTS
Teaching mode: 27h PW + E
Semester: Autumn
Evaluation mode: Practical

Aims of the course
- Learn to solve physically-based mathematical models with the computer
- Become accustomed with analogue modelling methods

Descriptions of the course
This course consists of two main components: (1) students will develop programming skills and learn numerical techniques required to simulate physical and/or chemical processes on the computer using MATLAB (80%), (2) students will become accustomed with various analogue models used to simulate geological processes in the laboratory (20%). Part two will include Earth surface process modelling, phase equilibria and kinetic experiments in the laboratory, analogue modelling of volcanic ash settling and sandbox rift modelling.

Sequence of the course Y. Podladchikov (23h) – computer based exercises S. Castelltort (1h) – laboratory visit J. Ruch (1h) – laboratory visit L. Baumgartner (1h) – laboratory visit C. Bonadonna (1h) – laboratory visit
Comments: Laboratory visits will be conducted.

From outcrop to 3D model - M3
De l'affleurement au modèle 3D

Coordinators: Marc-Henri Derron
Number of ECTS: 3 ECTS
Teaching mode: 9h C, 18h PW + F
Semester: Autumn
Evaluation mode: Practical (reports)

Aims of the course
- To combine classical fieldwork and recent technologies to analyze an outcrop
- To get a practical introduction to 3D data acquisition and processing (Lidar, SfM…)
- To build a virtual outcrop and produce a 3D geological interpretation
- To report in proper way the results of such analysis

Descriptions of the course
The course begins with a couple of days of fieldwork to investigate an outcrop. Geological features will be described, measured and mapped. Data from close-range remote sensing techniques (e.g. laser scanning, drone, hyperspectral imagery) will also be acquired in the field.
Then students will pass to a computer room for the rest of the course. They will learn to build a 3D model from pictures, to process Lidar data and work with 3D point clouds. All the data acquired in the field (and additional data such as borehole loggings if available) will be integrated into a 3D virtual outcrop.
Finally, a 3D geological model will be built, using various interpolators and geological criteria. Additional features will be then derived from this model. Depending on the site, that can be related to permeability and fluid circulation, slope stability, structural geology, engineering geology).

Students are expected to work independently outside of class hours.

Sequence of the course
M.-H. Derron: fieldwork remote sensing techniques, 3D data processing, 3D geological modelling → 14 h
J.-L. Epard: fieldwork, geological analysis and interpretation, 3D geological modelling → 13h

Comments: ---

Methods of isotope analysis - M3
Méthodes d'analyses isotopiques

Coordinators: Torsten Vennemann and N.N. *(U. Schaltegger successor)*
Number of ECTS: 3 ECTS
Teaching mode: 27h C + PW + personal work
Semester: Autumn – 2nd year
Evaluation mode: Practical (report)

Aims of the course
- Learning about various methods of isotope analysis by mass spectrometry
- Instrument calibration for data acquisition, determination of precision and accuracy
- Reading and understanding of analytical protocols

Descriptions of the course
- Introduction on mass spectrometry methods
- Lectures on various isotopic methods and key applications
- Laboratory tours
- Presentation of selected publications

During this course, students will receive a complete overview of the principles and key applications of mass spectrometry for isotope analyses in rocks, minerals and solutions. Numerous instrumental aspects are described and laboratory visit of the various mass spectrometers hosted by UNIL and UNIGE will be organized. Sample preparation methods as well as the techniques of calibration via reference materials (standards), and the determination of precision and accuracy of individual methods will be presented and discussed.
Publications on recent development in isotope analyses will be selected and further presented by students.

Sequence of the course

J. Marin Carbonne: Introduction to mass spectrometry, standard calibration, precision and accuracy (3h)
N.N. *(U. Schaltegger successor)*: Sample preparation, in-situ sampling of solids vs solution analysis (3h)
A. Ulyanov: Inductively coupled plasma mass spectrometry (ICP-MS) (3h)
J. Marin Carbonne, A. Meibom: Secondary-ion mass spectrometry (SIMS) and NanoSIMS (3h)
M. Chiaradia: Chemical separation for radiogenic and heavy isotopes (3h)
N.N. *(U. Schaltegger successor)*: Thermal ionization mass spectrometry (TIMS) (3h)
R. Spikings: Gas source MS noble gas (3h)
T. Vennemann: Gas source MS stable isotope and clumped isotope measurements (3h)
All teachers: Student presentations (3h)

Comments: Specific lectures on instrumentation and applications will be given by the laboratory scientific expert responsible of instruments.

Chemical analyses and imaging techniques for major and trace elements - M3
Techniques d'analyses chimiques et d'imagerie électronique pour les éléments majeurs et traces

Coordinators: Martin Robyr and Florence Bégué
Number of ECTS: 3 ECTS
Teaching mode: 49h C + PW
Semester: Autumn
Evaluation mode: Practical (poster presentation)

Aims of the course

- Learning the different techniques of chemical analysis and electronic imaging
- Electron probe micro-analyzer (EPMA)
- Scanning electron microscopy (SEM, CL, QEMSCAN)
- X-ray fluorescence (XRF)

Descriptions of the course

The aim of this course is to apply complementary geochemical and imaging analytical techniques to investigate geological samples from bulk-rock to submicron scales. The necessary theoretical and practical bases to operate an electron microprobe, a scanning electron microscope, an XRF spectrometer, a cathodoluminescence microscope, Raman and a QEMSCAN are provided. A large part of the course is devoted to hands-on work, including sample preparation, training on the different machines, and data quality check. In order to evaluate the applicability, specificity and limitations of each technique, the same sample set is used throughout the course.

Sequence of the course

MEB (14h C+TP): P. Vonlanthen – at UNIL for UNIL students. In parallel at UNIGE for UNIGE students by R. Martini and A. Martignier.
Microsonde (21h C+TP): M. Robyr: 14h for the theoretical courses at UNIL. The practice (7h) will be given at UNIL for UNIL students (M. Robyr) and at UNIGE for UNIGE students (F. Bégué).
XRF (7h C+TP): O. Reubi and A. de Haller at UNIL for all the students.
Raman (3h C+TP): O. Reubi at UNIL for all the students. Also the possibility at UNIGE.
QEMSCAN (4h C+TP): A. de Haller at UNIGE for all the students.

Comments: ---

Module M4a: Geobiosphere, Climate and the Sedimentary Rock Records

Life Evolving with Earth - M4a
La Vie évolue avec la Terre

Coordinators: Allison Daley and Rossana Martini
Number of ECTS: 4 ECTS
Teaching mode: 36h C + PW
Semester: Autumn
Evaluation mode: Practical (Students presentations) and written exam

Aims of the course

- Examine the interactions between life and the environment
- Explore examples throughout geological time showing how the evolution of life changed the abiotic world, and vice versa, how the environment can change the course of life's evolution
- Present the wide range of interdisciplinary tools that can be used for studying life's evolution

Descriptions of the course

This course revolves around two main themes: (1) The interactions between life and the abiotic environment; and (2) The interdisciplinary nature of studying life's evolution. A selection of examples from throughout geological time will be explored to show how the evolution of life can have drastic effects on the surrounding environment, and that vice versa, the nature of the abiotic environment can influence the evolution of life. These interactions and feedback loops occur at the micro-scale, macro-scale and global scale, and studying them brings a deeper understanding of major geological events in Earth's history and perspective on modern environmental crises. Research in paleoenvironmental geology is interdisciplinary, and this course showcases the wide variety of tools and approaches employed, including paleontological and paleoecological data, sedimentological proxies, and geochemical tracers. Teaching methods include seminars and student-led learning activities, such as computer modelling, laboratory experiments, and student presentations.

Sequence of the course

- A. Daley (3h): Introduction to the course. A look at the breadth of techniques used to extract information from fossils and reconstruct their preservation processes, and why it is critical to understand taphonomy when interpreting the incredible record of "fossil lagerstätten" – sites with exceptional preservation in fossil quality or quantity (case studies: eukaryote evolution, Ediacaran biota, the Cambrian Explosion).
- J. Marin Carbonne (3h): Precambrian life evolution, including microbial life and especially stromatolites.
- R. Martini (6h): Time dimension analysis in the study of sedimentary successions and paleogeographic implications. Case study of benthic foraminifera and their evolution from Carboniferous to Triassic.
- A. Daley (3h): Paleoecological concepts, examining the biological, physical, and chemical factors that shape communities of organisms in different environments, with case studies throughout the Phanerozoic.
- E. Samankassou (6h): Modern and ancient reef systems, and their evolution and distribution throughout geological time.
- J. Spangenberg (6h): Geochemical signature of life, including biomass in the marine and terrestrial environment; productivity and chemical makeup of sedimentary organic matter; from chemistry of life forms to preserved hydrocarbon biomarkers in rocks.
- S. Le Houedec (3h): The influence of the seawater geochemistry on biomineralization, e.g. impact of Mg/Ca, S and P concentration changes during the Phanerozoic on biomineralization.
- T. Adatte (6h): Major extinction events and their documentation in sedimentary archives to better understand the interactions between life and environment. Case studies: end Ordovician, end-Devonian, Permian-Triassic, Triassic-Jurassic, Cretaceous-Paleogene mass extinctions and Paleocene-Eocene events.

Comments: ---

Climate and Paleoclimate: from deep time to the Anthropocene - M4a
Climat et paléoclimat: des temps anciens à l'Anthropocène

Coordinators: Samuel Jaccard and N.N. *(D Ariztegui successor)*
Number of ECTS: 4 ECTS
Teaching mode: 36h C+PW
Semester: Spring
Evaluation mode: Oral presentation and written exam (report and exercise)

Aims of the course
- Interpret evidence of past climate change based on climate indicators and/or proxy reconstructions gleaned from geological climate archives
- Critically assess hypotheses underlying climate variability in the past
- Compare the magnitude and rates of past changes in the carbon cycle, ice sheets dynamics, water cycle and ocean circulation with observations and predictions for climate change in the near and distant future

Descriptions of the course
The climate and paleoclimate course will explore how the major aspects of the earth's climate system have evolved in the past, and the driving forces and feedbacks for these changes. The major topics include the earth's atmospheric CO2 concentration and mean temperature, ocean circulation, the size and stability of ice sheets and sea level, as well as variations in the water cycle. These past changes and their feedbacks will be considered in the context of anthropogenic climate change.

Sequence of the course
- Overview of the main climate archives and proxies (S. Le Houedec) – 3h
- Evolution of the global carbon cycle across time (long and short term regulation and feedbacks of atmospheric CO_2) (S Jaccard/M Galvez) – 3h
- Proterozoic Glaciations (Snowball Earth) (S. Jaccard/M. Ovtcharova) – 3h
- Climatic Change and faunal evolution: case study of mass extinction at the Permian-Triassic boundary (R Martini/M. Ovtcharova) – 3h
- Global anoxic events: case studies from the Cretaceous (T. Adatte) – 3h
- Cenozoic CO_2 and Paleocene/Eocene Thermal Maximum (PETM) (S. Jaccard) – 3h
- Pliocene - permanent El Nino, onset of Northern Hemisphere Glaciation (S. Jaccard) – 3h
- Orbital- and millennial-scale CO_2 variability during the Pleistocene (S. Jaccard/P. Blaser) – 3h
- Reconstructing climate change from continental archives (NN D Ariztegui successor) – 3h
- Tropical climate evolution based on coral archives (E. Samankassou) – 3h
- Holocene climate reconstructions based on tree rings (M. Stoffel) – 3h
- Perspectives on the Anthropocene (T. Adatte) – 3h

Comments: The course work will include reading of literature, seminar talks and discussions. The first 3 lectures will provide the basic framework for the course. The lecturers will also provide supplementary information on the individual topics and background introduction on proxies used in the individual studies throughout the course.

Surface processes and depositional environments from source to sink (SURFPRO) - M4a
Processus de surface et environnements de dépôt sédimentaires des sources aux bassins

Coordinators: Sébastien Castelltort and Elias Samankassou
Number of ECTS: 4 ECTS
Teaching mode: 36h C + E
Semester: Autumn
Evaluation mode: Practical (Presentations, exercises, essays/reports), and written exam

Aims of the course
- Acquire essentials of modern source-to-sink (S2S) analysis: 1) history of the approach (from all-eustatic sequence stratigraphy to tectonic geomorphology, numerical landscape evolution models, sediment budgets and signal propagation), 2) physical processes: terminology and key orders of magnitude for tectonic, climatic and autogenic signals in the erosional zone, transfer subsystem and depositional sink, 3) theory (diffusion) and examples of signal propagation, 4) gains, limitations and challenges of the S2S approach
- Acquire advanced and state-of-the-art knowledge and interpretation skills in sedimentological, stratigraphic and geomorphological analysis of major depositional environments of the S2S system, both in the clastic and carbonate domains
- Acquire essentials of the physical, chemical and mineralogical processes characteristic of sedimentary basin evolution

Descriptions of the course

This course is designed to bring students to the expert level in a modern approach of sedimentary geology. In part 1 of the course, we will learn the history, and main concepts and applications of source-to-sink analysis, which is the new paradigm for the interpretation of the stratigraphic record. This part notably allows students to merge the last advances in geomorphology with classical stratigraphy in a “systems” approach of sediment routing systems. In part 2, we will focus on essential carbonate depositional environments of the source-to-sink systems and study carbonate production, carbonate accumulation and carbonate budgets in response to sea level, climate and tectonics. In part 3, a focus is made on the mechanical and mineralogical evolution of sedimentary basins and how can subsidence and burial be estimated. This last part is essential for the understanding of the processes that control the creation of space for sediment accumulation.
At the end of this course, students are ideally prepared to tackle research and project-leading in sedimentary geology, in the frame of their master’s thesis, a PhD thesis in surface processes, carbonate sedimentology and sedimentary geology, or in industry.
The course is delivered through frontal lectures, exercises, and practicals, but also uses peer instruction and flipped classroom modules. Students get exposed to new knowledge not taught in the bachelor, directly linked with the research developed by the academics involved. Through homework and exercises, the course also helps develop autonomous work, scientific methodology, independent thinking and written and oral presentation skills.

Sequence of the course

Part 1: Surface processes from Source-to-Sink: main concepts of erosion, transport and deposition (surface processes), signal propagation (steady state, response time) in response to climate and tectonic perturbations. Essentials of weathering, soil formation and paleosoil records of past perturbations.

- S. Castelltort, 4x3h
- E. Verrecchia, 1x3h

Assignment: reading and presenting papers, exercises, report.

Part 2: Carbonate Depositional Environments: A Source-to-Sink approach. Main concepts of carbonate facies, carbonate production and accumulation, carbonate budgets in response to past sea level, tectonic and climatic changes.

- E. Samankassou, 4x3h

Assignment: reading and presenting papers, exercises, report.

Part 3: Sedimentary basins

- G. Simpson, 1x3h, Mechanisms of subsidence through extension, cooling, and flexure (including isostasy)
- T. Adatte, 1x3h, estimating burial with organic matter and mineralogical transformations
- R. Spikings, 1x3h, estimating burial with thermochronological methods

Assignment: reading and presenting papers, exercises, report.

Comments: ---

Sedimentology analytics - Collecting, Interpreting and Presenting Field Data - M4a

Récolte - analyse, interprétation et présentation des données de terrain en sédimentologie

Coordinators: Thierry Adatte and Rossana Martini
Number of ECTS: 4 ECTS
Teaching mode: 28h PW + F and personal work
Semester: Spring
Evaluation mode: Written report and oral presentation

Aims of the course

The course aims to provide hands-on experience with sampling strategies and analytical methods used in sedimentology, including mineralogical and geochemical techniques. This practical course will allow the students to plan and conduct fieldwork, apply lab techniques on the samples that they collected themselves in the field, and analyse the data to interpret the results.

Descriptions of the course

The course consists of a short* theoretical introduction to the analytical methods and practical hands-on work in the laboratories at the University of Lausanne.

- In the field: section logging, collection of samples and sedimentological interpretation.
- In the lab: sample preparation, mineralogical and geochemical analyses, use of different analytical tools (e.g. XRD, XRF, stable isotopes, organic matter by Rockeval, granulometry).
- Treatment and interpretation of the data.
- Presentation of results.

** The theoretical part of most of the analytical techniques proposed in this practical course will have already been introduced in the "Chemical analyses and imaging techniques for major and trace elements" course of the Quantitative and analytical methods module during the Fall semester, which is a prerequisite of this course.*

Sequence of the course

- **Fieldwork -** 8h all together:

T. Adatte, E. Samankassou, J. Marin Carbonne, R. Martini. One fieldwork day in the Jura Mountains including section logging and sample collection.

- **Lab analyses** - 20h as follows:

T. Adatte and J. Marin Carbonne: preparation lab (4h) / T. Adatte: XRD-Rockeval (4h) / O. Reubi: XRF preparation (3h) / J. Spangenberg: Organic Carbon isotopes (3h) / T. Vennemann: carbonate isotopes (3h) / E. Verrecchia: granulometry (3h).

a. Preparation of the samples for analyses (crushing, grinding, etc.). Short recap to the analytical methods used. Sample preparation of fusion disks and powder tablets for X-ray fluorescence and X-ray diffraction analyses. $^{13}C/^{12}C$ and $^{18}O/^{16}O$ carbonate stable isotopes. Organic matter analyses (Rockeval, $^{13}C/^{12}C$). Laser granulometry.
b. Processing and interpretation of the data.

Comments: This practical course has to be planned during the spring semester following the course *"Chemical analyses and imaging techniques for major and trace elements"* (autumn semester, Module 3) which is a pre-requisite.

Sedimentology, Climate, Paleontology and Geomorphology Field Camp (SedClimPal-Camp) – M4a

Camp de terrain de sédimentologie, climatologie, paléontologie et géomorphologie

Coordinators: Sébastien Castelltort and Allison Daley
Number of ECTS: 4 ECTS
Teaching mode: 12d F
Semester: Spring
Evaluation mode: Field report handed in at the end of the camp

Aims of the course

You know the saying: "The best geologists have seen the most rocks".
- Examine rock sections in the field to interpret sedimentological and paleontological data in order to reconstruct paleoenvironment, paleoclimate, and taphonomic history
- Independent field exercises describing sections to interpret their depositional setting, post-depositional processes and paleontological content
- Exposure to an exhaustive range of clastic and depositional environments from source-to-sink (proximal alluvial, fluvial, marine, shelf, slope, basin)
- Examine 2D sections for stratigraphic geometries and relationships with tectonic deformation
- Train observational and deductive skills, including hypothesis framing and testing

Descriptions of the course

Interdisciplinary field camp studying various aspects covered during the courses of this module. There are two main parts of this camp, and the students also work several days on the field in autonomy without the teachers. The ELSTE master's program offers one of the world's best field experiences for students.

Clastic and carbonate sedimentary record of climate and tectonics in the field

S. Castelltort, others - *Duration: 6 days*

Annually alternating between :

1. Tremp-Ainsa-Jaca-Zumaya (Spain)
2. Dignes (France)
3. Other possible areas (e.g. Sardinia, Dolomites)

The students examine sedimentary facies and stratigraphic relationships in relation to climate and tectonics, from source-to-sink. Usually the settings chosen are in peripheral foreland or in extensional basins. In addition to disciplinary knowledge and observational skills, a focus is given to deductive thinking and high-level interpretational competences The course is shared with Geneva 3rd year bachelor students, and students are asked to work in multi-level/multidisciplinary teams to develop their ability to collaborate.

Paleontology in the field

A. Daley, T. Adatte, others - *Duration: 6 days*

Examination of exceptionally preserved fossil localities in southern Germany (Holzmaden and Solnhofen) to contrast and compare their preservation processes, fossil content, and environment of deposition. Examination of the Nördlinger Ries impact crater to examine how this event affect the paleoecology and structure of the community, and the recovery processes after the impact.

Sequence of the course The structure of each field course and temporal order of the teachers is highly dependent on the visited and studied areas which may vary from one year to another. The teachers are normally present at all times and deliver different expert perspective on all outcrops. Field days are normally from 8am to 7pm and may require a good physical condition. - S. Castelltort: clastics, geomorphology, tectonics and climate relationships - A. Daley: paleontology, evolution, impact of extreme events - T. Adatte: carbonate, paleoclimate, extreme events and crises - S. Girardclos: clastics, lacustrine sedimentology and limnogeology, quaternary geomorphology - S. Jaccard: paleoclimate, paleoceanography, isotope and geochemical proxies - E. Samankassou: carbonate sedimentology and stratigraphy, paleontology - M. Stoffel: landslides and glacial geomorphology, quaternary geology and paleoclimate, dendrochronology
Comments: ---

Module M4b: Dynamic Earth

Physical-chemical mechanisms of geological processes – M4b
Mécanismes physico-chimiques des processus géologiques

Coordinators: Stefan Schmalholz and Lukas Baumgartner
Number of ECTS: 4 ECTS
Teaching mode: 36h C + PW (3h per week)
Semester: Autumn
Evaluation mode: Practical

Aims of the course
- Understand the basic concepts of continuum mechanics
- Understand the basic concepts of thermodynamics
- Understand the mechanisms of rock deformation (fluid and solid behavior)
- Understand the mechanisms of heat transfer
- Understand the mechanisms of metamorphic reactions, including melting
- Understand fundamental mechanisms of porous flow, including reactive transport
- Obtain ability to solve/analyze first-order geological questions (educated guess; TP)
- Obtain ability to quantify geological processes with mathematical models (TP)
- Know dimensionless numbers relevant for geological processes
- Application of theoretical concepts to geodynamic processes

Descriptions of the course
The course teaches the basic physical and chemical mechanisms underlying geological processes. These mechanisms are explained with the concepts of continuum mechanics and non-equilibrium thermodynamics. The fundamental equations of continuum mechanics and thermodynamics are explained. These basic equations are applied in the context of fluid and solid mechanics, heat transfer, metamorphic processes, melting, kinetics, porous flow, volcanic eruptions and large scale geodynamic processes.
The concepts and equations are applied in TP and homework exercises to investigate and quantify geological processes by using dimensionless numbers, analytical solutions, numerical simulations, metamorphic phase diagrams etc.

Sequence of the course
1. Fundamental continuum mechanics and thermodynamic concepts (S. Schmalholz and L. Baumgartner)
2. Dimensional analysis applied to geological processes (S. Schmalholz)
3. Fluid mechanics: viscous flow, including folding, shear zones etc. (S. Schmalholz)
4. Heat transfer: conduction, advection, convection, production etc. (S. Schmalholz)
5. Solid mechanics: elasticity and fracture mechanics, including flexure (S. Schmalholz)
6. Equilibrium thermodynamics: melting, solidification, latent heat (L. Baumgartner or O. Müntener)
7. Non-equilibrium thermodynamics: basic concepts, kinetics etc. (L. Baumgartner)
8. Flow in porous media: porous convection, melt migration (Y. Podladchikov or O. Müntener)
9. Fluid/melt migration by porosity waves and reactive transport (Y. Podladchikov or S. Schmalholz)
10. Volcanic eruption trigger mechanisms (L. Caricchi)
11. Application to geodynamic processes: Mantle convection, plate driving forces, subduction initiation (S. Schmalholz)
12. Application to geodynamic processes: Mountain building processes and rock exhumation (S. Schmalholz)

Comments: ---

Geophysics across scales – M4b
Géophysique à différentes échelles

Coordinators: György Hetényi
Number of ECTS: 4 ECTS
Teaching mode: 36h C + PW (3h per week)
Semester: Autumn
Evaluation mode: Practical (exercises and homework)

Aims of the course
- Understand the broad range of geophysical methods

- Understand the variability in spatial and time scales of geophysically imageable structures and geophysically constrainable processes
- Understand the suitability and limitation of various methods in solving geoscience problems
- Understand the complementarity of methods and the need to apply them jointly
- Obtain ability to solve/quantify geophysical problems with programming tools, incl. code writing
- Know some of the relevant geophysical data repositories

Descriptions of the course

The course partly builds on earlier knowledge to complete the presentation of various geophysical methods and tools, and how they can serve solving modern geological problems at a great variety of scales. It will also highlight the limitations of the methods (resolution, relevance, non-uniqueness etc.), to incite joint use of methodological or/and disciplinary approaches. As much as possible, elements seen in the BSc program and the Kickstarter module will not be treated, unless it is to dig deeper into the method or/and to a dataset. Several geographical targets and process-oriented applications will be presented, often with recent discoveries or still open questions. The TP exercises aim to provide hands-on training, with subsequent homeworks from about half of the lecture constituting the final grade.

Sequence of the course

G. Hetényi, 22.5h
-Introduction and History of geophysics; Structural seismology; The seismic cycle incl. paleoseismology; InSAR; Remote sensing and applications; GNSS-based methods and applications; Orogenic examples; Selected database and search tools; Gravity; Heat flow; “Geollywood” critique session.

M. Lupi, 6h
-Volcano seismology, volcanic geophysical signals; Spectral seismology.

B. Quintal, 4.5h
-Drilling; Borehole logging.

S. Pilet, 3h
-The lithosphere and the lithosphere-asthenosphere system, its geophysical-petrological structure.

Comments: ---

Minerals, rocks and magma – M4b

Minéraux, roches et magma

Coordinators: Luca Caricchi and Othmar Müntener
Number of ECTS: 4 ECTS
Teaching mode: 36h C + PW
Semester: Spring
Evaluation mode: Practical (exercises)

Aims of the course

The students will learn how to extract information from the chemical and textural analysis of minerals, rocks and magmas to understand processes that occurred in the past and/or at inaccessible depths.

Descriptions of the course

1. Physics and structure of minerals and magmas, including aspects of diffusion and thermobarometry (O. Müntener, L. Caricchi)
2. Mineral growth, nucleation, and transport limited mineral growth (L. Baumgartner)
4. Geochemical modelling (S. Pilet)
5. Petrological modelling (MELTS, Perple_X, VesiCal) (O. Müntener, L. Baumgartner, F. Bégué)
6. Linking petrology, volcanology and geophysics (L. Caricchi, O. Müntener)

Sequence of the course

For the sequence see the section “Description of the course”.

Comments: ---

Geochemical cycles and rates of geological processes – M4b

Cycles géochimiques et taux des processus géologiques

Coordinators: Massimo Chiaradia and N.N. *(U Schaltegger successor)*
Number of ECTS: 4 ECTS
Teaching mode: 36h C + PW (3h per week)
Semester: Spring

Evaluation mode: Practice (report)

Aims of the course

-Make the students acquainted with the broad range of applicability of element and isotopic geochemical tools in Earth Sciences.
-Introduce the students to the use of geochemical tools to understand present and past large-scale processes of the Earth's surface and deep interior.
-Provide the students with the theoretical understanding of how rates of geological processes can be quantified and why this is important.
-Stimulate the active participation of students through readings and debate on controversial topics.

Descriptions of the course

The course will consist of theoretical classes on the geochemical contributions to the understanding of fundamental geological processes including, among others, the evolution of the Earth crust, use of transition element isotopes to study the evolution of the early Earth, ocean-crust interactions, timescales of rock uplift and exhumation, timing and tempo of magmatism, quantification of biotic evolution, and geochemical cycling at subduction zones. The theoretical classes will be integrated by readings and debates of key articles and some practical exercises.

Sequence of the course

- Torsten Vennemann (UNIL): 1. Earth's Crustal Evolution. 2. Seawater-Crust Interactions and the Evolution of seawater. 3. Diamonds and their Inclusions: Petrologic indicators of Earth's recycling. 4. Ore Deposits and Fluid-Rock Interactions (total 8h).
- Samuel Jaccard (UNIL): Ocean circulation and/or marine biogeochemistry (4h).
- Nicolas Greber (MUSEUM GE): Use of transition element isotopes to study the early Earth evolution (4h).
- Richard Spikings (UNIGE): 1. Geochemical and isotopic evolution of the crust at active margins over long time scales (>100 Ma). Arc and rift magmatism. 2. Time scales of rock uplift, exhumation and surface uplift at active margins (total 4h).
- Perach Nuriel (UNIGE): Geochronology of brittle upper-crustal deformation; timing and pattern of deformation along major fault systems (4h).
- Maria Ovtcharova (UNIGE): Absolute time in the geological record; quantifying biotic evolution on Earth (4h).
- Anne-Sophie Bouvier (UNIL): Volatile cycling in subduction zones (4h).
- Massimo Chiaradia (UNIGE): Lithophile and chalcophile element cycling at subduction zones (4h).

Comments: Homework will include preparatory readings for theoretical classes.

Mountain belts in the field – M4b

Les chaînes des montagnes sur le terrain

Coordinators: Othmar Müntener and Jean-Luc Epard
Number of ECTS: 4 ECTS
Teaching mode: 8d F + 2d PW
Semester: Spring
Evaluation mode: Practical (Example: 60% Field notebook, 10% Class participation, 30% Presentation)

Aims of the course

- Earth-science problems and processes approached through hands-on, problem-solving, data-gathering, and field-based studies using the natural landscape as an outdoor classroom
- This class will help you develop the following skills: ability to think, interpret data, and communicate. These are the 3 most important things that employers look for in recently graduated students

Descriptions of the course

This practical course involves a combination of data-based case studies performed in class (2 days), in short field trips (2 * 2-3 days), and a yearly field school (ca. 1 week) focusing on major orogenic mountain chains (including mainly the Alps and the Mediterranean, but also Andes, Himalaya-Tibet, Sierra Nevada or New Zealand Alps).
Topics (somewhat varying from year to year) : (i) Plate tectonics and deformation of the Earth; (ii) active faulting and seismic hazards; (iii) fluids, subduction zones and magma generation; (iv) metamorphism and microstructures; (v) glacial deposits, responses and climate change; (vi) volcano processes and hazard.

Sequence of the course

Field school: Field school Adamello: O. Müntener and L. Caricchi
Excursion 1: L. Baumgartner, coordinator
Excursion 2: J.-L. Epard, coordinator

Comments: ---

Module M4c: Geological Hazards and Risks

Risk and decision making – M4c Le risque et le processus décisionnel
Coordinators: Scira Menoni and Chris Gregg **Number of ECTS:** 4 ECTS **Teaching mode:** 35h C + E **Semester:** Spring **Evaluation mode:** Practical and written exam
Aims of the course At the end of this course, students should be able to: - Examine concepts of vulnerability and resilience - Describe damage and loss from an economic perspective - Reflect and propose strategies to resolve risk decision-making issues - Distinguish factors affecting response to short-term warnings from long-term hazard education
Descriptions of the course This course aims at broadening the view on risk by considering functional, systemic and economic vulnerability on one side, resilience on the other side as well as discussing factors influencing early warning messages, preparedness actions or risk decision-making processes.
Sequence of the course S. Menoni - Vulnerability and resilience - 10.5h G. Pesaro - Economic vulnerability - 7h A. Scolobig - Risk decision-making processes - 3.5h C. Gregg - Warning systems, hazard education and social science in disaster studies - 10.5h Other CERG-C lecturers - Topic/invited lecturer will vary depending on the year -3.5h
Comments: ---

Physical volcanology and volcanic risk – M4c Volcanologie physique et risque volcanique
Coordinators: Costanza Bonadonna **Number of ECTS:** 4 ECTS **Teaching mode:** 36 h C + E **Semester:** Autumn and Spring (block course) **Evaluation mode:** Practical and written exam
Aims of the course At the end of this course, students will be able to: - Characterize the dynamics of eruptions and their impacts - Understand the basics of numerical and experimental modelling of eruptive processes - Discuss the main volcanic hazards and associated risk - Identify key mitigation measures
Descriptions of the course This course covers the dynamics and the physical characterization of volcanic eruptions and their impacts. Using case studies and practical exercises, we explore how theoretical, numerical and experimental modelling can be used to describe a variety of eruptive process. Main concepts of volcanic hazard and risk assessment are also introduced.
Sequence of the course Teacher 1: C. Bonadonna - Physical characterization of volcanic eruptions; volcanic impact, hazard and risk – 24h (6h in the Autumn and 18h in the Spring semester) Teacher 2: to be decided - Experimental and numerical modelling of volcanic processes -12h (Autumn semester)
Comments: ---

Volcanic risk field trip – M4c
Evaluation du risque volcanique – camp de terrain

Coordinators: Costanza Bonadonna
Number of ECTS: 4 ECTS
Teaching mode: 7d F
Semester: Spring
Evaluation mode: Seminar

Aims of the course
At the end of this field camp, students will be able to:
- Characterize different volcanic hazards
- Analyze exposure, vulnerability and risk
- Select appropriate risk mitigation strategies
- Discuss strategies of crisis management
- Develop strategies to strengthen the resilience of local communities

Descriptions of the course
This field camp provides the opportunity to familiarize and discuss the main steps required to assess and manage volcanic risk including hazard assessment, exposure analysis and assessment of various dimensions of vulnerability.

Sequence of the course
C. Bonadonna - Physical volcanology, hazard assessment, capacity building - 3 days
S. Menoni - Physical, economic and systemic vulnerability - 2 day
C. Gregg - Early warning, social vulnerability - 1 day
C. Frischknecht - Risk assessment and management - 1 day

Comments: Prerequisites: “Risk and decision making” and “Physical volcanology and volcanic risk”.

Seismic risk – M4c
Risque sismique

Coordinators: Donat Fäh and Blaise Duvernay
Number of ECTS: 3 ECTS
Teaching mode: 28h C + E, 1d F (block course)
Semester: Spring
Evaluation mode: Written exam

Aims of the course
At the end of the course, students will be able to:
- Discuss seismic hazard products, the required input data and related uncertainties
- Describe the main principles of good practice in earthquake engineering
- Explain the components of seismic loss and risk modelling
- Identify appropriate seismic risk mitigation strategies

Descriptions of the course
This course discusses seismic hazard, vulnerability and associated risk. It provides an overview of the input data and of the tools in deterministic and probabilistic seismic hazard assessment and discusses the related uncertainties. Earthquake-induced effects such as liquefaction of soils, the triggering of landslides and tsunami generation are also presented. The second part of the course focuses on the different factors affecting the seismic vulnerability of buildings and gives an insight into how seismic loss and risk models work.

Sequence of the course
D. Fäh - Engineering seismology, seismic hazard, seismic site effects - 14h
B. Duvernay - Seismic vulnerability, seismic loss and risk quantification - 14h + 1 day field trip

Comments: ---

Erosion and slope movement – M4c
Erosion et mouvements de terrain

Coordinators: Michel Jaboyedoff
Number of ECTS: 5 ECTS
Teaching mode: 56h C + PW
Semester: Spring
Evaluation mode: Practical and oral exam

Aims of the course
Slope movements are initially approached as an integral part of erosion processes. This course provides an overview of slope movements and certain erosion processes (mountain range erosion and soil erosion), illustrates them with examples, classifies them and gives elements of characterization. Then the physics of each type is described. Landslides, boulder falls, landslides, debris-flows and aspects related to flooding are discussed. Both the stability and the propagation of these phonemes are studied. An introduction to the modelling of each phenomenon is proposed. Each part of the course is illustrated with examples, applications and some modeling elements are practiced. Throughout the course, the characterization of the hazard, as well as the principles of mitigation are illustrated, providing the necessary elements for risk management.

Descriptions of the course
TO BE COMPLETED

Sequence of the course
All by M. Jaboyedoff.

Comments: Course proposed in the Master in Environment (UNIL).

Module M4d: Earth resources

Exploration Methods – Mandatory for all if the module is chosen - M4d Méthodes d'exploration
Coordinators: Beatriz Quintal **Number of ECTS:** 2 ECTS **Teaching mode:** 18h C + PW **Semester:** Autumn **Evaluation mode:** Practical (Exercices)
Aims of the course The aim of this course is to expose the student with the main methods of exploration applied to geo-energy and mineral resources. The lectures and exercises will go from the description of the basic concepts involved in each method to the discussion in depth of relevant case studies in the two scenarios.
Descriptions of the course This course will cover methods in geophysics and geochemistry that are used for the exploration of geo-energy and mineral resources. Basic methodological knowledge of the main tools will be exposed and their application and integration will be discussed in the context of selected case studies. Main methods that will be covered: IP; EM; gravity; borehole logging; VSP; active surface seismic; methods used for reservoir monitoring; methods and concepts in geochemical exploration; methods for evaluating alteration zones and contamination; methods for greenfield exploration.
Sequence of the course B. Quintal – 6h (4 lectures) – Introduction; IP and EM methods with applications in mineral resources; borehole logging case studies in geo-energy and mineral resources. G. Hetényi – 1.5h (1 lecture) – Gravity method applications and case studies in geo-energy and mineral resources. A. Moscariello – 4.5h (3 lectures) – VSP and active seismic case studies in geo-energy and mineral resources; 3D models; monitoring geothermal and hydrocarbon reservoirs. L. Guglielmetti – 6h (4 lectures) – Geochemical footprint, mineralization and alteration; identification of alteration zones at different scales; assessing and monitoring contamination and other environmental impacts; greenfield exploration; geothermal systems in sedimentary and magmatic regions.
Comments: -

Fluids in the crust – Mandatory for all if the module is chosen - M4d Fluides dans la croute terrestre
Coordinators: Matteo Lupi **Number of ECTS:** 4 ECTS **Teaching mode:** 36h C + TP (3h per week) **Semester:** Spring **Evaluation mode:** Oral or written exam
Aims of the course - Learn the physics driving darcian fluid flow in the crust - Learn the chemistry of fluids in the deep crust and how they interact with rocks - Learn how deep crustal processes generate fluids at depth - Learn the interconnection between tectonic processes, magmatic activity, geothermal systems and groundwater - Learn the basics of hydrothermal geochemistry and the modeling of metal transport in high-temperature fluids - Acquire an overview on the spatial and temporal relationship between ore deposits and high- and medium-enthalpy hydrothermal systems - Acquire an overview on hydrocarbon systems and their impact on life
Descriptions of the course This course will provide insights on the key role of fluids in geological processes in the crust. It develops by illustrating concepts and processes taking place at various depths in the crust. Its structure follows a journey from deep to shallow structural levels. After a preliminary introduction to the physics of darcian fluid flow (ML 6h), we will study how fluids are changed by rocks and how they change the chemistry of rocks (LB 9h). Next, the course will discuss the link between fluid transport and tectonic processes (JR 3h) and how this leads to the development of ore-forming hydrothermal and

geothermal systems. The students will be introduced to the basic concepts of hydrothermal geochemistry and gain some practical experience with the modeling of metal transport and precipitation in hydrothermal systems (ZZ 9h). The final part of the course will tackle fluid-driven geological processes occurring in the upper crust that directly affect our daily life (SO 3h and ML 6h). The goal of the course is to address the impact that fluids have on geological processes and ultimately on human life on the long and short term.

Sequence of the course

M. Lupi : the physics of fluid flow (12h)
L. Baumgartner: the chemistry of fluid-rock interaction (9h)
J. Ruch : the magma-tectonic interaction (3h)
Z. Zajacz: hydrothermal geochemistry (9h)
S. Omodeo Sale: hydrocarbons (3h)

Comments: ---

Economics and Management of Earth Resources Exploration and Development - Mandatory for all if the module is chosen - M4d

Économie et gestion de l'exploration et de l'exploitation des ressources de la Terre

Coordinators: Andrea Moscariello
Number of ECTS: 2 ECTS
Teaching mode: 18h C + PW (3h per week)
Semester: Spring
Evaluation mode: Oral or written exam

Aims of the course

Earth Resources exploration and development can be realized only if the planned activities are economically attractive and the management of exploration and development activities is carried out and completed according to plans.
An effective economic analysis is about the process of gathering project data, calculating whether a project should proceed and delivering recommendations. The course will address the science of Earth Resources economics, starting from the basics, the tools of the trade that economists use on a daily basis and also their application. This course will unravels the decision-making behind why a mining, a geothermal or a petroleum project moves ahead or ends.
In addition students will learn the basics of project management and the different steps of road maps which will help to move from the identification of opportunities, their selection based on a variety of key driver criteria (i.e. economic, political, environmental, social, etc.) and the process to mature one or several of them to add value to the shareholders.
The student will experience with practical exercises the fundamental steps, including identification and quantification of uncertainties and risks, to be able to take important decisions and ensure a good investment is taken and an effective project management practices is ensured.

Descriptions of the course

In this course, divided in 3 parts, will provide the fundamentals notions of economics and project management applied of geo-energy projects.
The first part of the course will be dedicated to the explanation of fundamental concepts of economics such as Cash Flow, Net Present Value, Discount rates, Inflation, Internal rate of Return, Payback, Maximum Exposure etc. The importance of these concepts will be explained and appreciated with practical examples.
The second part of this course will be dedicated to Earth resources exploration and development Project initiation and management describing some of the fundamental steps from making a business case, rise capital funding to FID (final investment decision) to operation, and tools used for this capital intensive projects such as Opportunity Road Maps Uncertainty and Risk Register, PESTEL analysis (political, economic, social, technological ecological and legal), United Nations Resource and Reserves Classification (including probabilistic analysis P10, P50, P90), After Action Reviews etc.
The third part will be dedicated to a hand-on exercise where based on real case, students will have to apply the learnings acquired during the course.

Sequence of the course

A. Moscariello - (6h) Introduction, project roadmaps and critical project elements (TECOPE) opportunity realization framework, UN Reserves vs Resources classification, stakeholders, for natural resources exploration and development projects.
S. Carmalt - (6 h/TP) Project economics parameter set up, commercial strategies
A. Moscariello / industry expert – (2h) Sustainable Development Goals. Social responsibility, political and environmental aspects. Stakeholder engagement strategies and action.
External experts from industry and international organizations (D. Salacz, Evolution Res., G. Davis, World Bank, etc.) and case studies explained (4h).

Comments: ---

Fieldcamp in Earth Resources - Mandatory for all if the module is chosen - M4d
Camp de terrain en ressources de la Terre

Coordinators: Zoltan Zajacz, Andrea Moscariello and Matteo Lupi
Number of ECTS: 3 ECTS
Teaching mode: 9d F
Semester: Spring
Evaluation mode: Practical (Report)

Aims of the course
- To experience in the field the notions acquired in the class-room concerning the genesis, distribution and dynamics of crustal fluids
- Learn the processes controlling different types of fluid circulation (petroleum, CO_2, methane, hydrogen, water etc.) in the upper crust, including sedimentary basins and magmatic systems
- Study the geology and tectonic context of diverse regions characterised by hydrocarbon migration and accumulation, as well as fluid accumulations controlled by shallow magmatic intrusions
- Appreciate the geological settings where geo-energy resources are found and see how they can be exploited to contribute to the development of our society through sustainable industrial processes
- Investigate hydrothermal mineralization associated with upper crustal magmatic intrusions
- Perform a geological and structural mapping of hydrothermal features, fluid-flow controlling structures and host lithologies

Descriptions of the course
The excursion will start with 3 days in the Bubbio-Acqui Terme area where active hydrocarbon and geothermal systems coexist and interact. Here we will examine the characteristics that control the distribution and properties of geo-energy play elements (i.e. reservoir, seal and traps, source rocks etc.) which in turn control the genesis the accumulation of hydrocarbons at depth and the occurrence of hot thermal springs at the surface. The excursion will then continue in the Tuscan Magmatic province where outcrops highlight a complex tectonics history. Here, magmas, groundwaters and deep fluids have interacted since the Miocene to form ore mineralization, hydrothermal systems under the influence of different local and regional tectonic regimes, often affected by supra-lithostatic pore pressure. Over 3 days, we will study the key role of geological structures on controlling fluid flow and we will also concretely appreciate how geothermal energy supports our society. The next 3 days of excursion will take place in Campiglia Marittima with the study of a Miocene magmatic-hydrothermal system, part of the Tuscan Magmatic province, resulting in the formation of spectacular skarns and a large variety of ore deposits. It will include a 1-day geological and structural mapping exercise of a region affected by hydrothermal mineralization. This 3-days excursion provides a comprehensive overview on industrial minerals, ore deposits and geothermal resources.

Sequence of the course
A Moscariello (days 1-3).
L Guglielmetti (days 1-3)
M Lupi (days 4-6)
J Ruch (days 5-7)
Z Zajacz (days 7-9)
K Kouzmanov (days 7-9)

Comments: This field-course covers the aspects of several courses inside the Earth Resources module.

Ore deposit models - M4d – part Mineral Resources
Modèles de gisements métallifères

Coordinators: Kalin Kouzmanov and Zoltan Zajacz
Number of ECTS: 4 ECTS
Teaching mode: 36 h C + PW
Semester: Spring
Evaluation mode: Practical (Reports, oral presentations) and written exam

Aims of the course
- Introduce the students to the current understanding of ore-forming processes

- Provide an overview of major ore deposit models as a foundation for mineral exploration and exploitation
- Gain skills for recognizing and describing different styles of mineralization and associated alteration patterns in rock specimens and thin sections
- Provide deeper understanding of selected topics through personal work (reporting, presentations)

Descriptions of the course

This course will provide introduction to key geological features, classification, distribution and characteristics of major economically important ore deposit types relevant to both genesis and exploration strategies. Major types of ore deposits to be covered include: orthomagmatic, porphyry systems (porphyry-skarn-epithermal), IOCG, VMS, orogenic gold, sedimentary-hosted, and deposits of critical metals. The course will be process-oriented and the principals of metal transport, concentration and deposition in various magmatic, metamorphic and hydrothermal environments will be examined. Tectonic and structural framework, associated magmatism, alteration-mineralization characteristics, and major fluid processes for each deposit type will be discussed. Laboratory exercises will be conducted on representative macro samples and thin/polished sections, allowing full characterization of textural, structural, mineralogical (ore, gangue and alteration) and host-rock features. Personal work on three different topics/projects will complete the course.

Sequence of the course

K. Kouzmanov (19h – C/TP/seminars; various topics)
Z. Zajacz (8h – C/TP/seminars; various topics)
R. Moritz (4h – C/TP; Orogenic gold deposits; Critical metals)
M. Chiaradia (6h – C; Geotectonic and magmatic framework of magmatic-hydrothermal systems; Volcanic-hosted massive sulfide deposits)
R. Spikings (2h – C; Application of geochronology and thermochronology to ore deposits)

Comments: ---

Fluid and melt inclusions in minerals - M4d – part Mineral Resources
Inclusions fluides et vitreuses dans les minéraux

Coordinators: Zoltan Zajacz
Number of ECTS: 3 ECTS
Teaching mode: 27h C+ PW (4 consecutive days)
Semester: Spring
Evaluation mode: Practical (Reports, oral presentations) and written exam

Aims of the course

- Cover important high-pressure-temperature phase relationships in fluid systems of geological significance
- Provide the students with an understanding of how fluid and melt inclusions form in minerals and what geological information can be gained from them
- Introduce the students to the basics of fluid and melt inclusion petrography
- Provide the students with theoretical background and introductory level hands-on experience with experimental and analytical techniques applied to the analysis of inclusions in minerals (e.g. microthermometry, Raman spectroscopy, LA-ICP-MS

Descriptions of the course

The course will focus on the application of fluid and silicate melt inclusions in minerals to understand magmatic, metamorphic, hydrothermal and diagenetic processes within the Earth's lithosphere. The theoretical part will cover the petrographic interpretation of fluid and melt inclusions, phase diagrams in various H-O-C-salt fluid systems along with their application for the interpretation of fluid inclusion data, and the fundamentals of micro-analytical techniques applied to fluid and melt inclusions. The practical part of the course will incorporate microthermometric measurements using various microscope heating – freezing stages, introduction to software used for the interpretation of microthermometry data and practical demonstration of the use of Raman spectroscopy and Laser Ablation Inductively Coupled Plasma Mass Spectrometry for fluid and melt inclusion analysis.

Sequence of the course

Z. Zajacz – fluid phase diagrams, silicate melt inclusions, post-entrapment modification of fluid and melt inclusions (40%)
K. Kouzmanov – inclusion petrography, microthermometry, fluid inclusion application case study (30%)
A. Tsay (30%) – analytical methods applied in inclusion studies

Comments: ---

Applied mineralogy in resource exploration and modern technologies - M4d – part Mineral Resources
Minéralogie appliquée à l'exploration des ressources et aux hautes technologies

Coordinators: Kalin Kouzmanov
Number of ECTS: 2 ECTS
Teaching mode: 18h C + PW, 1d F
Semester: Spring
Evaluation mode: Practical (Reports) and written exam

Aims of the course
- Introduction to the reflected-light microscopy technique and its applications in the characterization of opaque minerals in ore and various types of rocks and materials
- Introduction to basic concepts and application of portable analytical devices in exploration mapping and material characterization
- Provide the students with theoretical background for and application of new geological materials used in modern technologies
- Production site and R&D department visit – the applied side of Earth sciences

Descriptions of the course
The course is organized in 3 parts:
- Part-I will cover reflected-light microscopy as a technique to study opaque minerals in ore, magmatic, metamorphic and sedimentary rocks, and application of portable analytical devices (e.g., SWIR TerraSpec; pXRF; portable magnetometer) to rock and mineral characterization and exploration mapping techniques
- Part-II will provide a short introduction to the mineralogy of materials important for modern technologies such as REE elements, cement and concrete, phosphates, glass or ceramics among others; economical, environmental and medical aspects will also be discussed
- Part-III of the course consists of a 1-day visit of a production site or a R&D department to learn about specific production processes, the instrumentation used and the role of quality control

Sequence of the course
K. Kouzmanov (12h C/TP; topics – reflected light microscopy; portable devices in the field; production site visit)
B. Putlitz (6h C/TP; topics – applied mineralogy and new materials in modern technologies; production site visit)

Comments: ---

Petrophysics and Reservoir Characterization - M4d – part GeoEnergy
Pétrophysique et caractérisation des réservoirs

Coordinators: Beatriz Quintal and Andrea Moscariello
Number of ECTS: 3 ECTS
Teaching mode: 27h C + PW
Semester: Autumn
Evaluation mode: Practical (Exercises) and written report

Aims of the course
The aim of this course is to provide the student with the understanding of basic technical and scientific concepts that are necessary in the exploration, field development and production of geo-energy resources. The lectures and exercises will go from theoretical concepts in rock physics and descriptions of main types of reservoir rocks to the principles and utilization of borehole logs.

Descriptions of the course
This course will cover concepts in rock physics that are important for the exploration, field development and production of geo-energy resources. The distinct properties of several types of reservoir rocks, including clastic, carbonate and fractured rocks, will be analysed and discussed. Some notions of borehole environment and formation testing will be presented. Then, the principles of the main borehole logging tools used for the characterization of geo-energy resources will be presented in detail. The course ends with a diverse collection of practical exercises of quantitative interpretation of borehole logs, including exercises in Petrel (a software designed for integrated interpretation of geological and geophysical data).

Sequence of the course
B. Quintal – 18h – Theoretical concepts in rock physics, reservoir properties, some aspects of borehole environment and formation testing, principles of borehole logs and their quantitative interpretation.

A. Moscariello – 9h – Integrated interpretation of borehole logs using Petrel.
Comments: ---

Geo-Energy Exploration and Development Workflow - M4d – part GeoEnergy
Méthodes des développement des geo-energies

Coordinators: Luca Guglielmetti
Number of ECTS: 3 ECTS
Teaching mode: 27h C + PW
Semester: Spring
Evaluation mode: Practical and oral exam

Aims of the course

The course will cover in detail the main steps concerning the exploration and development of geo-energy resources including hydrocarbons, geothermal. In addition, students will be also confronted with the challenges regarding the geological underground storage of methane and CO_2, the latter considered one of the key future measure to contrast the emission of Green House Gases in the atmosphere.
All the concepts acquired by the students during all previous courses thought in the ER Module will be transposed to real industrial case-studies where applications of the different geophysical, geochemical, borehole logging etc. methods have been used to solve practical problems. Any industrial geo-energy development is always associated with uncertainties and risks. In this course student will learn how the effective subsurface characterization can help the discovery and development of geo-resources or ensure that the geological storage of gas can have been carried out both effectively and safely.
More specifically the aim of the course will be:

- Provide an overview of global energy demand and main related challenges;
- Appreciate the different steps moving a project from the prospection and exploration phases followed by drilling and eventually to geo-energy development;
- Provide example practical examples on how to Quantify subsurface uncertainty and geologic risks;
- Learn about Play Fair-way Analysis concepts and applications in the geo-resources industry;
- Learn the concept of Probability of Success;
- Understanding of the main environmental risks and how to monitor and mitigate them, with applications of Machine Learning approaches;
- Combine the interpretations of the different exploration methods (gravity, seismic, fluid geochemistry, borehole data) into a decision-making workflow; and
- Quantify uncertainties on geophysical data in order mitigate the risks of failure in placing exploration wells and to ensure longevity in the production.

Move from theory to practical applications in the industry by linking the subsurface characterization to energy system configurations and energy demand.

Descriptions of the course

The course will start with an overview of energy demand, challenges and global opportunities especially driven by renewable energies such as the geothermal energy (4h).
The course will then cover the main aspects of applied subsurface description and uncertainty in order to identify, find, characterize, and operate reservoirs for:

1) geothermal energy (low to high enthalpy) (4h)
2) hydrocarbons (conventional and unconventional reservoirs) (3h)
3) geological storage of CO_2 (3h)
4) underground gas storage (UGS) of methane (2h)
5) metal extraction and hydrogen production (2h)

For each of these 5 types of geo-energy a detailed explanation of the geo-energy play concepts, play element and play definition including the difference between lead and prospect and their identification and maturation methods, the establishment of favorability maps to drive geo-energy development.
For each of these 5 geo-energy types students will be exposed to the main steps to move from prospecting to geo-energy production (geothermal, petroleum, gas, methane or hydrogen, metal extraction) or storage (heat, methane and CO_2).
More precisely for the 5 geo-energy types the following topics will be addressed:
1) Geothermal energy: the student will learn about the different types of possible exploitation ranging from shallow heat pumps allowing both heating and cooling, to more sophisticated techniques for direct use of heat or power generation a such as the enhanced or engineered geothermal systems (EGS).

2) Hydrocarbon: the students will be confronted with the key learning steps from the identification, characterization and definition of a source rock and its maturity, the different modalities of migration and trapping of fluids and appreciation of the criticality of the combination of factors which can allow the accumulation and preservation over millions of years of hydrocarbon accumulations in the subsurface.
3) and 4) Geological storage of CO_2 and UGS, the students will learn about the critical geological and physical conditions necessary to allow long term and safe injecting and conservation of gas in the subsurface. The latest development and experience of various ongoing studies (source-to-sink approach for CO_2 storage) and pilot projects around the world will be explained and discussed addressing also the topic of induced seismicity which is one of the major societal concerns associated with a variety of storage methods.
5) metal and hydrogen extraction will be also presented, and student will learn about recent development in these innovative but very promising techniques which could address some of the societal need in the future such as lithium for battery construction or H_2 for energy production which are often associated with hydrocarbon or and geothermal fluids
This course will also include a number of practical exercises aimed at learning how to use different approaches for multi-criteria Play-fairway analysis and to combine subsurface exploration results and uncertainties to economic and energy system evaluations to finally move to identify and select the best development scenario(s). (8h)
The course will end with a seminar from representatives of the Swiss geothermal industry (1h) who will present the challenges and the results of the ongoing projects.

Sequence of the course

L. Guglielmetti (21h)
S. Omodeo Salé (3h) hydrocarbons (conventional and unconventional reservoirs) + support TP
A. Moscariello (4h) geological storage of CO2 (2h), underground gas storage (UGS) of methane + support TP
L. Perozzi (4h) Support for TP in play analysis
External experts from Industry (M. Meyer and C. Nawratil de Bono from SIG, P. Meier and O. Zingg from GeoEnergie Suisse) (1h)

Comments: ---

Integrated Geo-Energy Seismic Interpretation and 3D Modelling Workflows - M4d – part GeoEnergy

Workflow pour l'interprétation sismique et modélisation 3D appliqués aux Géo-énergies

Coordinators: Andrea Moscariello
Number of ECTS: 3 ECTS
Teaching mode: 27h C + PW
Semester: Spring
Evaluation mode: Practical (exercises)

Aims of the course

This course will allow students to discover the fascinating world of 2D and 3D seismic data one of the most useful and advanced geophysical tool allowing the extraordinary imaging of the subsurface. Students will be able to navigate inside incredible seismic data sets which will unravel 10s-of-km-scale underground 'virtual outcrops' where stratigraphy, tectonic and sedimentology are all integrated in one data set providing unbeatable images of the variety of the crust nature and structure. Through the interpretation of these data, by learning the different approaches, steps challenges and pitfalls, students will then build 3D geological models and experience the challenges of capturing the complexity of the nature and variety of sedimentary basin infill and their relationship with the bedrock using a variety of industry standard tools. The multiple purposes of building a model at different scales will be explained and applications to a variety of case studies shown.
This course will use a variety of seismic data sets including the Swiss Plateau, onshore France and Gabon, offshore Mediterranean, Namibia, Nigeria, Australia, The Netherlands, UK and many other basins in the world. In addition, one specific datasets from the UK North Sea will be used as a reference a red thread exercises which will be also used in other geo-energy courses offered in the ER module.

Descriptions of the course

The course will be split in two parts.
The first part (Autumn semester) offers the hands-on basics principle of seismic interpretation of 2D and 3D data set with a variety of state-of-the-art industry software tools learning the fundamental steps of:

1) seismic-well calibration, synthetic generation and time-depth conversion;
2) structural interpretation;
3) seismic stratigraphy horizon mapping;
4) attributes extractions and interpretation;
5) generation of wheeler diagrams and reconstruction of basin infill sequences.

All the above tasks will be logically followed by doing several practical exercises with limited ex-cathedra teaching where students will learn a variety of techniques and tricks to maximize the befits of working with this kind of data.

The second part (Spring semester), after the explanation of the fundamental basics of modelling and the variety of their purposes, students will learn how to build a 3D geological model (from outcrops and subsurface data) going through all the necessary building steps such as:

1) building the framework (horizons and faults from structural and stratigraphic interpretation);
2) well correlation and horizon QC (Quality Check);
3) facies interpretation and reservoir properties;
4) fracture modelling;
5) volumetrics;
6) from upscaling to dynamic modeling (concepts).

All the above tasks will be logically followed by doing several practical exercises with limited ex-cathedra teaching. familiarization with software of be then used to examine and modelling 2D-3D seismic interpretation (recap principles, exercises) to 3D geological models static and dynamic (purpose, definition of conceptual geological modelling, model building techniques, intro to software, exercises).

Sequence of the course

A. Moscariello - (2h) seismic interpretation principles and techniques, advanced methods and applications to geo-energy projects.
O.E. Eruteya - (11.5 h TP) Seismic interpretation hands-on exercise using Petrel and Kingdom workstations: 2D and 3D stratigraphic and structural interpretation (attribute analysis, time-depth conversion) and implication for geo-energy exploration and development.
A. Moscariello - (2h) 3D reservoir modelling principles, techniques and strategy based on business purposes. Examples from different tectono-stratigraphic settings and different modelling objectives.
O.E. Eruteya - (11.5 h TP) 3D reservoir modelling hands-on exercise using Petrel software: fit-for-purpose 3D modeling workflows and implication for geo-energy projects

Comments: Part 2 of this course will benefit for the learnings acquired in the Reservoir Characterisation course.

Free choice courses

For courses related to other Master program please look at their program directly

Gemmology – **Free choice**
Gemmologie

Coordinators: Laurent Cartier
Number of ECTS: 3 ECTS
Teaching mode: 5d CE + PW, 2d F
Semester: Spring 2nd year
Evaluation mode: Validation without grade (Practical exercises and written report)

Aims of the course

Courses part

- Understand how gemstones form, how they can be treated and synthesized
- Overview of mineralogy, crystal chemistry and geology of gems
- Learn about scientific techniques to test gemstones, and different approaches available
- Learn how to identify the over 100 gemstone varieties available using practical hand-held instruments during the course using the UNIL gemstone collection

Discuss trade issues and sustainable development issues around the extraction, manufacturing and trade of gemstones

Field part

- Gain an understanding of the gem industry from mine to market by visiting the most important hub for gems in Europe (Idar-Oberstein, Germany). This includes visiting a mine, museums, a gem lab, gem cutters, diamond cutter and gem traders
- Students will be able to see and touch many gems and get a deeper understanding of how gemmology (the science of gemstone testing) ties in with the global gemstone trade
- This field trip is a unique opportunity to visit all steps of the gem supply chain and for students to interact with and learn from industry professionals

Descriptions of the course

Course parts
General gemmology: Gemstone deposits and formation of gemstones, treatments of gems, production of synthetics. Gemstone cutting and polishing, identification methods in gemmology: simple instruments and scientific methods.
Gemmology of gemstones: The characteristics of diamonds, corundum, beryl, garnet, tourmaline, feldspar, spinel, chrysoberyl, organic gems, quartz, opal, jadeite, nephrite, peridot, topaz, zircon, zoisite, and rare gems.
Practical gemology: Use of gemmological instruments: refractometer, hydrostatic measurements, specific gravity, spectroscopy, dichroscope, UV-lamp, diamond tester, use of loupe and gemmological microscope, identification of natural, synthetic, treated gemstones and imitations. Learn to use and interpret gemmological tables and literature for conclusive identification.
Field part:

- Visit an old quartz and agate mine to understand local geology and past mining techniques
- Visit a diamond cutting facility
- Visit an advanced gem testing lab and a gemmology school
- Visit coloured gemstone cutters and learn about all the different professions involved from gem mining to the final piece of jewelry
- Visit one of the best museum gem collections in the world

This mix of visits will give students a good overview into practical aspects of gemmology, and how their expertise in mineralogy/geology/gemmology can apply to the trade.

Sequence of the course

All by L. Cartier

Comments: ---

Sites contaminés : application géologique et environnementale – Free choice Sites contaminés : application géologique et environnementale
Coordinators: Stéphanie Girardclos **Number of ECTS:** 3 ECTS **Teaching mode:** 5d C + PW **Semester:** Spring 2nd year **Evaluation mode:** Practice (oral presentation and report)
Aims of the course La gestion des sites contaminés est traitée dans ce cours-bloc comme un concept intégral de la gestion des ressources naturelles et de la protection de l'environnement dans le cadre des objectifs du développement durable en Europe. Il s'agit de: - Connaître les différentes sources des contaminants les plus importants et dangereux, leur persistance et leur diffusion dans les compartiments environnementaux - Acquérir des connaissances approfondies des techniques physico-chimiques et biologiques (bioremédiation) de remédiation des sites contaminés - Elaborer un programme d'investigation de sites pollués théorique et évaluer les risques liés à la pollution à l'aide de données géologiques et hydrogéologiques réelles Ce cours s'accompagne d'une visite sur le terrain d'installations de gestion d'un site contaminé
Descriptions of the course • Typologie de pollution et famille de micropolluants et macropolluants: pollutions minières, urbaines, industrielles en rapport avec les compartiments environnementaux associés • Lois et procédures liées à la gestion des sites contaminés en Suisse et UE • Les mesures techniques préventives et d'assainissement des sites; approches physicochimiques et de bioremédiation • Visite sur le terrain d'un site contaminé du canton de Genève qui illustre les concepts et techniques présentés dans le cours • La gestion d'un site contam*iné* issu d'une décharge industrielle d'importance nationale • Exercices issus de la pratique en bureau d'ingénieur
Sequence of the course S. Girardclos, J. Poté et intervenants externes selon disponibilité (programme détaillé distribué en début de semestre).
Comments: This course is given in French because of the study of Swiss-cantonal-local legislation that is only available in French. Visits of local industries also happen only in French. Course given for the Master MUSE.

Les déchets: Gestion environnementale et contraintes géologiques – Free choice Les déchets: Gestion environnementale et contraintes géologiques
Coordinators: John Poté **Number of ECTS:** 3 ECTS **Teaching mode:** 5d C + PW **Semester:** Spring 2nd year **Evaluation mode:** Practice (oral presentation and report)
Aims of the course La gestion des déchets participe à la gestion des ressources naturelles et à la protection de l'environnement dans le cadre des objectifs du développement durable en Suisse. Dans ce cours-bloc de 5 jours, il s'agit de: - Connaître le cadre historique, économique et social de la gestion des déchets / Acquérir des connaissances sur le cadre légal de la gestion et du stockage des déchets; - Comprendre les technologies et les pratiques de valorisation des déchets organiques et leur optimisation énergétique; - Mettre en pratique les concepts de la gestion des déchets avec l'aménagement du territoire avec des données réelles.
Descriptions of the course • Histoire des déchets en Europe centrale / Législation de la gestion des déchets en Suisse et UE • Valorisation des déchets organiques et optimisation énergétique. Compostage et biométhanisation • Gestion intégrée des déchets «Life cycle et écobilan». Gestion des déchets solides urbains et assimilés dans les pays en voie de développement • La Voirie et présentation du programme de gestion des déchets en Ville de Genève / Usine d'incinération des Cheneviers ou de Tridel. Tri, incinération et optimisation énergétiques dans la pratique industrielle (visites)

• Site de Châtillon. Tri des déchets, biométhanisation, compostage, la décharge cantonale (GE) et le traitement des percolats (visite)
• Exercice pratique de sélection de sites de décharges dans le Canton de Genève sur la base de données réelles et géoréférencées

Sequence of the course
J. Poté, S. Girardclos, G. Giuliani, M. Patel (programme détaillé distribué en début de semestre)

Comments: This course is given in French because of the study of swiss-cantonal-local legislation that is only available in French. Visits of local industries also happen only in French. Course given for the Master MUSE.

Construction and interpretation of cross-sections in complex deformed areas – Free choice
Construction et interprétation de coupes transversales dans des zones déformées complexes

Coordinators: J.-L. Epard
Number of ECTS: 3 ECTS
Teaching mode: 27h C + TP
Semester: Autumn 2nd year
Evaluation mode: Practical (Exercices)

Aims of the course
Provide the necessary skills to study and interpret the tectonic structures in a mountain chain (map and cross section)

Descriptions of the course
Three main topics will be addressed:
1) Methods for balancing detachment folds. In particular, the area conservation methods involving a change in the bed length which are more suitable for the study of the structures of the outer part of mountain ranges.
2) Analysis of the superposition of deformations, mainly interference figures between several folding phases.
3) Analysis of a geological map in the Alps and construction of sections including analysis of axial traces, determination of fold axes and use of these data for the realization of a cross section by cylindrical projection.
The course will be given mainly in the form of guided exercises. It will also include an important part of independent personal work for the construction of a cross-section in the Alps.
It will be validated by the presentation of exercises and a cross-section in the Alps.

Sequence of the course
The detailed sequence of the course depends on the schedule allocated to this course. J.-L. Epard will be the only teacher.

Comments: This course is a partial complement to the Microtectonics course offered by M. Robyr (superposition of deformation phases).

Microtectonics – Free choice
Microtectonique

Coordinators: M. Robyr
Number of ECTS: 2 ECTS
Teaching mode: 18h C + TW
Semester: Autumn - 2nd year
Evaluation mode: Practical

Aims of the course
Successive stages in the deformational and metamorphic evolution of a rock are commonly preserved as part of a fabric of a rock and the recognition and correct interpretation of the geometry of the fabrics is essential for the understanding of the evolution of the rock. The main objective of a microstructural analysis is therefore to unravel the sequence of deformation phases in a specific area and to link this sequence to metamorphic events, in order to establish a pressure-temperature and relative time path. A large part of the course is dedicated to practical work based on the description and interpretation of microstructures in thin sections of rocks.

Descriptions of the course.
This course will provide the tool to identify the specific geometries of the fabric in deformed rocks that can be used to link the crystallization of a mineral with a specific deformational phase. Similarly, this course will give the tools to correctly interpret the geometry of the fabric in order to establish the sense of shear associated with a phase of

deformation. The description and interpretation of those specific microstructures will be done through the observation of thin sections of rocks with the microscope
Sequence of the course The course will start with about one hour of theory on a specific topic and the remaining time of the course will be dedicated to practical work consisting on the observation of microstructures in thin sections.
Comments: ---

SPACE-RISKS – Free choice
Géomatique appliquée à l'analyse du risque

Coordinator : Corine Frischknecht
Number of ECTS : 3 ECTS
Teaching mode : 5d C + PW
Semester : Spring 2nd year
Evaluation mode : Practice and written report

Aims of the course
- Conduct a risk analysis, regardless of the hazard considered
- Understand the issues related to the spatial analysis of risk
- Present results in an understandable format
- Use different GIS analysis tools

Description of the course
This course aims at allowing participants to handle the notion of risk and to use GIS methods to assess risk qualitatively and quantitatively. This course will allow to work on the various aspects of risk, considering different hazards (floods, volcanic eruptions, earthquakes) and physical and social vulnerabilities in order assess the potential economic losses and loss of life induced by natural phenomena.

Sequence of the course
TO BE COMPLETED.

Comments
This course is given in French as it is part of the complementary certificate of geomatics at the University of Geneva, offered in French.
Pre-requisite: some basic knowledge in GIS (ArcGIS or QGIS)

Model parameter estimation and uncertainty quantification – Free choice
Estimation des paramètres du modèle et quantification de l'incertitude

Coordinator : Niklas Linde
Number of ECTS : 5 ECTS
Teaching mode : 56h C + PW
Semester : Spring 2nd year
Evaluation mode : Practice

Aims of the course
This course is directed to students that want to understand how to combine available data and prior knowledge to parameterize geological, geophysical, or hydrological models.

Description of the course

Many geoscientific problems consist of inferring system properties or to predict its response from a limited amount of noisy data. For example, what is the most likely permeability distribution of an aquifer or reservoir given a series of pumping tests? What is the maximum lateral extent of a geological body given geophysical data and surface observations? All such problems can be phrased as so-called inverse problem in which the data and its associated uncertainty is merged with a physical model that describes the relation between the model and its response under the constraint that any prior constraints about subsurface properties are honoured. This courses starts by reviewing basic probability theory before introducing classical solutions to the inverse problem, such as least-squares and maximum likelihood, as well as probabilistic formulations. Through a series of examples from the geosciences, we review the main components of an inverse problem and investigate how different solutions affect the resulting models and model uncertainty assessments. The students will work with existing data sets and software to gain an intuitive and practical understanding of how to obtain models that bring the most out of the data without resorting to interpretation of noise and artefacts. The course also considers both pragmatic and more theoretically based approaches to assess the reliability of the models obtained.

Sequence of the course

All done by Niklas Linde.

Comments

Course proposed in the Master in Environment (UNIL)

Hazards and risks of slope mass movements field camp – Free choice

Dangers et risques des mouvements de masse sur les pentes – camp de terrain

Coordinator : Marc-Henri Derron
Number of ECTS : 5 ECTS
Teaching mode : 80h F
Semester : Spring 2nd year
Evaluation mode : Practice

Aims of the course

Mise en pratique des bases de l'investigation de terrain pour l'analyse des aléas gravitaires

Description of the course

Camps de terrain associé au cours "Erosion and slope movements"
Introduction pratique à l'étude des stabilités et mouvements de versant:
- glissements de terrain
- laves torrentielles
- chutes de blocs

Méthodes:
- cartographie des phénomènes
- évaluations des aléas
- modélisation des phénomènes

Ce cours se déroule sur le terrain la journée (cartographie, relevés de mesures, LiDAR, photogrammétrie SfM,...) et au laboratoire le soir (analyse, modélisation, rédaction).

Sequence of the course

All done by Marc-Henri Derron.

Comments

Course proposed in the Master in Environment (UNIL)

Biomineralization – Free choice
Biomineralisation

Coordinator : Anders Meibom
Number of ECTS : 4 ECTS
Teaching mode : 42h C + PW
Semester : Autumn 2nd year
Evaluation mode : Practice

Aims of the course
Understanding process and role of biomineralization (minerals formed by living organisms) in context of Earth's evolution,global chemical cycles, climatic changes and remediation.

Description of the course
Biomineralization refers to the processes by which organisms form minerals. It is therefore, by definition, a highly multidisciplinary field that spans both the inorganic and the organic world. The phenomenon of biomineralization is relevant to the Earth, Environmental and Life Sciences on practically all length scales. From the immense scale of reef-systems and global ocean life-cycles to small bacterial communities, the impact of biomineralization spans length scales of at least 12 orders of magnitude and a large fraction of geological time! But despite the global environmental impact of biomineralization and its fundamental scientific importance, there is still no consensus about the basic biological mechanisms involved.
This class aims at giving the student an insight into the study of fundamental biological processes that shape biominerals and determine their chemical and isotopic composition. The physiology of biomineralization, matrix-mediated control of biominerals, cell-biomineralization interface will be discussed for a number of organisms, including bacteria, corals, foraminifera and sponges.
The occurrence of biominerals in the geologic record and their use as paleo-climate recorders will be discussed together with biomineralization induced by bacteria, with important implications for mineral ore formation and remediation of contaminated sites.

Sequence of the course
All done by Anders Meibom

Comments
Given at EPFL – please look at the schedule on the EPFL: https://edu.epfl.ch/coursebook/fr/biomineralization-from-nature-to-application-ENV-406

SwissSIMS winter School– Free choices
Ecole d'hiver SwisSIMS

Coordinators: J. Marin-Carbonne
Number of ECTS: 2 ECTS
Teaching mode: 4.5 days C + TP
Semester: Spring 2nd year – biannual (in early February, before the beginning of the spring semester)
Evaluation mode: Practical

Aims of the course
This SwissSIMS winter school aims to provide advanced knowledge on Secondary Ion Mass Spectrometry (SIMS) instrumentation and applications in geosciences. During the school, students will attend lessons on SIMS theory, isotope mass spectrometry, standard calibration, data reduction and error propagation as well as practical sessions. Various application examples will be given by SwissSIMS researchers. One invited SIMS expert will give a short course on a research topic approached from a SIMS prospective, like geochronology, volcanology, cosmochemistry or geobiology. During the week, students in small groups will have the opportunity of to follow a basic training on tuning the instrument as well as the possibility of preparing one SIMS mount with a specific material ands and analyzing it/them for isotope analyses. Particular sessions on sample preparation protocols and characterization of the surface will be included and students will use the laboratory equipment. A lab tour will be organized that will include other laboratories in the Centre of Advance Surface Analyses (CASA, NanoSIMS, cryo SEM and Electronic Microprobe). Exercises on standard calibration, data reduction and error propagation will be mandatory.

Descriptions of the course

The week will be organized around a combination of lecture, exercise groups and practical sessions in the laboratories. Interactions with SwissSIMS researchers as well as with other SIMS experts will be encouraged as students will work in small groups. At the end of the week, students will be invited to design potential applications of SIMS in their research project and will write a short proposal for isotope analyses. Videos and online documentation will be provided. Students will have the opportunity to spend time in the lab and to learn by doing, either during sample preparation, characterization or basic tuning of the instrument. The final grade will consist on the sum of grades on the exercises, on a short presentation of the SIMS proposal research plan and on the quality of the sample prepared.

Sequence of the course :

<table>
<tr><th>time</th><th colspan="3">Monday</th><th colspan="3">Tuesday</th><th colspan="3">Wednesday</th><th>Thursday</th><th>Friday</th></tr>
<tr><td>8:00 - 8:30</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>8:30 - 9:00</td><td></td><td></td><td></td><td colspan="3" rowspan="4">Guest lecture</td><td colspan="3" rowspan="2">Calibration of standards</td><td rowspan="4">Applications - SIMS users</td><td rowspan="7">Exercises: write a SIMS proposal for your resaerch/ present your proposal in 2 min.</td></tr>
<tr><td>9:00 - 9:30</td><td colspan="3">Welcome/Introduction</td></tr>
<tr><td>9:30 - 10:00</td><td colspan="3" rowspan="2">SIMS theory</td><td colspan="3" rowspan="2">SIMS - stable isotopes and its applications</td></tr>
<tr><td>10:00 - 10:30</td></tr>
<tr><td>10:30 - 11:00</td><td colspan="3">coffee break</td><td colspan="3">coffee break</td><td colspan="3">coffee break</td><td>coffee berak</td></tr>
<tr><td>11:00 - 11:30</td><td colspan="3" rowspan="2">SIMS theory</td><td colspan="3" rowspan="2">Data reduction/Error propagation</td><td colspan="3" rowspan="2">Geochronology</td><td rowspan="2">Applications - SIMS users</td></tr>
<tr><td>11:30 - 12:00</td></tr>
<tr><td>12:00 - 12:30</td><td colspan="3" rowspan="3">lunch</td><td colspan="3" rowspan="3">lunch</td><td colspan="3" rowspan="3">lunch</td><td rowspan="3">lunch</td><td rowspan="3">lunch</td></tr>
<tr><td>12:30 - 13:00</td></tr>
<tr><td>13:00 - 13:30</td></tr>
<tr><td>13:30 - 14:00</td><td colspan="3">Sample preparation</td><td rowspan="8">Sample prep I (epoxy)</td><td rowspan="8">Sample prep II (indium)</td><td rowspan="8">Instrument tuning/measurmets</td><td rowspan="8">Sample prep II (indium mounts/whitelight)</td><td rowspan="8">isstrument tuning/measuremts</td><td rowspan="8">sample prep I</td><td rowspan="4">Excercises data reduction/calibration/error propogation</td><td rowspan="2">Questions/Feedback</td></tr>
<tr><td>14:00 - 14:30</td><td rowspan="5">Instrument Tuning/measurements</td><td rowspan="5">Sample prep I (epoxy)</td><td rowspan="5">Sample prep II (indium mounts/whitelight)</td></tr>
<tr><td>14:30 - 15:00</td><td rowspan="6">END!</td></tr>
<tr><td>15:00 - 15:30</td></tr>
<tr><td>15:30 - 16:00</td><td rowspan="4">Data visualisation (QGIS, others)</td></tr>
<tr><td>16:00 - 16:30</td></tr>
<tr><td>16:30 - 17:00</td><td colspan="3" rowspan="2">Lab tour</td></tr>
<tr><td>17:30 - 18:00</td></tr>
</table>

Group 1
Group 2
Group 3

Intervenants : Guest Lecturer from another SIMS laboratory, Prof Rubatto (Uni Bern), Prof Marin Carbonne (UNIL) Dr Anne Sophie Bouvier, and Thomas Bovay (UNIL)

Comments: ---

COMPANY INTERNSHIP – Free choice

Stage en entreprise

Comments: The internship agreement is available on the ELSTE website:
https://www.unil.ch/geoleman/en/home/menuinst/etudiantes/formulaires.html